BIRKELAND CENTRE
FOR SPACE SCIENCE

01

CONTENTS

OUR MISSION

The Birkeland Centre for Space Science (BCSS) was established in March 2013. It is led from the Department of Physics and Technology at the University of Bergen, with nodes at NTNU and UNIS. The overarching scientific objective of the BCSS is to understand "How the Earth is coupled to space." BCSS is organized into three research groups:

- **Dynamics of the Asymmetric Geospace**
- **Particle Precipitation**
- **Hard Radiation from Thunderstorms**

BCSS additionally houses two instrumentation groups that design, build, and operate state-of-the-art space- and ground-based instrumentation, and a group dedicated to education and public outreach.

< Cover image: Bireland Centre for Space Science / Mt. Visual

FROM THE CENTRE LEADER

This annual report covers the year 2021.

SCIENCE & RECOGNITION

Although working conditions have improved since last year, many have spent a great deal of time working from home, and travelling has also been severely limited in 2021. Nevertheless, BCSS members have attended many virtual meetings, and even some physical ones, giving 67 presentations (10 invited). Our publication record is the next best year in our history (70 publications). By the end of 2021, we have had 412 publications listed on ISI Web of Science which have been cited 6594 times. Our H-index made a jump by 5 points up to 33.

Also in 2021, we have had some publications that have received considerable attention around the world. On February 22, *Nature Communications* published a paper by Zhang et al. (2021), with Kjellmar Oksavik from BCSS as the fourth author, about the "Space Hurricane". This "hurricane" was observed in the ionosphere as a cyclone-like auroral spot around the north magnetic pole, having a diameter over 1000 km with multiple arms and anti-clockwise rotation. This new phenomenon was seen during very low geomagnetic activity and northward interplanetary magnetic field. *National Geographic* picked up this story and made a wonderful animation, which triggered massive interest all over the world, with ~380 stories in the media.

An important scientific highlight was the news on August 10, 2021, that the paper by PhD student Fasil Tesema at UNIS (including Hilde Nesse Tyssøy and Christine Smith-Johnsen from UiB as co-authors) was among the 10% most downloaded papers in 2020. The paper was about electron precipitation during pulsating aurora and its chemical impact (Tesema et al., 2020).

Another highlight of 2021 was that Master's student Ole Martin Borge (NTNU) was the winner of the annual NIFRO Prize.

By the end of the year (December 22), *Nature* published a paper (Castro-Tirado, Østgaard, Göğüş et al., 2021) based on ASIM data on a giant flare from a magnetar. The gamma-ray signal was only 160 ms long and had travelled more than 10 million light years to reach the Earth. The energy release during this short time is comparable to what the Sun radiates in 100 000 years. Given ASIM's excellent time resolution, we were able for the first time to identify very high frequency oscillations in the very first 3 milliseconds of the burst. More than 630 media outlets covered these findings. Together with the main collaborators from Spain, Turkey, and Denmark, the eight co-authors from BCSS worked hard for more than 1.5 years to make this happen.

NEW PROJECTS

Martino Marisaldi, who became a professor in 2021, was awarded the FRIPRO project "TAO-TGF Airborne Observatory – Understanding the link between lightning, terrestrial gamma-ray flashes and gamma-ray glows". This project will explore the data from a new flight campaign that BCSS will be leading in July 2023. The Centre leader is now close to finalizing the contract between UiB and NASA headquarters to rent an ER-2 aircraft to fly at an altitude of 20 km over Central America and the Caribbean, an area known to be a hot spot for TGFs. We will have 50 hours flight time.

INSTRUMENTS

Despite all restrictions, SMILE is progressing well, and 2022 will be an intense year as we prepare to get ready for launch at the end of 2024.

ASIM is still doing satisfactorily and everything is working as it did from Day One. In 2021, it was decided that ASIM should be moved to a different location on the outside of the Columbus module for 2.5 years, and then back to the original location for another 1.5 years. The original plan was that ASIM would stay on ISS for

2.5 years, but now it is very likely that we will have ASIM in operation for a total of 7 years, thanks to all the wonderful results the instrument has provided.

The DEEP instrument, designed and built at BCSS, will be one of the instruments on the next ICI-5bis rocket (PI: Wojciech J. Miloch, UiO). The planned launch month is February, 2023.

LEADERSHIP

Hilde Nesse Tyssøy is the Science Discipline Representative in Scientific Committee on Solar-Terrestrial Physics (SCOSTEP). She is also the current chair of the HEPPA-SOLARIS Scientific Organizing Committee. She has been the leader of the Young Center for Advanced Study Network: Unravelling the Drivers of Energetic Electron Precipitation, a project that finished with a workshop and seminar at the Norwegian Academy of Science in Oslo in October 2021.

We are currently leading two international teams at the International Space Science Institute (ISSI) in Bern, Switzerland. Karl Magnus Laundal is leading the project "Understanding Mesoscale Ionospheric Electrodynamics Using Regional Data Assimilation" that started in 2020. Prof. Martino Marisaldi leads the project "Understanding the properties of the Terrestrial Gamma-ray Flash population." Both projects have been extended by one year.

BCSS leader Nikolai Østgaard serves as national representative in the steering committee of SCOSTEP and ISWI and Prof. Kjellmar Oksavik is the national representative in URSI, Commission G.

Stefan Bender and Patrick Espy convened sessions at the German Physical Society meeting and at the Asia Oceania Geosciences Society (AOGS), respectively. Martino Marisaldi and Brant Carlson organized scientific sessions at the EGU and AGU meetings, respectively.

ORGANIZATION

In September 2021, the BCSS workshop was held at Hotel Terminus, Bergen. Although our guests and members from abroad had to attend through a video link, we were 53 attendees, including Ingrid Mann from UiT and Torsten Neubert (ASIM PI) from DTU, Denmark. This was the biggest meeting all of us had attended in a rather long time.

EDUCATION/OUTREACH

In 2021, nine students (UiB: 4, NTNU: 4, UNIS: 1) received their Master's degrees at BCSS, and three PhD students received their degrees: Katie Herlingshaw (UNIS) in January, Carolina Maiorana (UiB) in May and Fasil Tesema (UNIS) in June.

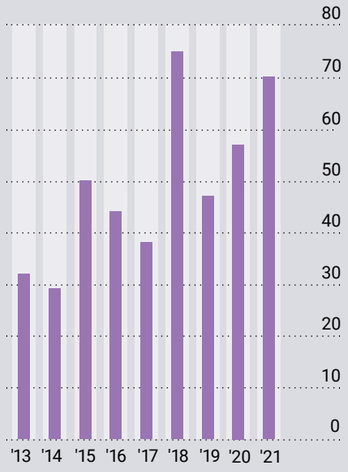
Although it has been a bumpy year, it has also been one of our absolutely most productive years.

Thanks to all BCSS members for contributing to this.

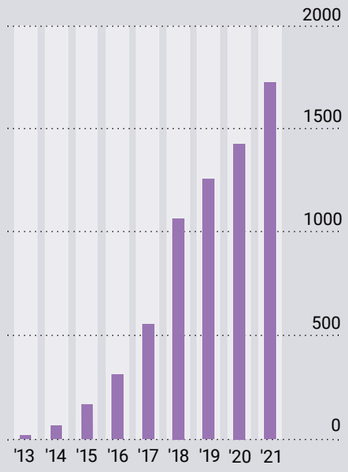
Nikolai Østgaard,
Leader of BCSS

Dissemination data

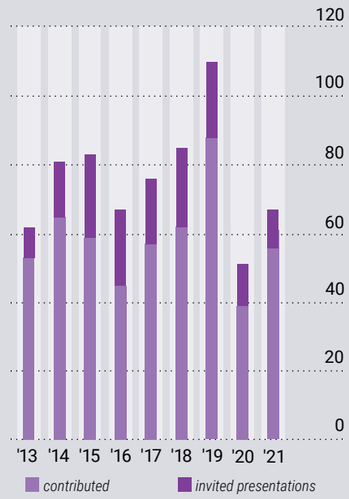
PUBLICATIONS



CITATIONS



PRESENTATIONS



ARTIST'S INTERPRETATION OF A SPACE HURRICANE

Image: Courtesy *National Geographic* / Mark Garlick

RELOCATION OF ASIM ON ISS

Images: Courtesy ASIM/DTU, Denmark

ILLUSTRATION OF A MAGNETAR

Illustration: BCSS / Mount Visual / Daniel Schmelling

02 Dynamics of the asymmetric geospace

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Professor

Nikolai Østgaard, UiB
Professor

Jesper Gjerloev, UiB
Professor II

Steve Milan, UiB
Professor II

Lisa Baddeley, UNIS
Assoc. Professor

Finn Søraas, UiB
Prof. Emeritus

Stein Haaland, UiB
Researcher

Spencer Hatch, UiB
Researcher

Jone Reistad, UiB
Postdoc > Researcher

Lindis Bjoland, UNIS
Postdoc

Anders Ohma, UiB
Postdoc

Margot Decotte, UiB
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Reham Elhawary, UiB
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Nina K. Eriksen, UNIS
Phd Candidate

Sara Gasparini, UiB
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Katie Herlingshaw, UNIS
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Anna Kvamsdal, UiB
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Master's Student

One of the main goals of the DAG group is to understand how inter-hemispheric asymmetries in the magnetosphere are created and removed. We know from past years that the interplanetary magnetic field plays a central role in setting up asymmetries. We also know from observations of auroras in the two hemispheres, a visible manifestation of the ionospheric "ends" of magnetospheric magnetic field lines, that asymmetries are reduced during very active times. However, not all magnetic field lines light up in this way, so observations of northern and southern lights are not enough to give a complete picture. In 2021, Ohma et al. [2021a] presented a study of global computer simulations of the magnetosphere to investigate how asymmetries evolve in different regions. These simulations confirmed our findings based on observations, and also added more detail about where the asymmetries are expected to be strongest, and where they are most variable. *(Fig. 1)*

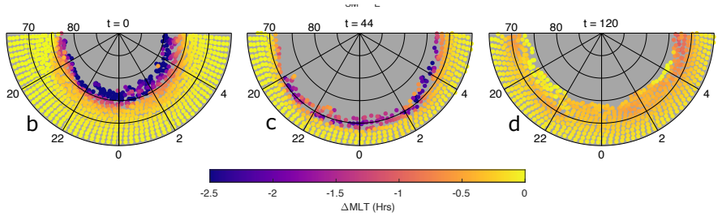

Figure 1: Maps of how distorted Earth's magnetic field lines were in a simulation of the magnetosphere. Darker color means more distortion. The view is from above the magnetic pole in the northern hemisphere, with midnight at the bottom, dusk to the left, and dawn to the right. The three frames show different times relative to a substorm occurring at t = 44 in the simulation. The gray regions are magnetic field lines that extend out in the solar wind. From Ohma et al. [2021a].

The group has also contributed to the Center for the Unified Study of Interhemispheric Asymmetries (CUSIA), led by University of Texas in Arlington. Jone Reistad and Anders Ohma were part of a project investigating how the magnitude of the dawn-dusk (B_y) component of the Interplanetary Magnetic Field (IMF) affects the response of the Earth's magnetotail. This has been a true international team effort, where all aspects of the project have been performed in digital spheres. The publication Holappa et al. [2021] shows that when the IMF B_y magnitude is small, the magnetotail more often produces a substorm, but at higher latitudes, and likely a weaker one, compared to the situation when IMF B_y magnitude is substantial. The results are interpreted as IMF By magnitude having an influence on the conditions leading to onset of reconnection in the tail, but not on the strength of the dayside coupling.

These findings are part of a recently emerging, broader picture of the role of IMF B_y in magnetosphere-ionosphere dynamics. For example, it has recently been discovered that the ionospheric response to positive and negative IMF B_y is different whenever the dipole tilt angle is non-zero. In a new study, we demonstrate that the substorm occurrence frequency is explicitly dependent on the sign of IMF B_y during non-zero tilt conditions. Substorms occur more frequently when the sign of IMF B_y and tilt is opposite compared to equal. This confirms that the explicit IMF B_y effect represents a difference in the global magnetospheric response. At the moment, it is unclear whether this is due to differences in dayside coupling or magnetotail response. This will be specifically targeted in future studies. *(Fig. 2)*

We have earlier demonstrated how the Spherical Elementary Current Systems (SECS) technique can be used to describe the high latitude ionospheric convection. One of the advantages of this technique is its intrinsic ability to separate the sources of the convection. While this separation has been shown to work well during a pure northward IMF, Reistad et al. [2021] used the technique for B_y-dominated periods. They separated between two fundamentally different modes of convection; lobe convection, and Dungey-type convection, by placing plasma flow observations from ground radars relative to boundaries inferred from magnetometers on the Iridium telecommunication satellite network. The results indicate that in summer, lobe convection is typically 20% of the Dungey-type convection during IMF B_y-dominated periods. Sometimes this can have very conspicuous results: Kjellmar Oksavik was co-author on a *Nature Communications* paper (Zhang et al., 2021) that reported a so-called "space hurricane", intense auroras in a spiral structure. The space hurricane was thought to be a signature of the convection patterns that develop in the summer during B_y-dominated periods. *(Fig. 3)*

The group's experience with SECS analysis has also been put to good use in a new project: The Electrojet Zeeman Imaging Explorer (EZIE) is a new NASA mission that will be launched in 2024. It will comprise three satellites that measure microwave emissions from the mesosphere, which

Dynamics of the asymmetric geospace

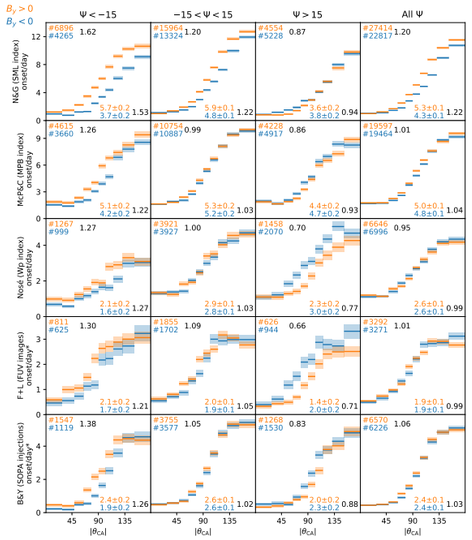

Figure 2: Occurrence frequency of substorms during negative (blue) and positive (orange) IMF B_y conditions based on five independent onset signatures. Each column displays different dipole tilt intervals. Substorms are more frequent for positive (negative) B_y conditions during periods with negative (positive) tilt.

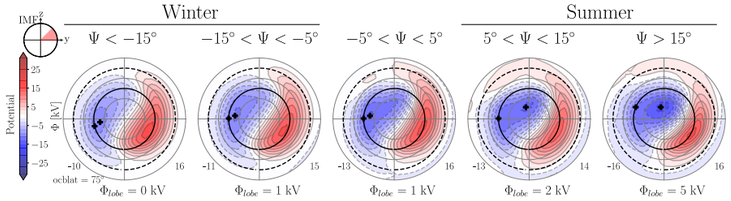

Figure 3: Average ionospheric convection in the Northern hemisphere during positive B_y and B_z conditions for increasing values of magnetic dipole tilt angle from left to right. Lobe cell convection increases when the tilt angle increases, and maximizes in the summer.

The EZIE satellite mission aligns very well with two projects in the DAG group that are funded by the Trond Mohn Foundation ("What Shapes Space?") and by the Research Council of Norway ("IIRARII"). One of the central topics of these projects is regional ionospheric data assimilation: using many different types of data in combination with a model to create a complete map of the ionospheric electrodynamics. The group has spent much time in 2021 developing a technique called Local Mapping of Ionospheric Electrodynamics (Lompe), and we expect to publish several papers that describe and/or use this technique in the coming years. The Lompe work is a true team effort that includes a growing number of DAG group members.

The DAG group continues to meet weekly on Zoom and in person when possible. The Bergen part of the group has had several workshops throughout the year, at Vatnahalsen, Solstrand, and Lofthus. We have a very active Slack workspace. In 2021 two PhD students and one postdoc started in the group. Four Master's students and one PhD student graduated.

will be used to estimate the magnetic field due to the Zeeman effect. This is the first mission dedicated to making Zeeman magnetic field measurements at Earth. Jesper Gjerloev, Professor-II in the DAG group, is the mission scientist, and several DAG group members are heavily involved in a team that develops the algorithm which will be used to calculate maps of the magnetic field and associated currents as the satellites pass over the auroral zone. Karl Laundal leads the team which also includes PhD students Michael Madelaire and Simon Walker, and DAG researcher Jone Reistad. The unique nature of the EZIE measurements calls for new ways of utilizing the data, and Laundal et al. [2021] presented a technique that can be used to discover fine-scale structures in the auroral electrojet which have so far not been possible to resolve. *(Fig. 4)*

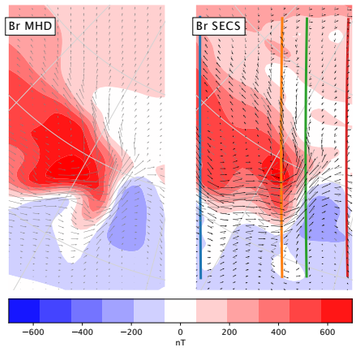

Figure 4: Electrojet Zeeman Imaging Explorer - results of an "Observing System Simulation Experiment" – where we used simulated measurements to investigate how EZIE data can be used to resolve fine-scale current structures. Simulation input to the left ("ground truth"), and maps based on simulated data to the right. The four lines represent the location of the EZIE measurements as the satellite flies along the vertical direction in the plot.

03 Particle precipitation

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Noora Partamies, UNIS
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Lidia Luque, NTNU/UNIS
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Particle precipitation

Near-Earth space is a stormy place where the magnetosphere is constantly being ripped and torn by the solar wind. Guided by the Earth's magnetic field, part of this energy is deposited into the atmosphere as energetic particle precipitation (EPP). The subsequent ionization of the neutral atmosphere initiates chemical reactions leading to the production of odd nitrogen (NO_x: N, NO, NO_2) and odd hydrogen (HOx: H, OH, HO_2) species. In the polar winter darkness, odd nitrogen has a long lifetime, allowing the seasonal downwelling to bring excess NO_x into the upper stratosphere. Here it can reduce the ozone concentration in catalytical reactions. Ozone is critically important in the energy budget, which implies that changes in ozone can impact temperature and winds which link to our weather system. The EPP group brings together space and atmospheric scientists with the expertise to unravel the complex relationship between EPP and its atmospheric effects by applying both observations and models.

Auroral particle (<30 keV) and Medium Energy Electron (MEE) (>30 keV) precipitation have recently become recognized as a potentially important driver of the chemistry and dynamics of the upper atmosphere. Indeed, the Intergovernmental Panel on Climate Change (IPCC) has recommended incorporation of space weather effects in climate models. A major impediment to this inclusion is the lack of global measurements of particle flux and energy needed to calculate the inputs. For example, despite providing such measurements at high spatial and temporal resolution on a global scale, the Special Sensor Ultraviolet Spectrographic Imager (SSUSI) satellite has long remained an under-utilized resource for the auroral energies due to its lack of calibration. Bender et al. [2021] validated the SSUSI observed characteristic electron energy and energy flux through an extensive comparison with EISCAT electron density profiles. The good agreement shows that SSUSI far-UV observations can be used to provide ionization rate profiles on a global basis at 10 km spatial resolution, providing realistic particle energy input for atmospheric climate models.

Knowledge gaps regarding the flux and energy spectrum of the MEE precipitation remain. The SOLARIS-HEPPA working group 5, co-lead by Miriam Sinnhuber (Karlsruhe Institute of Technology) and Hilde Nesse Tyssøy, represents an international collective effort to address this point. The HEPPA III intercomparison experiment has resulted in two companion papers. Nesse Tyssøy et al. [2021a] addressed the uncertainty related to the Medium Energy Electrons impact on the atmosphere. They compared eight different ionization rate estimates all based on the MEPED detectors on board the NOAA/POES spacecraft series. Different data handling, alongside different methods of calculating the ionization rates, and different choice of background atmospheres resulted in a wide range of mesospheric electron ionization rates. The ionization rates based on both the 0° and the 90° detectors were generally higher than the ionization rates based solely on the 0° detector. The ionization rates differed by about an order of magnitude both during geomagnetically quiet and disturbed periods. The largest spread was found in the aftermath of enhanced geomagnetic activity. The mesospheric NO densities simulated with the chemistry climate model WACCM driven by the highest and lowest ionization rates differed by more than a factor of 8. In the companion paper by Sinnhuber et al. [2021], the validity of three of these ionization rate datasets was evaluated by comparing the output of four chemistry climate models to observed NO densities. They found that the differences in the amount of NO in the individual models were much larger than the differences between the multi-model mean using different ionization rates. However, multi-model mean results were consistent with the different strengths of the ionization rate datasets used. This implies that the MEE ionization rates are only one of several aspects determining the atmospheric NO budget in chemistry climate models.

Another factor is the role of the background atmosphere responsible for transporting the EPP-produced NO_x. Maliniemi et al. [2020] showed how the EEP-NOx transport changed alongside the anthropogenic climate change. By using the chemistry climate model WACCM, Maliniemi et al. [2021] demonstrated one of the consequences of this to the ozone layer. The stratospheric ozone experienced a dramatic decrease from the 1960s until the early 2000s due to human-induced chlorofluorocarbon (CFC) emissions. Due to the Montreal Protocol, CFC emissions are now declining, and the stratospheric ozone is already showing signs of recovery. However, increasing greenhouse gas emissions and cooling stratosphere leads to a further enhancement of the ozone layer. Thus, the stratospheric ozone is expected to overshoot with respect to the level prior to the CFC era, i.e., experience a super recovery. Ozone super recovery is predicted to occur in the Arctic stratosphere and the Antarctic lower stratosphere in future scenarios with the strongest increasing greenhouse gas emissions. In the Antarctic upper stratosphere, different scenarios will have roughly the same level of ozone by 2100. This is due to the excess NO_x descending from above in scenarios with the highest greenhouse gas emissions. A likely origin of NO_x is the energetic electron precipitation to the thermosphere and upper mesosphere.

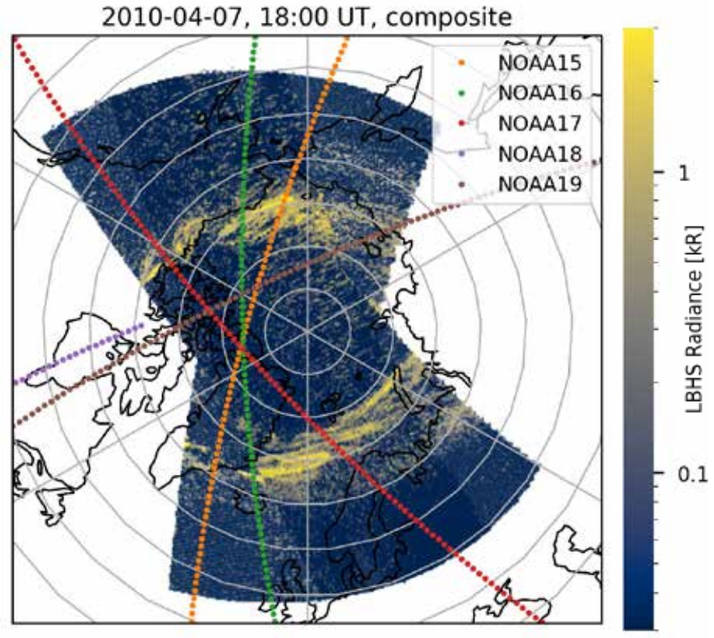

Figure 5: Northern polar composite of the UV radiance measured by three SSUSI instruments within one hour (blue and yellow) and all POES overpasses during that time (coloured lines). The SSUSI data can provide ionization rate and NO_x profiles for every 10x10 km ground pixel, in contrast to zonal averaging or interpolation from the indicated single satellite overpasses.

The group has also been strongly involved in the Young CAS international network linked to Hilde Nesse Tyssøy's fellowship period. The final workshop and a seminar took place in Oslo in October. Speakers from all Norwegian Universities involved in space physics were invited to give their perspective on EPP. The hybrid seminar had more than forty participants. So far two papers (Partamies et al., 2021, Nesse Tyssøy et al., 2021b) acknowledge the working group, and more are expected as the international collaboration continues beyond the fellowship period.

CHAMOS is another international collaboration involving EPP group members. A new WACCM-D simulation with the median energy spectrum of pulsating aurora showed not only production of odd hydrogen but also production of odd nitrogen during the winter season (Verronen et al., 2021). Consequently, an odd nitrogen plume was observed to descend to the upper stratosphere, causing a total ozone depletion of about 8%. The study further showed that the ionization in the thermosphere plays a key role in the total production of odd nitrogen.

With the pandemic still limiting our travels, the group has actively participated in both online and hybrid meetings, leading to more than 25 presentations. Stefan Bender and Patrick Espy convened sessions at the German Physical Society meeting and at the Asia Oceania Geosciences Society (AOGS), respectively. During 2021, the EPP group published 12 papers, and three Master's students successfully completed their theses. Furthermore, Dr. Fasil Tesema graduated one month ahead of time in June 2021 with the thesis titled "Energetic electron precipitation of pulsating aurorae and their mesospheric effects."

04 Hard radiation from thunderstorms

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Co-Leader, Assoc. Professor

Brant Carlson, UiB
Researcher

Nikolai Lehtinen, UiB
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Andrey Mezentsev, UiB
Researcher

Pavlo Kochkin, UiB
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David Sarria, UiB
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Anders Lindanger, UiB
PhD Candidate

Carolina Maiorana, UiB
PhD Candidate

Chris Alexander Skeie, UiB
PhD Candidate

Ingrid Bjørge-Engeland
Phd Candidate

Anders N. Fuglestad, UiB
Master's Student

Ragnar Landet, UiB
Master's Student

2021 has been a magical year for the Hard Radiation from Thunderstorms (HRT) group.

Thunderstorms and lightning are the most energetic natural sites of electron acceleration on Earth. The interaction of these energetic electrons with atmospheric molecules results in the production of gamma-ray photons with energies up to several tens of mega-electronvolts. The gamma-ray emissions can be disruptive, with a very large flux delivered on sub-millisecond time scale, resulting in a so-called Terrestrial gamma-ray flash (TGF), or it can be quasi-stationary, lasting several minutes and involving a large thunderstorm extension, resulting in a so-called gamma-ray glow. The study of TGFs and glows and their relation to lightning is the core activity of the HRT group.

A crucial asset of the group is the Atmosphere-Space Interactions Monitor (ASIM), a mission of the European Space Agency dedicated to the observation of TGFs and optical transients associated to lightning termed Transient Luminous Events (TLE). ASIM has key contributions from Norway, Denmark, and Spain, and has been operational since 2018 onboard the International Space Station (ISS). Scientific exploitation of ASIM data by our group resulted in key contributions to the field, that we present here:

The paper 'Simultaneous Observations of EIP, TGF, Elve, and Optical Lightning' by Østgaard et al. [2021] reports a detailed characterization of a TGF associated with ionospheric UV emissions termed Elve, a class of TLE. The paper shows that the TGF is produced before – or most likely simultaneously – with a large and short current pulse that emits an electromagnetic pulse to produce the Elve. This current pulse can be a combination of a current in a hot leader channel and the TGF itself. The key feature of the paper is the broad ensemble of simultaneous data included in the analysis (gamma-rays, optical and ultraviolet, radio data), pointing out that breakthrough results in this field most likely come when complementary observations are put into context together.

The paper 'Observation of Terrestrial Gamma-Ray Flashes at Mid Latitude' by Maiorana et al. [2021] reports the first TGF observations at mid-latitudes between 38°-51°, both north and south. These observations were made possible by the large orbital inclination of the ISS hosting ASIM, allowing for the first time TGF observation over continental Europe, Asia and North America. Although the lightning activity also in these regions is very high, only 14 TGFs were detected in more than two years. However, this small number is compatible with a TGF-to-lightning ratio close to what is observed at tropical latitudes when the larger gamma-ray attenuation due to the lower TGF production altitude expected at mid latitudes is taken into account. The paper also includes a meteorological characterization of the observed events,

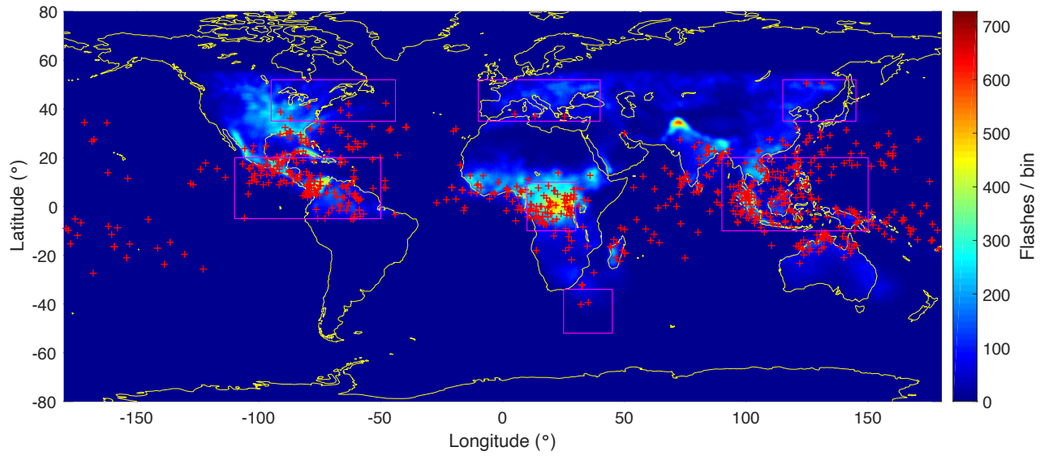


Figure 6: *(From Maiorana et al., 2021)* Lightning density corrected for ASIM exposure time (color scale) and ASIM TGFs (red crosses). The boxes highlight the three classical tropical lightning regions, and four mid-latitude regions.

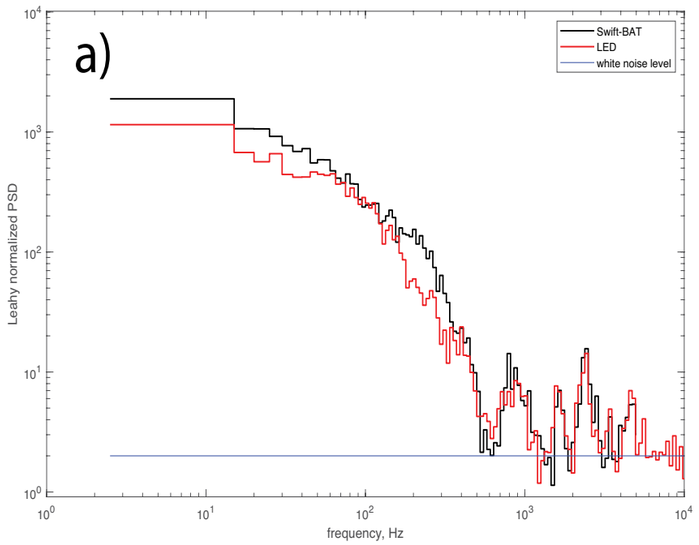
Hard radiation from thunderstorms

indicating that the host thunderstorms show significant convection with overshooting tops, but are not extreme events for those latitudes.

The paper 'Spectral Analysis of Individual Terrestrial Gamma-Ray Flashes Detected by ASIM' by Lindanger et al. [2021] reports the investigation of the source characteristics (production altitude, photon beam width) of 17 ASIM TGFs by spectral analysis. The paper includes a rigorous treatment of all instrumental effects affecting ASIM measurements, as well as robust statistical techniques. The analysis confirms that there is individual spectral variability among TGFs, but it is very difficult to constrain the source parameters and, as a result, the expected intensity at source spans over several orders of magnitude. This study also points out the intrinsic limitations of retrieving the source parameters, based on spectral analysis only, and highlights the importance of coordinated observation in radio to reduce the uncertainty.

The paper 'Very-high-frequency oscillations in the main peak of a magnetar giant flare' by Castro-Tirado, Østgaard, Göğüş et al. [2021], published in the prestigious journal *Nature*, shows how the novel design of ASIM enabled a game-changer observation in a field – high-energy astrophysics – outside the main scope of the mission.

Figure 7: *(From Castro-Tirado, Østgaard, Göğüş et al., 2021)* Power spectral density for ASIM LED (red) and Swift-BAT (black) instruments for 200 ms of data including the burst. Several broad peaks in the kiloHertz range are significant above the background.



The paper shows the analysis of a 160 millisecond-long gamma-ray flare coming from a highly magnetized neutron star (magnetar) in a nearby galaxy 11 million light years away. The burst was detected by several spacecraft, but the total energy release in such a short time was so large that all instruments except ASIM were saturated during the peak emissions. ASIM did not suffer from significant instrumental effect because its front-end electronics were designed to withstand the much larger observed fluxes of TGFs. Timing analysis of the first three milliseconds of such a burst, the most intense part of the event, shows quasi-periodic oscillations at kHz frequency never observed before, posing strong constraints to the theoretical models of such mysterious sources.

A key characteristic of most of these works is the exploitation of the large collaboration network of the group, including radio scientists and modeling experts, both in Europe and the USA, and now also extended to the gamma-ray burst and high-energy astrophysics community, with strong connections to groups in Spain and Turkey.

The project 'TGF Airborne Observatory: Understanding the link between lightning, terrestrial gamma-ray flashes and gamma-ray glows.' (principal investigator, PI M. Marisaldi) has been approved for funding by the Research Council of Norway. The project goal is the scientific support and exploitation of the ALOFT flight campaign, aimed at the detection of TGFs and glow by aircraft. It is slated to take place in summer 2023. This project secures funding to sustain the team and its research beyond the end of the Birkeland Centre.

As in the previous years, team members were actively involved as conveners of topical sessions at the annual plenary meetings of the European Geosciences Union (EGU) and American Geophysical Union (AGU). Team members contributed to these and other relevant international conferences with 21 presentations.

05 Space instrumentation

Maja Elise Rostad, UiB
Team Leader, Chief Engineer

Kjetil Ullaland, UiB
Professor

Georgi Genov, UiB
Senior Engineer

Shiming Yang, UiB
Senior Engineer

Thomas Poulianitis, UiB
Chief Engineer

Bilal Hasan Qureshi, UiB
Chief Engineer

Nuno Roque, UiB
Chief Engineer

Bendik Husa, UiB
Master's Student

Linn Amalie Kvaale Ramdal, UiB
Master's Student

Space instrumentation

Photo: Nuno Roque

Figure 8: Inspection of RSM BB2 (prototype) in the clean room after vibration test

Photo: Maja Rostad

Figure 9: Placement of RSM BB2 in the TVAC chamber for thermal testing

ASIM

The Atmosphere-Space Interactions Monitor (ASIM) continues to deliver unprecedented data of Terrestrial Gamma-ray flashes (TGF), Galactic Gamma-ray Bursts, lightning strokes and other exotic phenomena like blue jets and elves. In 2021 we got yet another paper published in a top-notch journal: Castro-Tirado, Østgaard, Göğüş et al., [2021] in *Nature*. This was a 60 ms long signal from a magnetar 11 million light years away. ASIM's excellent time resolution made it possible for the first time to identify very high frequency oscillations in the very first phase (3 ms) of the burst.

ASIM consists of two instruments. 1) "Modular X- and Gamma-ray Sensor" (MXGS) to image and obtain spectral measurements of Terrestrial Gamma-ray Flashes (TGF) and now also Galactic Gamma-ray Bursts. The two detector layers and read-out electronics were designed and built by the BCSS instrumentation group. MXGS will detect gamma-rays in two energy bands, 50-400 keV and 300keV - 30MeV. 2) The other instrument is the Modular Multi-Spectral Imaging Assembly (MMIA), designed and built by Danish Technical University and TERMA in Denmark. MMIA has three photometers and two cameras to image and obtain spectral measurements of lightning and Transient Luminous Events.

In early 2022 ASIM was moved to a different location on the Columbus module and will stay there for ~2.5 years. The plan is to move ASIM back to the original location for another 1.5 years. This means that ASIM will most likely be a 7-year mission, which is much longer than the nominal mission of 2.5 years. Thanks to all the amazing results from ASIM, both ESA and the national funding agencies have been pro-active in getting this extension funded.

We continue to support ASIM Science Data Center with a dedicated programmer/researcher funded through ESA-PRODEX throughout 2022. In 2022 we will apply for funding for the next three years (2023-2025).

SMILE

The Solar Wind Magnetosphere Ionosphere Link Explorer (SMILE) mission is a joint mission of the European Space Agency (ESA) and the Chinese Academy of Science (CAS). Launch is planned towards the end of 2024.

One of the instruments on board SMILE is the Soft X-ray Imager (SXI), which will provide unprecedented images of the entry of plasma from the Sun into the Earth's magnetosphere. The SXI project is a collaboration between several European universities, research institutes, and industrial partners. BCSS will deliver a Radiation Shutter to protect the SXI instrument against fatal exposure during spacecraft maneuvers and crossings of the Earth's radiation belt. The Radiation Shutter is comprised of the Radiation Shutter Mechanism (RSM) and Electronics (RSE).

In 2021 all the prototype testing of RSM was completed. Changes in US export regulations forced a new European supplier to be introduced for the RSM launch lock. Consequently, the RSM had to undergo a major structural re-design after the prototyping test campaign was completed.

During 2021 all procurement for piece parts to be used in the RSM Engineering Qualification Model (EQM) was completed, and the structural parts were shipped to different companies throughout Europe for dedicated surface treatments and coatings.

The prototype testing in 2020 revealed that the indicator switches for door position were somewhat unstable, thus, in 2021, significant work went into designing test jigs for full screening and acceptance testing of the lot of switches. All this testing must be done under thermal cycling in our vacuum chamber. The first part of this screening testing has been completed, and a second part will be completed early in 2022. The goal for the screening and acceptance testing is to eliminate any switches that show unreliable behavior.

The RSE EQM build was completed in summer of 2021 and has been tested, surface-treated and mounted onto a frame with a mass dummy. Preliminary functional qualification testing and preliminary thermal stress testing were successfully done at BCSS, but the RSE EQM will be delivered for external integration into the SXI instrument's electronics box in the first quarter of 2022. There it will undergo full functional and environmental qualification testing.

Photo: Maja Rostad

Figure 10: Mounting of RSM BB2 on the vibration bench at Prototech

Significant work has also gone into updating design and manufacturing documentation as well as various analyses (like part stress-, reliability-, thermal-, worst case analysis etc.). All are required as input to the Critical Design Review (CDR). The CDR has slipped and is currently scheduled for the third quarter of 2022.

The ESA PRODEX contract is approved through 2023. It covers all hardware activities from breadboard to flight models. The total BCSS involvement in SMILE adds up to around 39 MNOK, including in-kind assistance from UiB. The PRODEX funding is 1345 kEUR.

DEEP

Accurately quantifying the effect of energetic particle precipitation requires a good estimate of the energy deposited in the atmosphere and how the energy is distributed globally. The design and/or orbits of current particle detectors in space are inadequate for determining the amount of particles precipitating into the atmosphere. In particular, the electrons often have a strong anisotropic pitch angle distribution, which is essential in determining the particle loss to the atmosphere. DEEP is composed of three electron- and three proton-pixelated detectors in separate housings, covering a field of view of 180°. This makes it possible to determine the electron fluxes absorbed by the atmosphere, as well as the fluxes backscattered from the atmosphere.

The DEEP prototype was launched back in 2019, and in 2020/2021 the focus has been on developing the next model of DEEP for a potential launch in 2023.

ALOFT

In 2021 we have worked with NASA Headquarters to set up a contract to rent an ER-2 aircraft in July 2023, and we are very close to having a contract that will be signed by UIB and NASA HQ. BCSS is leading this aircraft campaign. The plan is to fly at 20 km altitude over Central America, the Caribbean, and northwest South America. These regions are hot spots for TGF production and July is the best part of the year to observe the short-lived TGFs (microseconds) and long-lasting gamma-ray glows (minutes to hours). ALOFT will make high-resolution measurements of both the gamma-rays, optical signals, and E-field. The main objective is to measure TGFs from an optimal venue point, but ALOFT will also spend 1/3 of the flight time to search for and follow the long-lasting gamma-ray glows from thunderclouds. ALOFT is a collaboration between BCSS, University of Alabama, Huntsville and NASA Marshall Space Flight Center. BCSS will fly one of the units from the ASIM High Energy Detector, which consist of 3 BGO/PMT. In addition, we will build a few smaller detectors to prepare for extremely high gamma-ray fluxes.

06 Ground-based instrumentation

Fred Sigernes, UNIS
Professor, Team Leader

Dag Lorentzen, UNIS
Professor & Co-leader

Robert Hibbins, NTNU
Professor

Lisa Baddeley, UNIS
Assoc. Professor

Mikko Syrjäsuo, UNIS
Chief Engineer

The ground-based instrumentation group is running and maintaining the already existing research infrastructure to which BCSS is granted access. This includes the Kjell Henriksen Observatory (KHO) and NTNU's meteor radar and optical instrumentation at Dragvoll campus in Trondheim and the LINET receiver in Bergen. The Scintillation and Total Electron Content (TEC) network of BCSS is also included in the infrastructure. This section reports on the main activity in 2021.

KJELL HENRIKSEN OBSERVATORY

KHO has now operated successfully for 13 years and is the largest facility of its kind for optical instruments studying the aurora. During the auroral winter season from November to the end of February, 29 optical instruments operate 24 hours a day. The 17 non-optical instruments run all-year-round, 24 hours a day. 24 different institutions from 12 nations are present at KHO.

The activity at KHO has been high despite the corona pandemic. Our co-operative partners / groups have started to show up for upgrades and repairs of their instruments. In addition, 3 new instruments are planned for 2022.

The observatory serves as the main laboratory for the Space Physics Group at UNIS. Four UNIS courses have used it as part of field work, producing a grand total of 45 ECTS, which is 60% teaching capacity compared to a normal year.

Fig. 11 shows students on excursion to KHO. Here they are trained on observational techniques, instrument building and introduced to the state-of-the-art facilities for remote observations of the aurora.

The observatory has been fully operative since the start of the optical season in November. Contact with our students has been through Teams or Zoom. Despite COVID-19, they all managed to finish their courses and degrees successfully. 3 Master's and 2 PhD students have graduated, and 17 papers were published from our group in 2021. See detailed report.

The observatory has supported 2 rocket campaigns. The first rocket, named SS-520-3 from JAXA (Japan Aerospace eXploration Agency), was launched by Andøya Space from the Svalbard Rocket Range (Svalrak) in Ny-Ålesund at 10:09:25 UT on November 4, 2021. The Primary Investigator (PI) was Prof. Yoshifumi Saito from JAXA. The rocket was launched into the dayside sunlit cusp aurora southwest of Svalbard.

On December 1 at 09:25:00 UT, the second NASA rocket named C-REX-2A (Cusp Region EXperiment-2A) was launched from Andøya Space. The PI of the campaign was Prof. Mark Conde from the University of Alaska, Fairbanks. The rocket released 20 Barium, Strontium and Tri-methyl aluminum clouds into the ionosphere over Svalbard. When the clouds were illuminated by the Sun, they acted as excellent tracers for the motion of charged and neutral particles in the ionosphere to study high altitude winds. The clouds were tracked by ground-based optics from both Ny-Ålesund and KHO. In addition, a NASA aircraft was used to track the artificial clouds from a third observational point close to Greenland. The target of the rocket was again sunlit dayside aurora over the Greenland Sea.

Our app, named Aurora Forecast 3D, is rated 4.8 and has reached over 50k+ active installs on Google Play for Android. On Apple iOS phones it is rated 4.5 with 1603 active users. The app is believed to be popular mainly in the auroral tourists' industry and in the amateur radio community. The Facebook page for KHO has 1.6k followers.

Figure 11: Fieldwork for AGF-301- Happy students posing in front of the DSLR All-Sky camera at KHO. Date: March 2, 2021

NTNU GROUND-BASED INSTRUMENTS

NTNU's ground-based programme consists of recording continuous middle atmosphere winds, temperatures, and gravity-wave momentum flux from the group's SKiYMET meteor radar system, and hydroxyl temperatures and radiances recorded with a compact near-infrared spectrometer together with collaborative projects with a large number of international groups.

In addition to the local cluster of instrumentation at Trondheim, the NTNU group has pioneered the development of a novel analysis of the SuperDARN meteor radar array. As published in a series of papers, this analysis has enabled global measurements of tidal motions, which represent the largest source of wind variability in the middle atmosphere. Due to the high temporal

Ground-based instrumentation

resolution of this analysis technique, it has been possible to observe tidal changes induced during impulsive perturbations such as stratospheric warming and particle precipitation events. This has resulted in four publications since 2020, where the Trondheim meteor radar observations have been combined with the SuperDARN analysis to characterize the natural variability of the atmospheric dynamics in order to better observe the perturbations caused by energetic particle precipitation.

Accompanying these observational techniques, BCSS PhD student Wim van Caspel has developed a sophisticated primitive-equation model of atmospheric tides. Using this model, he has been able to attribute the causes of the tidal variability, and to separate the effects of changes in the background atmosphere from those caused by perturbations in the atmospheric chemistry. Understanding how these large tidal amplitudes and phases change in time is critical to understanding how perturbations caused by particle precipitation, a key goal of the BCSS, can be quantified in the face of these much larger background variations.

Results from NTNU's instrumentation have been presented at international meetings run by the AGU, EGU, AOGS and JpGU during 2021 and have formed a core component of 3 Master's student theses and three specialization project reports submitted during the past year.

GNSS RECEIVER NETWORK

BCSS operates four scintillation and total electron content receivers that record signals from navigation satellites over Svalbard and the Barents Sea. The 60 second data have been published in the repository DataverseNO. This collection now contains 65 sub data sets for the years 2013-2020. The network operated nominally throughout 2021, and a new research project was started at UiT (PI: Andres Spicher) in collaboration with BCSS. The project "CASCADE: Characterization and Assessment of Structuring Connected to Auroral Dynamics using EISCAT_3D" will utilize data from the GNSS collection to investigate spatio-temporal characteristics of turbulence with space weather impacts on technology.

LINET

We have maintained the Bergen LINET station, which is a VLF/LF radio receiver that is part of the lightning detection network LINET. The LINET network was developed by the University of Munich and is now managed by Nowcast GmbH.

Photo: Mikko Syrjäsuo

Figure 12: C-REX-2A rocket sub-payloads deployed as seen from KHO

07 Education and public outreach

Kjellmar Oksavik, UiB
Team Leader, Professor

Arve Aksnes, UiB
Advisor, PhD

Kjartan Olafsson, UiB
Advisor, Assoc. Professor

Kavitha Østgaard, UiB
Senior Consultant

Education and public outreach

During 2021, BCSS researchers have contributed to 70 publications in scientific journals and 67 presentations (including 10 invited talks) at international conferences.

Groundbreaking ASIM observations of a giant flare from a distant magnetar

After a very long journey through space, a burst of high-energy radiation was detected by the Atmosphere-Space Interactions Monitor (ASIM) instrument aboard the International Space Station (ISS) on April 15, 2020. The origin of this energetic burst was found to be a giant flare from an extremely magnetized neutron star known as a magnetar, located more than 10 million light years away in the galaxy NGC 253. Six other instruments in space also recorded the flare, but they were all blinded by the giant flash of high energy which saturated the detectors at the time of the maximum emission. ASIM was the only instrument to detect the main burst phase in the entire energy range of photons without saturation, putting the instrument in a unique position to unveil some of the secrets surrounding magnetars. So, in the second last issue of Nature in 2021, the ASIM data were published in a groundbreaking study [Castro-Tirado, Østgaard, Göğüş et al., 2021], with 8 BCSS researchers as co-authors. This resulted in more than 600 media news all over the world, including exciting national TV reports in both Norway (NRK) and Spain (Channel 9). An illustration of the extraordinary shakings of the distant magnetar, developed by BCSS and Mount Visual, was later (the second week of 2022) chosen as NASA's "Picture of the Week".

Illustration: BCSS / Mount Visual / Daniel Schmelling

Figure 13: Cover page in *Nature* (January 2021)

ASIM results highlighted on the cover of *Nature*

On January 20, ASIM observations revealing clues to the nature of blue jet lightning were portrayed on the cover page of *Nature*. This study [Neubert et al., 2021] was led by Torsten Neubert at DTU, with BCSS-leader Nikolai Østgaard as co-author. In less than two weeks, the new findings resulted in almost 600 media news all over the world, including *Science News*, *ESA*, *BBC*, *The Independent* and *El Pais*. *(Fig. 13)*

A space hurricane observed for the first time

On February 22, a remarkable study [Zhang et al., 2021] about the first observations of a space hurricane over the Earth's polar ionosphere was published in *Nature Communications*. Co-author Kjellmar Oksavik of BCSS played an important role in this study, and in the wake of the publication, he was contacted by media from all over the world. Soon, one could read about the space hurricane in Kjellmar's hometown paper *Vestlandsnytt* from Fosnavåg in Norway, as well as in *National Geographic*! Kjellmar was also interviewed by the Norwegian national radio news (NRK), and in total almost 400 media reports were written about the historic space hurricane. *(Fig. 14)*

Heavy metal and rock in space

A study led by Stein Haaland was published in *JGR: Space Physics* on February 18 entitled "Heavy Metal and Rock in Space: Cluster RAPID Observations of Fe and Si". The new publication was soon to be described by ESA through 5 eye-catching twitter messages. *(Fig. 15)*

AGU/EOS spotlight: Uncovering the timing and triggering of high-energy lightning events

On June 11, 2021, the Research Spotlights section in EOS (Earth and Space Science) News highlighted Østgaard et al. [2021] through a news article entitled "Observations from Space and Ground Reveal Clues About Lightning". The concluding remarks are worth noting: "This combination of observations is unique and unprecedented. The detailed observations suggest that coordinated monitoring is the future method for lightning and thunderstorm research efforts".

Among the most downloaded in 2020

In the summer of 2021, then PhD Fasil Tesema and his BCSS co-authors (including Hilde Nesse Tyssøy and Christine Smith-Johnsen) were informed that their paper entitled "Observations of Electron Precipitation During Pulsating Aurora and Its Chemical Impact" was among the AGU journal's top 10 % most downloaded in 2020.

Winner of the NIFRO Prize

BCSS student Ole Martin Borge (NTNU) became the winner of the 2021 NIFRO Prize for his Master's thesis "Atmospheric Correction over Coastal Waters Based on Machine Learning Models". Borge has, under the supervision of Prof. Joseph Espy of NTNU, developed mathematical models that will make it easier for satellites to track ocean plankton.

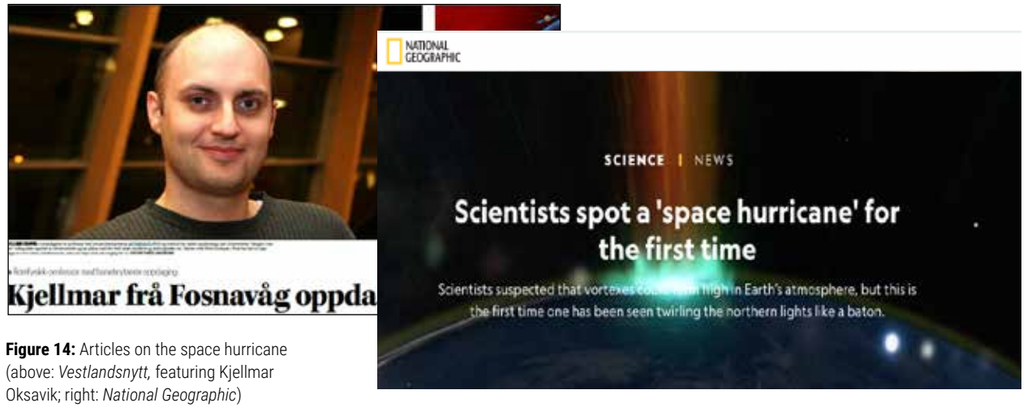


Figure 14: Articles on the space hurricane (above: *Vestlandsnytt,* featuring Kjellmar Oksavik; right: *National Geographic*)

Every year, the NIFRO Prize is given to the best Master's thesis in space technology. The goal of the prize is to encourage Master's students to make an extra effort in completing good projects that are of relevance to the Norwegian space industry. The prize is NOK 20,000.

Popular science in the Norwegian magazine *Naturen*

The second issue in 2021 of the magazine *Naturen* was devoted to polar research, and among the popular science articles was one about the aurora («Nordlyset: Den himmelske danserinnen") written by Arve Aksnes and Kjellmar Oksavik.

BCSS researchers in the news

Throughout this year, many researchers at the Centre have been active in promoting our science in mainstream news. For example, on January 17, post.doc Ville Maliniemi was interviewed by the Finnish newspaper *Iltalehti*. The topic of the article was weather forecasting, and whether there is a link between auroral activity and the winter climate in the Northern Hemisphere.

Professor Martino Marisaldi took a different approach, writing to the Italian ambassador to Norway, Alberto Colella, and outlining the collaboration between our two countries when it comes to research regarding terrestrial gamma-ray flashes. A version of his text in Italian was thereafter published on the institutional website of the Italian Embassy in Oslo, as well as on an official webpage managed by the Italian Ministry for foreign affairs dedicated to "scientific diplomacy".

Highlights from the BCSS homepage

To promote the many great publications by our researchers, we have made several news articles this year on our BCSS home page. We have, for example, presented an exciting study by postdoc Lindis Bjoland and her co-authors regarding electron density depletion regions. Briefly, their results indicated that the formation of a depletion region in the early morning F-region ionosphere was connected to frictional heating. Further, this formation was affected by the background effective temperature, as well as seasonal and local time variations in the O/N_2 ratio and solar zenith angle. We should also note that the study by Lindis Bjoland and co-authors were groundbreaking, as this was the first time the EISCAT Svalbard radar had characterized these regions of very low electron densities in a large statistical study. *(Fig. 16)*

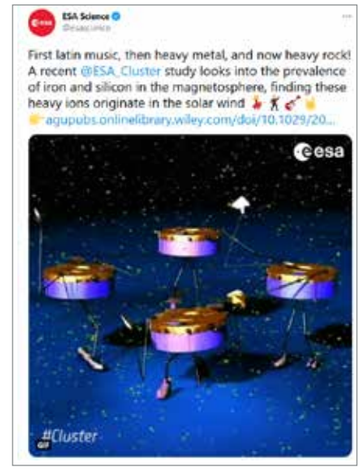


Figure 15: One of the "Heavy Metal and Rock" tweets regarding Cluster studies

Figure 16: Postdoc Lindis Bjoland poses in front of the Kjell Hendriksen Observatory on Svalbard.

08 Statistics

PROJECT FUNDING

Birkeland Centre for Space Science: CoE Funding 160 MNOK; Total Funding over ten years 440 MNOK

European Space Agency | Swarm+Coupling High-Low Atmosphere Interactions | Project: 4000126731

2019-2022	Info from Swarm and other satellites will be used to fill knowledge gaps related to "energetic ion outflow"	**P.I.** Spencer Hatch **150 KEUR**

European Space Agency | ASDC | Project: 4000123438

2018-2022	ASIM Science Data Centre (project extended, funding increased)	**P.I.** Nikolai Østgaard **433 KEUR**

European Space Agency | SMILE Phase 1 | Project: 4000123238

2018-2023	Radiation Shutter for SXI on SMILE (project extended, funding increased)	**P.I.** Nikolai Østgaard **1,345 MEUR**

European Space Agency | SWARM DISC ITT 1.3 | Project: 4000109587/13/I-NB SWARM ESL

2017-2021	Production and visualization of a climatological model of high latitude ionospheric and field aligned current systems (project extended, funding increased)	**P.I.** Karl Magnus Laundal **168 KEUR**

European Space Agency | Atmosphere-Space Interaction Monitor | Project: 40000101107/10/NL/BJ |TERMA DTU: TER_SPACE:CON_DTU_SPACE-002_rev2

2010-2023	This project started September 2010 and is an ESA contract to design and build the front-end electronics and detector arrays for Modular X- and Gamma-ray flashes (MXGS). ASIM is a payload for the ISS and was launched in 2018	**P.I.** Nikolai Østgaard **3,75 MEUR**

Research Council of Norway | Which types of particle precipitation matter in the middle atmosphere? | Project: 287427

2019-2022	Which types of particle precipitation are important for the chemistry of the atmosphere?	**P.I.** Noora Partamies **7 MNOK**

Research Council of Norway | FREPPIMA | Project: 263008/F50

2017-2020	Full Range Energetic Particle Precipitation Impacting the Middle Atmosphere	**P.I.** Hilde Nesse Tyssøy **3,52 MNOK**

Research Council of Norway | Program for Space Research | Project: 195385

2010-2021	Infrastructure for space physics-related research on Svalbard	**P.I.** Dag Lorentzen **9,1 MNOK**

Research Council of Norway | Magnetic pulsations and transients: the Sun-Earth connection and impact on the high latitude ionosphere | Project: 309135

2020-2024	INTPART Coordination and Support Activity Support for Network-related Activities	**P.I.** Lisa Baddeley **2,118 MNOK**

Research Council of Norway | Unravelling the Drivers of EEP – Revealing the Imprint of Space on Earth (DEEP - RISE) | Project: 302040

2020-2023	The main objective is to quantify the radiation belt loss of energetic electrons into the atmosphere.	**P.I.** Hilde Nesse Tyssøy **4,936 MNOK**

Research Council of Norway | Ionospheric Impact Response Analysis by Regional Information Integration | Project: 300844

2020-2025	The primary project objective is to determine how ionospheric conditions affect transient geospace phenomena like substorms and rapid changes in dynamic solar wind pressure.	**P.I.** Karl Magnus Laundal **11,055 MNOK**

Research Council of Norway | Effects of Energetic Electron Precipitation In a Changing climate | Project: 300724

2020-2023	The primary project objective is to determine how ionospheric conditions affect transient geospace phenomena like substorms and rapid changes in dynamic solar wind pressure.	**P.I.** Ville Maliniemi **5,826 MNOK**

Research Council of Norway | Understanding the link between lightning, terrestrial gamma-ray flashes and gamma-ray glows | Project: 325582

2021-2025	Primary objective: Understanding the connection between lightning, TGF, and gamma-ray glows	**P.I.** Martino Marisaldi **11,964 MNOK**

Norwegian Space Agency | DEEP | Project: VIT.02.19.7

2019-2020	DEEP – Electron and Proton Detector	**P.I.** Hilde N. Tyssøy **400 KNOK**

Trond Mohn Foundation | What Shapes Space? | Project: TMS2020STG02

2020-2024	The project investigates the time scales of large-scale changes in geospace, and how these time scales differ between hemispheres.	**P.I.** Karl Magnus Laundal **9,247 MNOK**

EU-MCSA SAINT | Grant: 722337 — SAINT (Science and Innovation with Thunderstorms)

2017-2021	**SAINT** – project with a multidisciplinary and inter-sectorial training platform for 15 ESRs. The platform brings together satellite and ground observations with modelling and lab experiments.	**P.I.** Nikolai Østgaard **286 KEUR**

PERSONNEL

Summary	TOTAL	UiB	NTNU	UNIS	MEN	WOMEN
Professors	9	5	2	2	9	-
Associate Professors	4	2	-	2	2	2
Professors Emeriti	2	2	-	-	2	-
Researchers	13	11	1	1	11	2
Postdocs	6	3	1	2	4	2
PhD Candidates	17	12	1	4	8	9
Technicians	7	6	-	1	6	1
Administration	3	3	-	-	1	2
Master's Students	9	4	3	2	4	5
Sum	70	48	8	14	47	23

Science Advisory Board (SAB)

Hermann Opgenoorth, *Prof. Emeritus, Umeå University*	SWE
Kristi Kauristie, *PhD, Finnish Meteorological Institute*	FIN
Steve Cummer, *Professor, Duke University*	USA

BCSS Team

Centre Leader	Nikolai Østgaard	UiB
Adm. Coordinator	Katarzyna Kosela-Dordevic	UiB
Centre Board	Anne Marit Blokhus, *Vice-Dean, Faculty of Math. & Natural Sciences*	UiB
	Elisabeth Müller Lysebo *Dep. Dir. Genl., Fac. of Math. Nat. Sci.*	UiB
	Øyvind Frette, *Head, Dept. of Physics and Technology (IFT)*	UiB
	Erik Wahlström, *Head, Dept. of Physics*	NTNU
	Jøran Moen, *Managing Director*	UNIS
	Grete K. Ersland, *Head of Admin., Secretary, IFT Board*	UiB

Technical and Administrative Team

Arve Aksnes, *Advisor*	M	UiB
Georgi Genov, *Senior Eng.*	M	UiB
Thomas Poulianitis, *Chief Eng.*	M	UiB
Bilal Hasan Qureshi, *Chief Eng.*	M	UiB
Nuno Roque, *Staff Eng.*	M	UiB
Maja Rostad, *Chief Eng.*	F	UiB
Mikko Syrjäsuo, *Head Eng.*	M	UNIS
Shiming Yang, *Senior Eng.*	M	UiB
Kavitha Østgaard, *Sr. Consultant*	F	UiB

Scientific Team

Lisa Baddeley	Assoc. Professor	F	UNIS
Patrick Espy	Professor	M	NTNU
Jesper Gjerloev	Professor II	M	UiB
Robert Hibbins	Professor	M	NTNU
Dag Lorentzen	Professor	M	UNIS
Martino Marisaldi	Assoc. Professor	M	UiB
Stephen Milan	Professor II	M	UiB
Kjellmar Oksavik	Professor	M	UiB
Kjartan Olafsson	Assoc. Professor	M	UiB
Noora Partamies	Assoc. Professor	F	UNIS
Fred Signernes	Professor	M	UNIS
Johan Stadsnes	Professor *Emeritus*	M	UiB
Finn Søraas	Professor *Emeritus*	M	UiB
Kjetil Ullaland	Professor	M	UiB
Nikolai Østgaard	Professor	M	UiB
Stefan Bender	Researcher	M	NTNU
Lindis Bjoland	Postdoc	F	UNIS
Brant Carlsson	Researcher II	M	UiB
Stein Haaland	Researcher II	M	UiB
Spencer Mark Hatch	Researcher	M	UiB
Kate Herlingshaw	Postdoc *(from 2/2021)*	F	UNIS
Jia Jia	Postdoc	F	NTNU
Pavlo Kochkin	Researcher	M	UiB
Karl Magnus Laundal	Researcher	M	UiB
Nikolai Lehtinen	Researcher	M	UiB
Ville Aleksi Maliniemi	Postdoc	M	UiB
Andrey Mezentsev	Researcher	M	UiB
Anders Ohma	Postdoc	M	UiB
Christine Smith-Johnsen	Researcher	F	UiB
Hilde Nesse Tyssøy	Researcher	F	UiB
Jone Petter Reistad	Researcher *(from 2/2021)*	M	UiB
Jone Petter Reistad	Postdoc *(till 1/2021)*	M	UiB
David Sarria	Researcher	M	UiB
Eldho Midhun Babu	PhD candidate	M	UiB
Ingrid Bjørge-Engeland	PhD candidate	F	UiB
Margot Decotte	PhD candidate	F	UiB
Jone Øvertvedt Edvartsen	PhD candidate	M	UiB
Reham Elhawary	PhD candidate	F	UiB
Nina Kristine Eriksen	PhD candidate	F	UNIS
Sara Gasparini	PhD candidate	F	UiB
Katie Herlingshaw	PhD candidate *(till 1/2021)*	F	UNIS
Anders Lindanger	PhD candidate	M	UiB
Michael Madelaire	PhD candidate	M	UiB
Carolina Maiorana	PhD candidate	F	UiB
Josephine Salice	PhD candidate	F	UiB
Chris A. Skeie	PhD candidate	M	UiB
Fasil Tesema	PhD candidate	M	UNIS
Wim van Caspel	PhD candidate	M	NTNU
Charlotte van Hazendonk	PhD candidate	F	UNIS
Simon Walker	PhD candidate	M	UiB

MAJOR ACHIEVEMENTS

December 2021

Publication: In a groundbreaking study (Castro-Tirado, Østgaard, Göğüş et al., 2021) published in *Nature*, the authors (including 8 researchers from BCSS) report – for the first time – the fine structure of the main burst phase of a magnetar. The ASIM observations were made on April 15, 2020, when a giant flare entered our Solar System after travelling more than 10 million light years through space.

Media coverage: The historic ASIM findings around a distant magnetar are covered by more than 600 news articles in media all over the world. This includes TV reports in both Norway (NRK) and Spain (Channel 9), as well as broad coverage in the popular magazine *Scientific American*. Also, an illustration of the extraordinary shakings of the distant magnetar, as developed by BCSS and Mount Visual, was later (the second week of 2022) chosen as NASA's "Picture of the Week".-

Publications: The High Energy Particle Precipitation in the Atmosphere (HEPPA) intercomparison experiments published designed to advance the EPP research with community-wide, collective efforts. HEPPA III started in 2017 and was led by Miriam Sinnhuber (Karlsruhe Institute of Technology) and Hilde Nesse Tyssøy. At the very end of 2021 two extensive companion papers with the aim to improve the representation of medium energy electrons in atmosphere and climate models are published.

October 2021

Workshop: Young CAS Fellow Hilde Nesse Tyssøy organises the third and final gathering in her Young CAS Fellow project Unraveling the Drivers of Energetic Electron Precipitation. The workshop includes researchers from Norway, Finland, England, and USA. The last day is celebrated with a hybrid seminar dedicated to the scientific achievement of the project as well as highlighting Norwegian research on Energetic Particle Precipitation with invited talks from the University of Oslo, UNIS, NTNU and UiB. It attracts more than 40 on site and online participants.

August 2021

Achievement: PhD Fasil Tesema Kebede and co-authors are informed by the AGU publications team that their paper, entitled "Observations of Electron Precipitation During Pulsating Aurora and Its Chemical Impact," was among the AGU journal's top 10% most downloaded in 2020.

Research Grant: Martino Marisaldi is informed by the Research Council of Norway that his research project about lightning, terrestrial gamma-ray flashes and gamma-ray glows has been awarded 12 million NOK. The full project title reads: "TAO–TGF Airborne Observatory: Understanding the link between lightning, terrestrial gamma-ray flashes and gamma-ray glows".

July 2021

Popular Outreach: The second issue in 2021 of the magazine *Naturen* is devoted to polar research, and among the popular science articles is one about the aurora ("Nordlyset: Den himmelske danserinnen") written by Arve Aksnes and Kjellmar Oksavik.

June 2021

Collaboration: Martino Marisaldi meets the Italian ambassador to Norway, Alberto Colella, who has a keen interest in the phenomenon known as Terrestrial Gamma-ray Flash (TGF). In particular, the ambassador wants to know more about the ongoing collaboration between Italy and Norway when it comes to TGF science.

After the meeting, Marisaldi writes to the ambassador, outlining the TGF collaboration between our two countries. A version of this text has been published on the institutional website of the Italian Embassy in Oslo, as well as on an official webpage managed by the Italian Ministry for foreign affairs dedicated to "scientific diplomacy."

Highlight: The Research Spotlights section in EOS (Earth and Space Science) News highlights Østgaard et al. [2021] through a news article in their latest edition entitled "Observations from Space and Ground Reveal Clues About Lightning". In particular, the concluding paragraph is worth noting: "This combination of observations is unique and unprecedented. The detailed observations suggest that coordinated monitoring is the future method for lightning and thunderstorm research efforts."

Award: BCSS student Ole Martin Borge (NTNU) is the winner of the annual NIFRO Prize for his Master's thesis "Atmospheric Correction over Coastal Waters Based on Machine Learning Models". Borge has, under the supervision of Prof. Joseph Espy of NTNU, developed mathematical models that will make it easier for satellites to track ocean plankton.

New PhD: Fasil Tesema Kebede successfully defends his PhD thesis "Energetic electron precipitation of pulsating aurorae and their mesospheric effects".

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MAJOR ACHIEVEMENTS (cont.)

May 2021

Social media: The Twitter account "ESA Science" publishes five eye-catching and informative tweets to highlight a new paper by Stein Haaland et al. (2021) entitled "Heavy Metal and Rock in Space: Cluster RAPID Observations of Fe and Si."

New PhD: Carolina Maiorana successfully defends her PhD thesis "Geographical Characteristics and Meteorological Environment of Terrestrial Gamma-ray Flashes."

February 2021

Publication: Kjellmar Oksavik is co-author on a paper in *Nature Communications* by Zhang et al. [2021], showing the first observations of a space hurricane over the Earth's polar ionosphere.

Media coverage: Groundbreaking observations of a space hurricane are covered by almost 400 news articles all over the world – from the local newspaper *Vestlandsnytt* from Fosnavåg, Norway (celebrating their local hero: "Kjellmar frå Fosnavåg oppdaga rom-orkan"), to *National Geographic*, one of the world's most renowned magazines.

January 2021

Cover page: The paper by Neubert et al. [2021] – in which Centre Leader Nikolai Østgaard is a co-author – on the observations of a blue jet by the ASIM instrument is featured on the cover page of *Nature*.

Media coverage: The recent ASIM findings regarding a blue jet are covered by more than 600 news articles in media outlets all over the world including *BBC*, *El Pais*, *The Independent*, *Science News*, *ESA*, *NASA*, and *NRK*.

New PhD: Katie Herlingshaw successfully defends her PhD thesis "Characterising Mesoscale Fast Flow Channels in the Polar Cap Ionosphere."

PUBLICATIONS

1. **S. Haaland,** P.W. Daly, E. Vilenius (2021), Heavy Metal and Rock in Space: Cluster RAPID Observations of Fe and Si, *J. Geophys. Res.: Space Phys*., doi.org/10.1029/2020JA0288522
2. S. Ohtani, S. Imajo, A. Nakamizo, **J.W. Gjerloev** (2021), Globally Correlated Ground Magnetic Disturbances During Substorms, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2020JA028599
3. Orr, L., Chapman, S.C., **Gjerloev, J.W.**, Guo, W. (2021), Network community structure of substorms using SuperMAG magnetometers, *Nature Communications*, doi.org/10.1038/s41467-021-22112-4
4. Wang, Y., Z. Cao, Z.-Y. Xing, Q.-H. Zhang, P. T. Jayachandran, **K. Oksavik,** N. Balan, and K. Shiokawa (2021), GPS scintillations and TEC variations in association with a polar cap arc, *J. Geophys. Res.: Space Physics*, doi.org/10.1029/2020JA028968
5. Zhang, Q.-H., Y.-L. Zhang, C. Wang, **K. Oksavik,** L. R. Lyons, M. Lockwood, H.-G. Yang, B.-B. Tang, J. I. Moen, Z.-Y. Xing, Y.-Z. Ma, X.-Y. Wang, Y.-F. Ning, and L.-D. Xia (2021), A space hurricane over the Earth's polar ionosphere, *Nature Communications*, doi.org/10.1038/s41467-021-21459-y
6. Moser, C., J. LaBelle, **S. Hatch**, J. I. Moen, A. Spicher, T. Takahashi, C.A. Kletzing, S. Bounds, **K. Oksavik**, **F. Sigernes**, and T. K. Yeoman (2021), The cusp as a VLF saucer source: First rocket observations of long-duration VLF saucers on the dayside, *Geophys. Res. Lett.*, 48, doi.org/10.1029/2020GL090747
7. **K. M. Laundal**, J. H. Yee, V. G. Merkin, **J. W. Gjerloev**, H. Vanhamäki, **J. P. Reistad**, **M. Madelaire**, K. Sorathia, **P. J. Espy** (2021), Electrojet Estimates From Mesospheric Magnetic Field Measurements, *J. Geophys. Res.: Space Phys.,* doi.org/10.1029/2020JA028644
8. Paschmann, J. M. Quinn, R. B. Torbert, C. E. McIlwain, H. Vaith, **S. Haaland**, H. Matsui, C. A. Kletzing, W. Baumjohann, G. Haerendel (2021), Results of the Electron Drift Instrument on Cluster, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2021JA0293130
9. **S. Haaland**, B. Lybekk, L. Maes, **K.M. Laundal**, A. Pedersen, P. Tenfjord, **A. Ohma**, **N. Østgaard**, **J. Reistad**, K. Snekvik (2021), "Ion Outflow and Lobe Density", Interhemispheric Asymmetries, Ch. 7, doi.org/10.1002/9781119815617.ch7
10. A. Fuselier, **S. Haaland**, et al. (2021), High-Density Magnetospheric He+ at the Dayside Magnetopause and Its Effect on Magnetic Reconnection, *J. Geophys. Res.: Space Phys*., doi.org/10.1029/2020JA028722
11. K. Li, **S. Haaland**, Y. Wei (2021), A New Concept to Measure the Ambipolar Electric Field Driving Ionospheric Outflow, *J. Geophys. Res.: Space Phys*., doi.org/10.1029/2020JA028409
12. D. Billett, G. W. Perry, L. B. N. Clausen, W. E. Archer, K. A. McWilliams, **S. Haaland**, **J. P. Reistad**, et al. (2021), The Relationship Between Large Scale Thermospheric Density Enhancements and the Spatial Distribution of Poynting Flux, J. Geophys. Res.: Space Phys., doi.org/10.1029/2021JA029205
13. Toledo-Redondo, M. André, N. Aunai, C. R. Chappell, J. Dargent, S. A. Fuselier, A. Glocer, D. B. Graham, **S. Haaland**, et al. (2021), Impacts of ionospheric ions on magnetic reconnection and Earth's magnetosphere dynamics, *Revs. of Geophys*., doi.org/10.1029/2020RG000707
14. Ohtani, S., **Gjerloev, J.W**., et al. (2021), Simultaneous Development of Multiple Auroral Substorms: Double Auroral Bulge Formation, *J. Geophys. Res.: Space Phys.*, doi: 10.1029/2020JA028883Pu
15. M. McGranaghan, J. Ziegler, T. Bloch, S. M. Hatch, E. Camporeale, K. A. Lynch, M. Owens, **J. Gjerloev**, et al. (2021), Toward a Next Generation Particle Precipitation Model: Mesoscale Prediction Through Machine Learning (a Case Study and Framework for Progress), *Space Weather,* doi.org/10.1029/2020SW002684
16. **Milan, S. E.**, Carter, J. A., Sangha, H., Bower, G. E., & Anderson, B. J. (2021), Magnetospheric flux throughput in the Dungey cycle: Identification of convection state during 2010, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2020JA028437
17. **Milan, S. E.** and A. Grocott (2021), High latitude ionospheric convection, in Space Physics and Aeronomy Collection Volume 3: Ionosphere Dynamics and Applications, *Geophysical Monograph Series*, eds. C. Huang and G. Lu, doi.org/10.1002/9781119815617.ch2
18. **Ohma, A.**, **Reistad, J. P.**, and **Hatch, S. M.** (2021), Modulation of magnetospheric substorm frequency: Dipole tilt and IMF By effects, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2020JA028856
19. **Ohma, A.**, **Østgaard, N., Laundal, K. M., Reistad, J. P., Hatch, S. M.**, Tenfjord, P. (2021), Evolution of IMF By induced asymmetries: The role of tail reconnection, *J. Geophys. Res.: Space Phys*., doi: 10.1029/2021JA029577
20. G. Branduardi-Raymont, M. Berthomier, Y. V. Bogdanova, ... **K. M. Laundal**, M. Lester, **S. Milan, K. Oksavik, N. Østgaard**, et al. (2021) Exploring Solar-Terrestrial Interactions via Multiple Imaging Observers, *Exp. Astron*., doi.org/10.1007/s10686-021-09784-y
21. M.J. Engebretson, L.Y. Ahmed, V.A. Pilipenko, E.S. Steinmetz, M.B. Moldwin, M.G. Connors, D.H. Boteler, ... **J. Gjerloev**, C.T. Russell (2021) Superposed Epoch Analysis of Nighttime Magnetic Perturbation Events Observed in Arctic Canada, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2021JA029465
22. **S. Haaland**, H. Hasegawa, G. Paschmann, B. Sonnerup, M. Dunlop (2021), 20 Years of Cluster Observations: The Magnetopause, *J. Geophys. Res.: Space Phys*., doi.org/10.1029/2021JA029362
23. D. Zhang, Q.-H. Zhang, Y.-Z. Ma, **K. Oksavik**, L. R. Lyons, Y.-L. Zhang, B. Nanan, Z.-Y. Xing, J. Liu, M. Hairston, and X.-Y. Wang (2021), Solar and geomagnetic activity impact on occurrence and spatial size of cold and hot polar cap patches, *Geophys. Res. Lett*., 48, doi.org/10.1029/2021GL094526
24. P.G. Ellingsen, **D. Lorentzen**, D. Kenward, J.H. Hecht, J.S. Evans, **F. Sigernes**, M. Lessard (2021) Observations of sunlit N2+ aurora at high altitudes during the RENU2 flight, *Ann. Geo*., doi.org/10.5194/angeo-39-849-2021
25. M.N. Pedersen, H. Vanhamäki, A.T. Aikio, S. Käki, A.B. Workayehu, C.L. Waters, **J.W. Gjerloev** (2021) Field-aligned and ionospheric currents by AMPERE and SuperMAG during HSS/SIR-driven storms, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2021JA029437
26. K. Li, . Andre, A. Eriksson, Y. Wei, J. Cui and **S. Haaland** (2021), High-latitude cold ion outflow inferred from the Cluster wake observations in the magnetotail lobes and the polar cap region, *Front. Phys.*, doi: 10.3389/fphy.2021.743316
27. Paschmann, G., Sonnerup, B. U. Ö., Phan, T., Fuselier, S. A., **Haaland, S.**, et al.. (2021), Anomalous Reconnection Layer at Earth's Dayside Magnetopause, *J. Geophys. Res*., doi:10.1029/2021JA029678
28. Retino, A, Khotyaintsev, Y, ... **Haaland S.** et al. (2021), Particle Energization in Space Plasmas: Towards a Multi-Point, Multi-Scale Plasma Observatory, *Earth Space Sci. Open Arch.,* doi:10.1002/essoar.10508140.1
29. L. Holappa, **J.P. Reistad**, **A. Ohma**, C. Gabrielse, D. Sur (2021), The Magnitude of IMF By Influences the Magnetotail Response to Solar Wind Forcing, *J. Geophys. Res.: Space Phys*., doi.org/10.1029/2021JA029752
30. **J.P. Reistad, K.M. Laundal, N. Østgaard, A. Ohma**, A.G. Burrell, **S.M. Hatch, S. Haaland**, E.G. Thomas (2021), Quantifying the lobe reconnection rate during dominant IMF By periods and different dipole tilt orientations, *J. Geophys. Res.: Space Phys*., doi: 10.1029/2021JA029742
31. Y.-X. Li, W.-Y. Li, B.-B. Tang, C. Norgren, ... **S. Haaland**, P. Tenfjord, et al. (2021), Quantification of Cold-Ion Beams in a Magnetic Reconnection Jet, *Front. Astron. & Space Sci.: Space Phys*., doi: 10.3389/fspas.2021.745264
32. M.W. Dunlop, X.-C. Dong, T.-Y. Wang, J.P. Eastwood, P. Roberts, **S. Haaland**, et al. (2021), Curlometer technique and applications, *J. Geophys. Res.: Space Phys.*, doi: 10.1029/2021JA029538

Continued on next page >>

PUBLICATIONS (cont.)

33. M. Øieroset, T.D. Phan, R. Ergun, ..., **S. Haaland**, et al. (2021), Spatial evolution of magnetic reconnection diffusion region structures with distance from the X-line, *AIP Physics of Plasmas*, doi.org/10.1063/5.0072182

34. **L. M. Bjøland**, Y. Ogawa, U. P. Løvhaug, **D. A. Lorentzen**, **S. M. Hatch**, **K. Oksavik** (2021,) Electron Density Depletion Region Observed in the Polar Cap Ionosphere, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2020JA028432

35. E. A. Kronberg, T. Hannan, J. Huthmacher, ... **S. Haaland**, et al. (2021), Prediction of Soft Proton Intensities in the Near-Earth Space Using Machine Learning, *Astrophys. J.*, doi.org/10.3847/1538-4357/ac1b30

36. E.A. Kronberg, J. Gorman, K, Nykyri, A.G. Smirnov, **Gjerloev, J.W.**, et al. (2021), Kelvin-Helmholtz Instability Associated With Reconnection and Ultra Low Frequency Waves at the Ground: A Case Study, *Frontiers Phys.*, 12, 1842 (2021), doi.org/10.3389/fphy.2021.738988

37. L. Norenius, M. Hamrin, O. Goncharov, H. Gunnell, H. Opgenoorth, T. Pitkänen, S. Chong, **N. Partamies, L. Baddeley** (2021), Ground-Based Magnetometer Response to Impacting Magnetosheath Jets, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2021JA029115

38. **N. Østgaard**, S. A. Cummer, **A. Mezentsev**, A. Luque, J. Dwyer, T. Neubert, V. Reglero, **M. Marisaldi**, P. Kochkin, **D. Sarria, N. Lehtinen, K. Ullaland, S. Yang, G. Genov**,et al. (2021), Simultaneous observations of EIP, TGF, Elve and optical lightning, J. *Geophys. Res.: Atmospheres*, doi.org/10.1029/2020JD033921

39. J. Montanya, J. A. Lopez, C. A. Morales Rodriguez, ..., **N. Østgaard**, et al. (2021), A simultaneous observation of lightning by ASIM, Columbia-Lightning Mapping Array, GLM and ISS-LIS, *J. Geophys. Res.: Atmos.*, doi.org/10.1029/2020JD033735

40. T. Neubert, O. Chanrion, M. Heumesser, K. Dimitriadou, L. Husbjerg, I. Lindgaard Rasmussen, **N. Østgaard**, V. Reglero (2021), Observation of the onset of a blue jet into the stratosphere, *Nature*, 589, 371-375 , doi.org/10.1038/s41586-020-03122-6

41. Tiberia, A., Mascitelli, A., D'Adderio, L.P., Federico, S., **Marisaldi, M.**, et al. (2021), Time Evolution of Storms Producing Terrestrial Gamma-Ray Flashes Using ERA5 Reanalysis Data, GPS, Lightning and Geostationary Satellite Observations, *Remote Sens.*, doi.org/10.3390/rs13040784

42. Tavani, M.,... **Marisaldi, M.**, et al., An X-ray burst from a magnetar enlightening the mechanism of fast radio bursts (2021), *Nature Astronomy*, doi.org/10.1038/s41550-020-01276-x

43. A. Tiberia, F. Porcú, **M. Marisaldi**, et al. (2021), GPM-DPR observations on TGFs producing storms, *J. Geophys. Res.: Atmos.*, doi.org/10.1029/2020JD033647

44. P. Kochkin, **N. Østgaard**, H. J. Christian,, J. E. Grove, M. Quick, S. Al-Nussirat, E. Wulf, **S. Yang** , **G. Genov, K. Ullaland, M. Marisaldi, N. Lehtinen, A. Mezentsev, D. Sarria** (2021), A rapid Gamma-Ray Glow flux reduction observed from 20 km altitude, *J. Geophys. Res.: Atmos.*, doi.org/10.1029/2020JD033467

45. D. Sarria , N. Østgaard, P. Kochkin, N. Lehtinen, A. Mezentsev, M. Marisaldi, A. Lindanger, C. Maiorana, B. Carlson,..., **K. Ullaland, S. Yang, G. Genov**, **B. Qureshi,** et al. (2021), Constraining spectral models of a terrestrial gamma-ray flash from a terrestrial electron beam observation by the Atmosphere-Space Interactions Monitor, *Geophys. Res. Lett.*, doi.org/10.1029/2021GL093152

46. Li, A. Luque, F. J. Gordillo-Vazquez, F. Liu, G. Lu, T. Neubert, O. Chanrion, B. Zhu, **N. Østgaard**, V. Reglero (2021), Blue Flashes as Counterparts to Narrow Bipolar Events: the Optical Signal of Shallow In-Cloud Discharges, *J. Geophys. Res.: Atmos.*, doi.org/10.1029/2021JD035013

47. C. Maiorana, **M. Marisaldi**, M. Füllekrug, ..., **A. Mezentsev, C. A. Skeie**, M. Heumesser, O. Chanrion, **N. Østgaard**, T. Neubert, V. Reglero (2021), Observation of Terrestrial Gamma-ray Flashes at Mid Latitude, *J. Geophys. Res.: Atmos.*, doi.org/10.1029/2020JD034432

48. N. G. Lehtinen, Physics and mathematics of electric streamers (2021), Izv. VUZov (Radiofizika), 64(1):12–28, doi:10.52452/00213462_2021_64_01_12 (in Russian), Springer Link (English) doi: 10.1007/s11141-021-10108-5

49. **Lehtinen, N.G.** and Marskar, R. (2021), What Determines the Parameters of a Propagating Streamer: A Comparison of Outputs of the Streamer Parameter Model and of Hydrodynamic Simulations, *Atmosphere*, doi.org/10.3390/atmos12121664

50. S. Soler, F. J. Gordillo-Vazquez, F. J. Perez-Invernon, ..., **N. Østgaard** (2021) Global frequency and geographical distribution of nighttime streamer corona discharges (BLUEs) in thunderclouds, *Geophys. Res. Lett.*, doi.org/ 10.1029/2021GL094657

51. F. Liu , G. Lu, T. Neubert, J. Lei, O. Chanrion, **N. Østgaard**, et al. (2021) Optical emissions associated with narrow bipolar events in radio signals from thunderstorm clouds penetrating into the stratosphere, *Nature Communication*, doi.org/10.1038/s41467-021-26914-4

52. **A. Lindanger, M. Marisaldi, D. Sarria, N. Østgaard, N. Lehtinen, C. A. Skeie, A. Mezentsev,** P. Kochkin, **K. Ullaland, S. Yang, G. Genov, B. E. Carlson**, et al. (2021), Spectral Analysis of Individual Terrestrial Gamma-ray Flashes Detected by ASIM, *J. Geophys. Res.*, doi.org/10.1029/2021JD035347

53. J. A. Lopez, J. Montanya, O. van der Velde, ..., **N. Østgaard** and V. Reglero (2021) Initiation of lightning flashes simultaneously observed from space and the ground: Narrow bipolar events, *Atmospheric Res.*, doi.org/10.1016/j.atmosres.2021.105981

54. A. J. Castro-Tirado, **N. Østgaard**, E. Gogus, C. Sanchez-Gil, ..., **A. Mezentsev**, M. Gabler, **M. Marisaldi**, T. Neubert, C. Budtz-Jørgensen, **A. Lindanger, D. Sarria**, ..., **G. Genov**, ..., **K. Ullaland, S. Yang** (2021) Very-high-frequency oscillations in the main peak of a magnetar giant flare, *Nature*, doi.org/10.1038/s41586-021-04101-1

55. M. Heumesser, O. Chanrion, T. Neubert, H. J. Christian, ..., **N. Østgaard**, et al. (2021), Spectral Observations of Optical Emissions Associated With Terrestrial Gamma-Ray Flashes, *Geophys. Res. Ltr.,* doi.org/10.1029/2020GL090700

56. **Partamies, N.**, **Tesema, F.**, **Bland, E.**, Heino, E., **Nesse Tyssøy, H.**, Kallelid, E. (2021), Electron precipitation characteristics during isolated, compound, and multi-night substorm events, Ann. Geophys., doi.org/10.5194/angeo-39-69-2021

57. **Bland, E., Tesema, F., and Partamies, N.** (2021), D-region impact area of energetic electron precipitation during pulsating aurora, *Ann. Geophys.,* doi.org/10.5194/angeo-39-135-2021

58. J. Zhang, ... **P.J. Espy, R.E. Hibbins** (2021), Climatological westward-propagating semidiurnal tides and their composite response to sudden stratospheric warmings in SuperDARN and SD-WACCM-X, *J. Geophys. Res.: Atmos.*,126, doi.org/10.1029/2020JD032895

59. G. Liu, R.S. Lieberman, V.L. Harvey, ..., **R.E. Hibbins, P.J. Espy,** D. Janches (2021), Tidal variations in the mesosphere and lower thermosphere before, during, and after the 2009 sudden stratospheric warming, *J. Geophys. Res.: Space. Phys.*, 126, doi.org/10.1029/2020JA028827

60. **V. Maliniemi, H. N. Tyssøy, C. Smith-Johnsen**, P. Arsenovic, and D. R. Marsh (2021), Effects of enhanced downwelling of NOx on Antarctic upper-stratospheric ozone in the 21st century, *Atmos. Chem. Phys.*, doi.org/10.5194/acp-21-11041-2021

61. **Bender, S., Espy, P. J.**, and Paxton, L. J.(2021), Validation of SSUSI derived ionization rates and electron densities, *Ann. Geophys.*, doi.org/10.5194/angeo-2021-15

62. **Nesse Tyssøy, H. , N. Partamies, E. M. Babu, C. Smith-Johnsen and J. A. Salice** (2021), The predictive capabilities of the Auroral Electrojet index for Medium Energy Electron Precipitation, *Front. Astron. Space Sci.*, doi: 10.3389/fspas.2021.714146

63. **Nesse Tyssøy, H.**, M. Sinnhuber, T. Asikainen, **S. Bender**, ..., **C. Smith-Johnsen**, et al. (2021), HEPPA III intercomparison experiment on electron precipitation impacts, part I: Estimated ionization rates during a geomagnetic active period in April 2010, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2021JA029128

64. **Bender, S., Espy, P. J.,** and Paxton, L. J. (2021), Validation of SSUSI-derived auroral electron densities: comparisons to EISCAT data, *Ann. Geophys.*, doi: 10.5194/angeo-39-899-2021

65. P.T. Verronen, A. Kero, **N. Partamies**, M.E., Szeląg, S.-I. Oyama, Y. Miyoshi, and E. Turunen (2021), Simulated seasonal impact on middle atmospheric ozone from high-energy electron precipitation related to pulsating aurorae, *Ann. Geophys.*, doi: 10.5194/angeo-39-883-2021

66. F. Enengl, **N. Partamies**, N. Ivchenko, and L. Baddeley (2021), On the relationship of energetic particle precipitation and mesopause temperature, *Ann. Geophys.*, doi: 10.5194/angeo-39-795-2021

67. G. Stober, A. Kozlovsky, A. Liu, Z. Qiao, M. Tsutsumi, ..., **P.J. Espy, R.E. Hibbins**, N.J. Mitchell (2021), Atmospheric tomography using the Nordic Meteor Radar Cluster and Chilean Observation Network De Meteor Radars: network details and 3DVAR retrieval, *Atmos. Meas. Tech.*, doi.org/10.5194/amt-14-6509-2021

68. Sinnhuber, M., **Nesse Tyssøy, H.,** Asikainen, **T., Bender**, S., Funke, B., Hendrickx, K., et al. (2021), Heppa III intercomparison experiment on electron precipitation impacts: 2. Model-measurement intercomparison of nitric oxide (NO) during a geomagnetic storm in April 2010, *J. Geophys. Res.: Space Phys.*, doi.org./10.1029/2021JA029128

69. V. A. Andreeva, S. V. Apatenkov, E. I. Gordeev, **N. Partamies**, K. Kauristie, (2021), Omega Band Magnetospheric Source Location: A Statistical Model-Based Study, *J. Geophys. Res.: Space Phys.*, doi.org/10.1029/2020JA028997

70. D.K. Whiter, H. Sundberg, B.S. Lanchester, J. Dreyer, **N. Partamies**, et al. (2021), Fine-scale dynamics of fragmented aurora-like emissions, *Ann. Geo.*, doi.org/10.5194/angeo-39-975-2021