annual report 2019

BIRKELAND CENTRE
FOR SPACE SCIENCE

CONTENTS

Cover image: Illustration based on animation video "Introduction to asymmetric geospace" (see Figure 1 on page 5).

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." As of the end of 2019, 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.

FROM THE CENTRE LEADER

This annual report covers the year 2019.

SCIENCE & RECOGNITION

2019 has been yet another very good year for the Centre. It started with a big splash on the 24th of January with the American Geophysical Union (AGU) press release of *Ohma et al.* (2018), a BCSS-led study about how asymmetric aurora are produced, and both how and why the symmetry is restored. This press release was picked up by about 120 media outlets all over the world, including *Science* and the *New York Times*.

The year ended with another AGU press release during the AGU Fall Meeting that highlighted three papers on first results from Atmosphere-Space Interactions Monitor (ASIM); one in *Science (Neubert, Østgaard et al., 2019, online)* and two in *Journ. of Geophysical Research (JGR): Sarria et al. (2019)* and *Østgaard et al. (2019)*.

Almost exactly 10 years after we landed UiB-led aurora research on the front cover of *Nature*, we landed BCSS-led research on the front cover of the 10 Jan 2020 issue of *Science*, with an illustration of coincident observations of a Terrestrial Gamma-ray flash and an Elve produced by the same lightning stroke, as reported by *Neubert, Østgaard, et al. (2019, online)*.

Results from ASIM are widely viewed as a "game changer" in lightning research communities, and have received plenty of attention in media outlets all over the world.

As of the end of 2019 BCSS has published 294 papers (47 in 2019), that have been cited more than 2700 times. The seven-year-old centre now has an H-index of 22. In 2019 BCSS gave more than 100 presentations at international meetings, of which 22 were invited.

NEW PROJECTS

One European Space Agency (ESA) project based on ESA's Swarm satellites started in 2019 and is led by Spencer Mark Hatch. Noora Partamies at UNIS started the project "Which types of particle precipitation matter in the middle atmosphere?" funded by the Research Council of Norway (RCN).

In December 2019, we received news that 3 BCSS researchers—Karl Magnus Laundal, Hilde Nesse Tyssøy, and Ville Maliniemi—won substantial RCN funding for multi-year projects. We also received very welcome news that Karl Magnus Laundal had won the Trond Mohn Foundation (TMS) Starting Grant.

For both Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) and ASIM, we have negotiated extended funding from the ESA PRODEX program that will secure both projects for the coming years.

AWARDS

In February 2019 the leader of the BCSS "Particle Precipitation" group, Hilde Nesse Tyssøy, won a Young Centre for Advanced Study (CAS) Fellowship.

INSTRUMENTS

ASIM has been working perfectly since launch in April 2018. ASIM is continuously providing unprecedented measurements of terrestrial gamma-ray flashes (TGFs), lightning and transient luminous events (TLEs). In March 2019, a software upgrade that brings the relative time resolution between the instruments on board down to +/- 5 microseconds was successfully implemented.

On March 5, 2019 the SMILE spacecraft, a joint effort between the European Space Agency (ESA) and the Chinese Academy of Sciences (CAS), was officially adopted as an ESA mission. During fall 2019, SMILE's SXI instrument, in whose production BCSS is involved, passed a big milestone: the Preliminary Design Review.

DEEP was one of the instruments on the ICI-5 rocket (PI: Jøran Moen, UiO) that was launched from Ny-Ålesund in November 2019 and the first data from DEEP were transmitted to ground successfully.

In October 2019, a new aircraft campaign to be flown over thunderstorms, "Airborne Lightning Observatory for FEGS and TGFs"

(ALOFT) was initiated. The first flight is planned for spring/summer 2021, and will include cutting-edge BCSS instrumentation.

LEADERSHIP

In August 2019, Assoc. Prof. Martino Marisaldi convened the first meeting of the International Space Science Institute (ISSI) team that he leads. The topic of the meeting was "Understanding the Properties of the Terrestrial Gamma-ray Flash population." This team brings together twelve of the leading TGF scientists in the world.

BCSS leader Nikolai Østgaard serves as national representative in the steering committee of SCOSTEP and ISWI.

As usual, BCSS members organized scientific sessions at both EGU and AGU, and participated in EGU's Solar-Terrestrial Early Career Scientists team.

ORGANIZATION

BCSS is now comprised of three research groups after the Theory and Modeling group was established as an independent group at the Department of Physics and Technology beginning in September 1, 2019.

EDUCATION AND OUTREACH

Last year, two PhD students (Christoph Franzen and Anders Ohma) and six master's students received their degrees.

The BCSS Research School started in 2019. We organized two one-week long intensive schools: "Solar Impact on the Winter Polar Atmosphere – from space to surface" and "Atmospheric Electricity and Hard Radiation from Thunderclouds". In these two courses, we had, respectively, 17 and 32 participants (comprised of master's students and early career scientists) from 22 institutions in 14 countries.

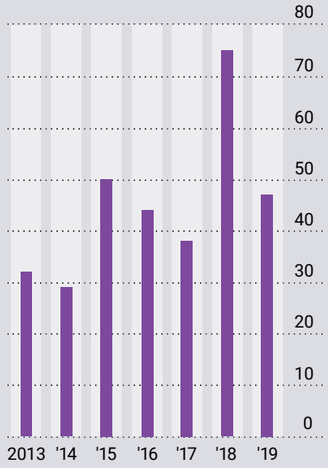
In a collaborative effort to unite science and art, the Bergen Philhamonic Orchestra and the University of Bergen organized the "Next Step" concert series in Grieghallen. BCSS participated in the first concert, called "Space," of that series. Arve Aksnes from our Education and Public Outreach (EPO) group and Susanne Flø Spinnanger (PhD student) gave an excellent introduction, while astronaut Luca Parmitano greeted the audience on video from the International Space Station. The concert was a big success.

I want to take this opportunity to thank all the members of BCSS for making 2019 yet another productive and successful year.

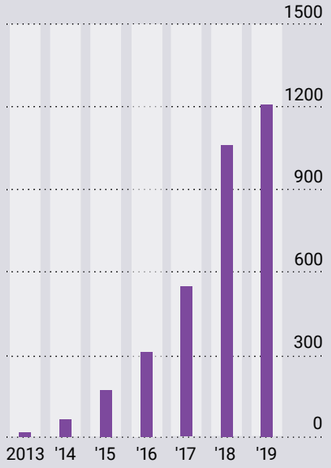
Nikolai Østgaard,
Leader of BCSS

Dissemination data

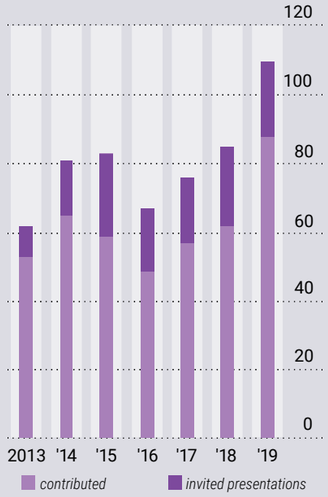
PUBLICATIONS



CITATIONS



PRESENTATIONS



SCIENCE COVER

Illustration: BCSS / Mount Visual / Daniel Schmelling

January 10, 2020 *Science* cover featuring ASIM results

FIRST ISSI TEAM MEETING

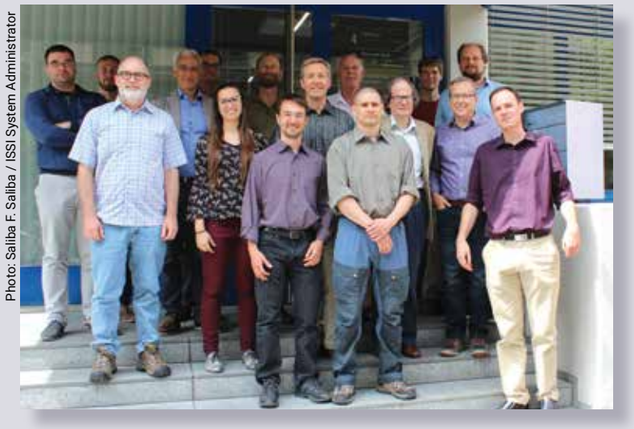


Photo: Saliba F. Saliba / ISSI System Administrator

Bern, August 2019. BCSS members first row: Carolina Maiorana (2nd from left), followed by Martino Marisaldi and Andrey Mezentsev

YOUNG CAS AWARD

Photo: Camilla K. Elmar / CAS

Hilde N. Tyssøy (right), BCSS group leader, winner – Young CAS Award

TROND MOHN FOUNDATION STARTING GRANT

Taken from video, UiB

Karl M. Laundal, BCSS group leader, winner – Trond Mohn Foundation Starting Grant

KAVLI PRIZE / ASTRO EXHIBIT

Photo: Thor Brødreskift, UiB

Passion for Science astrophysics exhibit at UiB Museum

KAVLI PRIZE / ASTROPHYSICS SYMPOSIUM

Speakers at the astrophysics symposium–*Inspired by Space*– organized by BCSS during the Kavli Prize event:

Right: 2018 Kali Prize laureate, Dr. Ewine van Dishoeck.
Far right: 2012 Kavli Prize laureate, Dr. Jane Luu

Photo: Peter Badge/Typos1 ;Photo: Knut Falch

Photo: NASA Photo: IAASARS

Far left: Dr. Holly Gilbert, NASA
Left: Dr. Olga Malandraki, Inst. for Asronomy, Astrophysics, Space Applications & Remote Sensing, Athens (IAASARS)

02 Dynamics of the asymmetric geospace

Karl M. Laundal UiB
Team Leader, Researcher

Kjellmar Oksavik, UiB
Co-Leader, Professor

Dag Lorentzen, UNIS
Professor

Nikolai Østgaard, UiB
Professor

Jesper Gjerloev, UiB
Professor II

Lisa Baddeley, UNIS
Assoc. Professor

Finn Søraas, UiB
Prof. Emeritus

Stein Haaland, UiB
Researcher

Lindis Bjoland, UNIS
Postdoc

Spencer Hatch, UiB
Postdoc

Jone Reistad, UiB
Postdoc

Nina Kristine Eriksen, UNIS
Phd Candidate

Katie Herlingshaw, UNIS
PhD Candidate

Anders Ohma, UiB
PhD Candidate

One of the main questions that has emerged from the work of the DAG group in the past years concerns the role of lobe reconnection in controlling interhemispheric asymmetries. Lobe reconnection is the merging of magnetic field lines of the solar wind with terrestrial magnetic field lines that are connected to only one hemisphere. Magnetic field lines which connect to only one hemisphere are called "open", and they form two enormous regions in the magnetosphere called "lobes". Lobe reconnection is known to produce sunward plasma convection in the ionosphere, typically poleward of the auroral oval. In a paper from *2018, Østgaard et al.* reported observations of an auroral spot which is seen only in the summer hemisphere, and speculate that lobe reconnection is the underlying mechanism. They suggested that lobe reconnection is much stronger in summer than in winter, when lobe magnetic field lines are tilted towards the Sun.

To test this hypothesis, *Reistad et al. (2019)* used radar measurements of ionospheric plasma convection *(Figure 1)*. The plasma in the polar ionosphere moves in response to a number of processes in the outer magnetosphere, such as dayside reconnection, tail reconnection, and lobe reconnection. Untangling the different effects is a big challenge since they are often present simultaneously. Reistad et al. presented a solution to this problem, based on a technique that has previously been used primarily for magnetic field disturbances and electric currents. They showed that this technique can be used to separate and quantify the contributions from different magnetospheric source regions to the overall ionospheric convection pattern.

In a companion paper, *Reistad et al. (2019)* used this technique to investigate how the lobe reconnection rate changes with dipole tilt angle. This study confirmed the idea that lobe reconnection is stronger in summer than in winter. Furthermore, they established that the lobe reconnection rate has a linear dependence on the tilt angle of the Earth's magnetic dipole. Their result implies that during solstices, the convection patterns are very different in the two hemispheres when the interplanetary magnetic field is northward. It seems likely that lobe reconnection is important also when the interplanetary magnetic field is not strictly northward, and that the tilt angle dependence is similar. DAG group members continue to study this important topic.

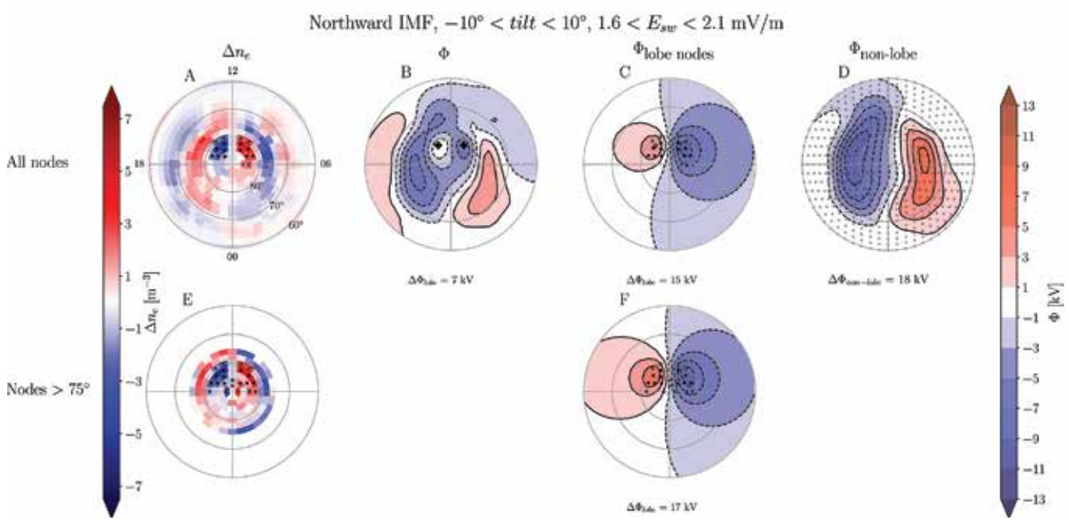


Figure 1: Illustration of the technique developed by *Reistad et al. (2019)*, which allows for segmentation of ionospheric convection patterns in terms of source region. The columns show, from left to right: Electric charge density consistent with the convection electric field, electric potential, electric potential associated with charges in the polar cap, and electric potential associated with charges equatorward of the polar cap.

Dynamics of the asymmetric geospace

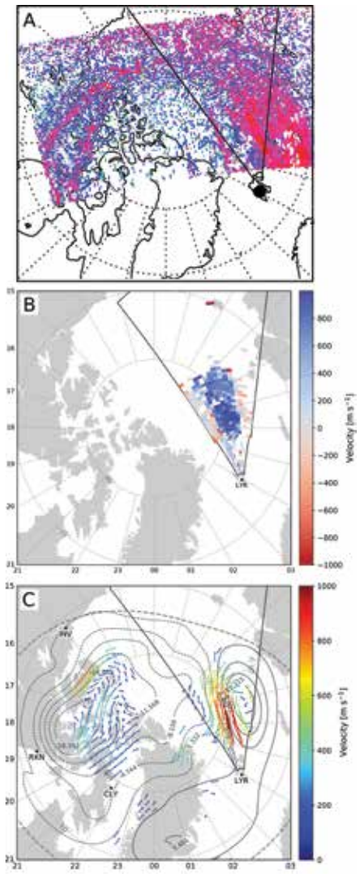


Figure 2: Observations of a polar cap flow channel. A) UV emissions observed with the SSUSI instrument on DMSP17, B) Line-of-sight velocities from the Longyearbyen SuperDARN radar, and C) Estimated convection pattern using the full network of SuperDARN radars.

Another recent finding from the DAG group, which in 2019 received global media coverage, was reported by *Ohma et al. (2018*): By comparing simultaneous auroral forms in the two hemispheres over periods of minutes to hours following the onset of substorms, they concluded that interhemispheric asymmetries in magnetic field line footpoints are reduced when tail reconnection is strong. They hypothesized that reconnection changes the pressure balance in the magnetotail so that the inward flow of lobe magnetic field lines become more symmetric. This hypothesis was tested in a follow-up study *(Ohma et al., 2019)* that was based on direct observations of lobe convection. Using the entire Cluster Electron Drift Instrument dataset, they showed that substorm activity is associated with a stronger but more symmetric flow in the lobes.

A fourth study from the DAG group, also about polar cap and lobe convection, was published by *Herlingshaw et al. (2019)*. They used the Longyearbyen SuperDARN radar to identify flow channels in the polar cap *(Figure 2)*. Flow channels are narrow regions of enhanced convection. Even though they are very narrow, they carry a significant fraction of the total transport of plasma and magnetic flux from the dayside to the nightside. Herlingshaw et al. pioneered a new method to detect polar cap flow channels in radar data, resulting in > 500 events during one year of observations. Their spatial structure and frequent occurrence open new questions about how plasma is transported over the polar cap and how this convection maps to its magnetospheric counterpart, in the lobes.

2019 was an active and successful year for securing additional funding. Karl Laundal won the Trond Mohn Foundation Starting Grant, which will allow him to form a group of researchers to study the processes behind the large variations in geospace geometry that have been unraveled in the last years. He also won a researcher project proposal with the space science program in the Research Council of Norway. Both projects will last for about 4 years.

The group has also been active in other projects. Spencer Hatch leads a European Space Agency (ESA)-funded project to investigate how Swarm can be used to increase our understanding of ionospheric outflow. This project, which will last for about one year, had its kickoff meeting in May 2019. In addition, a web visualization was produced and published in early 2019 for the Average Magnetic field and Polar current System (AMPS) model, an official data product of the ESA Swarm mission. This visualization, which allows the user to plot polar electric currents and magnetic field disturbances, can be found at birkeland.uib.no/data/amps.

03 Particle precipitation

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Team Leader, Researcher

Patrick Espy, NTNU
Co-Leader, Professor

Robert Hibbins, NTNU
Professor

Noora Partamies, UNIS
Assoc. Professor

Johan Stadsnes, UiB
Prof. Emeritus

Yvan Orsolini, NILU
Researcher

Christine Smith-Johnsen, UiB
Researcher

Stefan Bender, NTNU
Postdoc

Emma Bland, UNIS
Postdoc

Ville Maliniemi, UiB
Postdoc

Eldho Midhun Babu, UiB
PhD Candidate

Wim van Caspel, NTNU
PhD Candidate

Christoph Franzen, NTNU
PhD Candidate

Fasil Tesema Kebede, UNIS
PhD Candidate

Particle precipitation

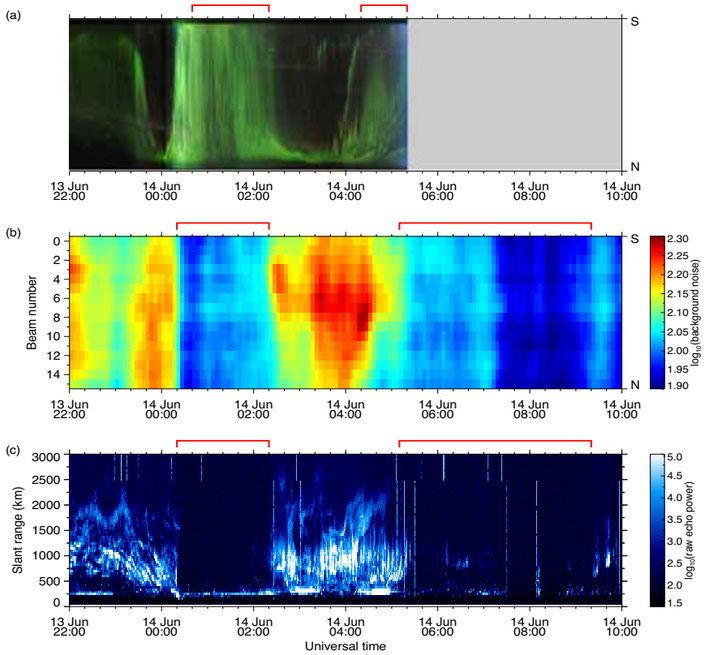

Figure 3: Energetic electron precipitation during pulsating aurora events can be detected using SuperDARN HF radars. Panel (a) shows two pulsating aurora events observed using the all-sky camera at Syowa Station, Antarctica (red brackets). This optical signature is accompanied by a sudden reduction in the HF radio noise and echo power parameters measured by the Syowa East SuperDARN radar (panels b and c). The radar data indicate that the HF radio absorption associated with the second pulsating aurora event continued for 4 hours after the camera stopped imaging due to daylight.

Energetic electrons and protons, from both the solar wind and the Earth's magnetosphere, can deposit their energy into our atmosphere via collision with neutral gases in our atmosphere. The depth to which they penetrate the atmosphere depends on their initial energy. The collisions initiate a number of chemical reactions that lead to the production of odd nitrogen (N, NO, NO_2) and odd hydrogen (H, OH, HO_2) species, which in turn can reduce the ozone concentration. As an effective absorber and emitter, ozone is critically important in the energy budget of the mesosphere and stratosphere. Hence changing the concentration of ozone at these altitudes can impact temperature and winds linking to our weather system. To unravel the impact of Energetic Particle Precipitation (EPP) on the atmospheric system we need to understand both the nature of EPP and the atmospheric dynamics. The EPP group brings together space and atmospheric scientists with the expertise necessary to unravel the complex relationship between EPP and its atmospheric effects. The EPP group accomplishes this via observations and models.

The growing evidence of how EPP could affect the polar winter regional temperature and pressure at sea level (e.g. *Maliniemi et al., 2019; Salminen et al., 2019*) has led to the recommendation to include solar-driven particle forcing as part of the Coupled Model Intercomparison Project 6 (CMIP6). The CMIP model runs have regularly been assessed as part of the IPCC Climate Assessments Reports. EEP at energies >30 keV is parameterized by the geomagnetic Ap index based on 0° MEPED detector measurements on the NOAA/POES satellites. As the 0° detector is only seeing a small fraction of the bounce loss cone, it provides an estimate of the flux level lower bound. *Nesse Tyssøy et al. (2019)* compared the modelled electron fluxes with estimates of the loss cone fluxes using both the 0° and 90° detectors in combination with calculated electron pitch angle distributions. They showed that the Ap-based model falls short with respect to the flux level and variability associated with strong geomagnetic storms (Ap > 40) as well as the duration of corotating interaction region storms.

Geomagnetic index proxies fall particularly short in parametrizing pulsating aurora *(Partamies et al., 2019)*. This study suggests that the part of the energy deposition not captured by magnetic indices is the subset of events with decreasing patch sizes. This can provide an important auroral indicator for EEP events, which are not captured by basic proxies but may stil have a significant impact on the mesospheric chemistry.

In a proof-of-concept paper, *Bland et al. (2019)* demonstrated that the SuperDARN radars can be used to detect high frequency radio wave attenuation in the Dregion ionosphere during EEP events, such as pulsating auroras *(Figure 3)*. The results show that high frequency attenuation that commences during periods of optical pulsating aurora typically continues for 2–4 hours after the camera stops imaging at dawn. Based on 555 events detected in 2011, the EEP occurrence rates are highest in the early morning sector and lowest in the afternoon. The results suggest that the SuperDARN radars will be useful for giving a global view of EEP occurrence rates.

Hibbins et al., (2019) demonstrated that SuperDARN radars can also be used to observe tidal variability in the Mesosphere Lower Thermosphere (MLT) region. Development of an algorithm for extracting global-scale waves resulted in a long term climatology of the semidiurnal tide's migrating wavenumber 2 and non-migrating wave number 1 and 3 components. Some of these components propagate into the ionosphere, creating longitudinal structuring and variability. Examining the behavior of the individual components enables quantification of the contribution of MLT tides to ionospheric variability. During Sudden Stratospheric Warming (SSW) events, some of these propagating tidal components enhance and will carry the SSW signature into the ionosphere. *Hibbins et al. (2019)* shows, for the first time, both the observed climatology of the tidal components as well as which tidal components strengthen during SSW events *(Figure 4)*. Due to the innovation of these tidal measurements and the resulting advancement in efforts to examine the effects on ionospheric variability and atmospheric coupling processes, this paper was selected as a JGR editor's highlight.

Zawedde et al. (2019) examined the impact of EPP on mesospheric ozone. We know that the EPP increases the production of HO_x species in the mesosphere, which catalytically destroy ozone in sunlight. Hence, the EPP-HO_x impact on the tertiary ozone maximum depends on a complex interplay between the geographic-oriented ozone distribution, the geomagnetic-oriented auroral zone, producing short-lived HO_x species, together with a destruction process which depends on the solar zenith angle. The results, although limited by the satellite's viewing conditions, imply that the importance of EEP on the ozone mixing ratio is strongly influenced by the background atmosphere, both in terms of chemistry and dynamics.

In contrast to short-lived HO_x, long-lived EPP produced NO impacts ozone deep into the stratosphere. *Bender et al. (2019)* provides an empirical model for EPP-produced NO. The model, based on SCHIMACHY instrument data from ENVISAT, represents a first step towards incorporating the effects of chemical production by EPP into climate models to examine their role.

Modelling the effects of EEP on NO is also one of the key aspects in the SOLARIS-HEPPA working group led by Miriam Sinnhuber and Hilde Nesse Tyssøy, where Stefan Bender and Christine Smith-Johnsen participate. Hilde Nesse Tyssøy is a Young Centre for Advanced Study (CAS) fellow leading a working group which aims to "Unravel the drivers of energetic electron precipitation" supported by the Center for Advanced Study. It includes Fasil Tesema, Eldho Midhun Babu, Christine Smith-Johnsen and Noora Partamies from the BCSS. In addition, several members of the EPP group are part of ISSI-team initiatives, and the UNIS node continues to be an active part of the science collaboration Chemical Aeronomy in the Mesosphere and Ozone in the Stratosphere (CHAMOS).

During 2019, our group published 11 papers. We gave more than 20 presentations at international conferences, three of which were invited talks. Christoph Franzen successfully defended his thesis: "Aeronomy of Hydroxyl Airglow Variability by Means of High-Resolution Telescope Observations and Gravity Wave Simulations." We organized the BCSS research school course: "Solar impact on the winter polar atmosphere- from space to surface." Patrick Espy organized a session at the 2019 Asia Oceania Geosciences Society 16th annual meeting (AS-13) and Hilde Nesse Tyssøy was a co-convener for a session at the 2019 Joint IAPSO-IAMAS-IAGA Assembly. As a Fulbright fellow, Hilde Nesse Tyssøy, visited Dr. Dan Marsh and Prof. Robert Marshall at the National Center for Atmospheric Research and University of Colorado. Wim van Caspel received a stipend to work at NASA Goddard with Ruth Liebermann to acquire and enhance a first-principles-tidal model. Hilde Nesse Tyssøy and Ville Maliniemi were awarded external funding from the Research Council of Norway (RCN) Space Physics and Climate calls.

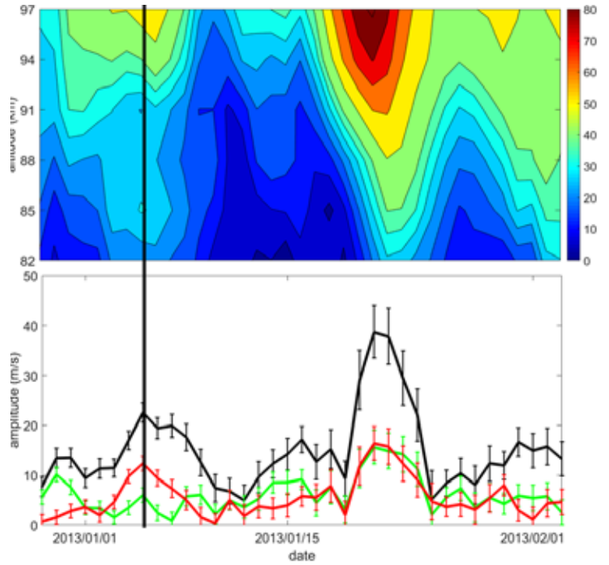

Figure 4: *(Top panel)* Four-day running mean amplitude of the 12-hr variability in the meridional wind observed with the SKiYMET meteor radar at Trondheim, Norway (63°N) between 82 and 97 km altitude. *(Bottom panel)* The three components of the semidiurnal tide resolved from the longitudinal chain of SuperDARN radars (green = SW1; black = SW2; red = SW3). Data span the 2013 sudden stratospheric warming over a 5-week interval starting 1 week before the onset date of 5 January 2013 which is indicated by a vertical black line.

04 Hard radiation from thunderstorms

Nikolai Østgaard, UiB
Team Leader, Professor

Martino Marisaldi, UiB
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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Kjetil Albrechtsen, UiB
PhD Candidate

Anders Lindanger, UiB
PhD Candidate

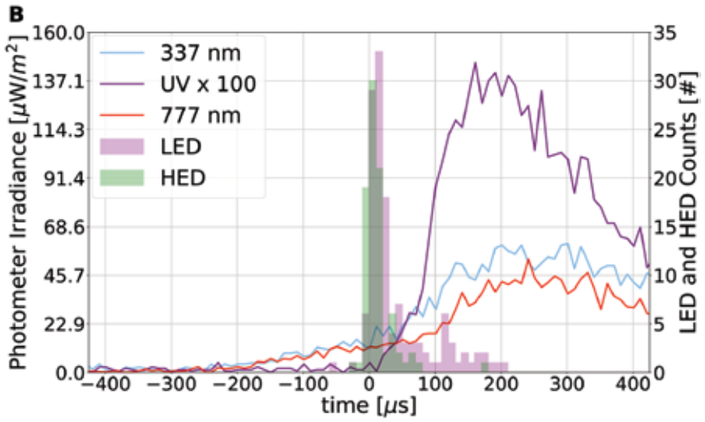
Carolina Maiorana, UiB
PhD Candidate

Chris Alexander Skeie, UiB
PhD Candidate

It has been known for 20 years that thunderclouds are the most energetic natural particle accelerators on Earth, capable of accelerating electrons up to relativistic speed and of producing photons of energies up to several tens of mega-electronvolt, more than ten times the maximum photon energy that is associated with natural radioactivity. In addition to electrons and photons, positrons and neutrons are also observed in association with thunderstorms. All this energetic radiation is emitted at very different timescales, from sub-millisecond Terrestrial Gamma-ray Flashes (TGFs) to minute-long Gamma-ray Glows. The emerging research field, aptly named "high-energy atmospheric physics," is dedicated to the understanding of this variety of energetic phenomena and its impact on the surrounding environment and is the core focus of BCSS Group "Hard Radiation from Thunderstorms."

2019 has been a golden year in terms of the science return from the Atmosphere-Space Interactions Monitor (ASIM) mission installed onboard the International Space Station and in nominal operation since June 2018. Three papers were published in December and presented in a press release of the American Geophysical Union (AGU) during the annual AGU Fall meeting in San Francisco, USA. In the first paper, *Neubert et al.*, which was published in the prestigious journal *Science*, we report ASIM observation of a bright ultraviolet transient emission simultaneous with a TGF *(Figure 5)*. This is interpreted as an Elve, a class of Transient Luminous Events (TLE), triggered at the ionosphere by the electromagnetic pulse. This pulse is produced by a strong current pulse simultaneous with the TGF and possibly associated with the TGF production itself. Given the different production mechanisms and source regions (below cloud tops for TGFs, high in the mesosphere and up to the ionosphere for TLEs) it has been thought for more than a decade that TGFs and TLEs were unrelated phenomena. These observations show for the first time that TGFs and a special class of TLEs can indeed be related, as they were both powered by the same lightning stroke.

Figure 5: From *Neubert, Østgaard et al., Science, 2019 (online)*, showing the TGF measured in both the low and high energy detector (LED and HED), as well as the three optical channels. The blue (337 nm) and red (777 nm) show a weak signature of a leader development starting at -200 microsecond. The TGF is produced at the same time as the UV signal brightens up. The UV is the signature of an Elve.



The second ASIM paper, *Østgaard et al.*, shows the main science achievements of the ASIM mission during the first ten months of operation, with special focus on the timing sequence relating the lightning leader progression, TGF production, and optical emission *(Figure 6)*. They demonstrate, with unprecedented statistical evidence, that the TGF is either simultaneous or precedes by a few hundred microseconds the main optical pulse associated with lightning discharge. These two papers demonstrate the key asset of the ASIM mission: the unprecedented capability of performing simultaneous observations in hard X- and gamma rays as well as optical bands with high temporal resolution. The third ASIM paper, *Sarria et al.*, reports the first Terrestrial Electron Beam (TEB) observed by ASIM. TEBs are bursts of energetic electrons produced by TGF scattering in the upper atmospheric layers and traveling along the geomagnetic field lines. TEBs are more difficult to observe than TGFs (about one TEB out of 100 TGFs) because the electrons are confined in a narrow spatial region with a radius of a few tens of kilometers.

In addition to ASIM results, we also want to highlight two additional papers published in 2019.

Østgaard et al. reports the observation of a gamma-ray glow observed by a NASA aircraft flying at 20-km altitude over Colorado, in the frame of a dedicated flight campaign targeted at TGFs and glows in collaboration with the University of Alabama, Huntsville and other institutions in the USA. Gamma-ray glows are quasi-stationary emissions of gamma-rays active for several tens of seconds and extend over regions tens of

Hard radiation from thunderstorms

kilometers in size. Although less bright than TGFs, they likely deliver much more energy given their extension and duration. Relative to TGFs, gamma-ray glows have received much less attention. The observations reported in *Østgaard et al.* are the most complete up to now, including high- and low-frequency electric field measurements, showing that it is difficult to reconcile observations with modeling when the cloud charge structure inferred from the electric field measurements is taken into account.

Marisaldi et al. elaborates on the highest TGF photon energy detected by the AGILE satellite, solving an eight-year-long controversy on the high-energy spectral shape of TGFs. The paper shows that the observed counts of unexpectedly high energy are compatible with standard production models of TGFs, when the correct behavior of the instrument's electronics and data acquisition system are properly accounted for.

We also highlight two other successful initiatives coordinated by our group.

During May 20–24, the research school "Atmospheric Electricity and Hard Radiation from Thunderclouds" was held at the Dept. of Physics and Technology at the University of Bergen. The school was attended by 32 master's and PhD students from 22 institutions and 14 different countries, and included as teachers world experts such as Dr. Joseph Dwyer from the University of New Hampshire, USA, Dr. Vernon Cooray from the Uppsala University, Sweden, and Dr. Hamid Rassoul from the Florida Institute of Technology, plus members of our own group. This highly successful school contributed to the BCSS mission of "educating the next generation of space scientists."

An international team led by Martino Marisaldi was selected for funding and was established at the International Space Science Institute (ISSI), Bern, Switzerland. This team, whose goal is "Understanding the Properties of the Terrestrial Gamma-ray Flash Population," brings together twelve world-leading TGF scientists with the goal of harmonizing all currently available TGF observations in a single, comprehensive population study. In addition, the team will identify TGF science requirements not accessible by current or near future missions, as the basis for possible future mission proposals. The first meeting was held in Bern on August 12–16.

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 31 presentations, including two invited talks at the AGU fall meeting. ●

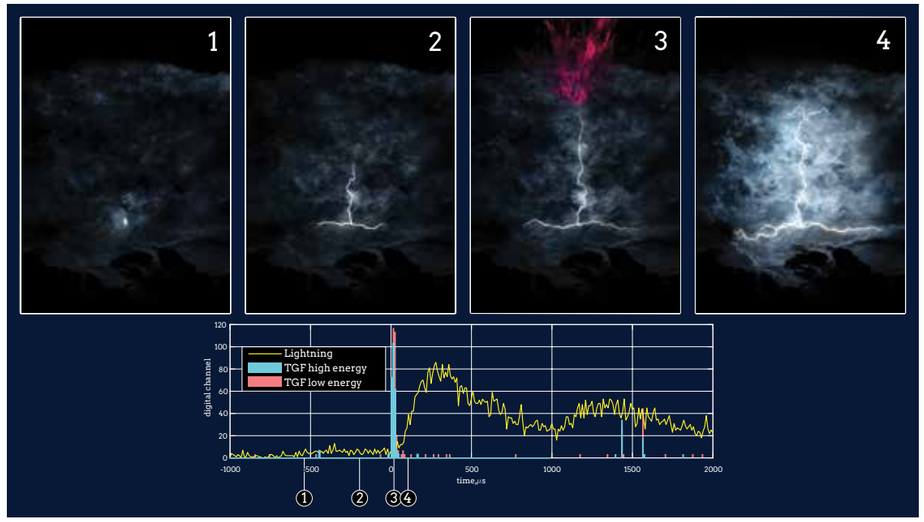


Figure 6: The sequence of terrestrial gamma-ray flash and optical lightning. 1) A leader is formed inside the cloud and is also seen as a weak increase in the optical signal (lower panel). 2) The leader propagates upward, and 3) a terrestrial gamma-ray flash is produced in the high electric field ahead of the extended leader, just before 4) a large current flows through the leader and produces a large optical pulse that lasts several milliseconds. This is the main discovery presented by *Østgaard et al. (2019).*

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

Torstein Frantzen, UiB
Chief Engineer

Jon-Thøger Hagen, UiB
Chief Engineer

Thomas Poulianitis, UiB
Chief Engineer

Bilal Hasan Qureshi, UiB
Chief Engineer

Space instrumentation

SMILE

Solar Wind Magnetosphere Ionosphere Link Explorer (SMILE) is a joint mission of the European Space Agency (ESA) and the Chinese Academy of Science (CAS) which was officially adopted as an ESA mission in the March 2019. Launch is scheduled for the end of 2023.

One of the instruments onboard 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. The SXI team completed its Preliminary Design Review towards the end of 2019, and preparations are now underway for the Critical Design Review.

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). BCSS has manufactured different prototypes of the RSM and RSE, which were tested in the spring of 2019. Following the initial testing, and due to updated mission requirements, a complete redesign of the RSM was started during summer 2019 *(Figure 9)*. Manufacturing of the piece parts for a second breadboard of the RSM is ongoing, and testing of this improved prototype is planned for April 2020.

Procurement of components for the Engineering Qualification Models (EQMs) of RSE and RSM, has been initiated. The EQMs will be built in the summer of 2020 and tested towards the end of the year. University of Leicester will in parallel build an RSM dummy to use for the structural and thermal verification at the instrument level.

In December 2019, the Norwegian Space Agency endorsed our planned activities for phase two (2020-2023) of the ESA PRODEX funding for the SMILE project. This activity covers qualification activities and the procurement of flight components for RSE and RSM. Work is currently ongoing with the ESA PRODEX office to update our PRODEX Experiment Arrangement contract accordingly. Our total involvement in SMILE will add up to around 29 MNOK, including in-kind assistance from UiB.

Photo: Helge Tore Markussen

Figure 7: The 12,1-meter-long ICI-5 sounding rocket was launched from SvalRak, the Andøya Space Center (ASC) launch site at Ny-Ålesund, Svalbard in November 2019. The first DEEP prototype was one of the onboard payloads.

Photo: Georgi Genov

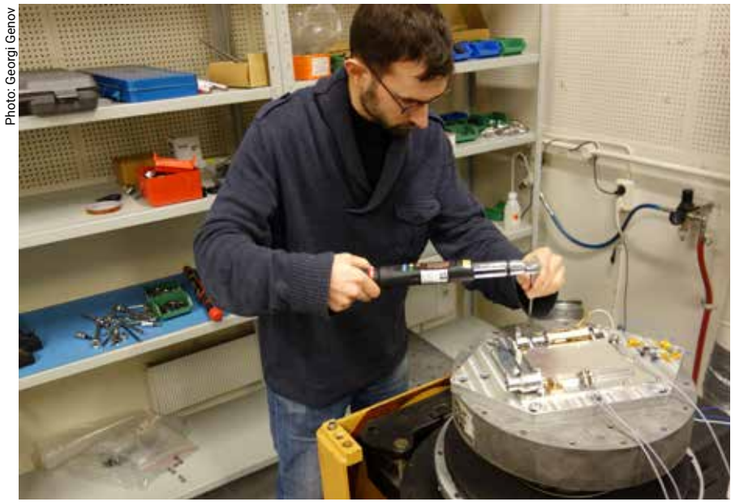
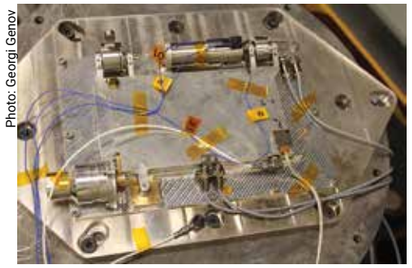


Figure 8: *Left:* Vibration testing of ASIM breadboard model of the Radiation Shutter Mechanism (RSM) at Prototech

Below: Close-up of breadboard model of the RSM

Photo: Georgi Genov



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 number of particles precipitating into the atmosphere. In particular, the electrons often have a strong anisotropic pitch angle distribution, and to measure this distribution is essential for determining the particle loss to the atmosphere. To solve this issue, our group has designed the Distribution of Energetic Electrons and Protons (DEEP) detector, which is composed of three electron- and three proton-pixelated detectors in separate housings, covering a field of view of 180°. This wide coverage makes it possible to determine the electron fluxes absorbed by the atmosphere, as well as the fluxes backscattered from the atmosphere.

In 2019, the DEEP prototype was finalized, and it was launched on ICI-5 *(Figure 7)*, one of 12 rockets that are part of the "Grand Challenge Initiative – Cusp" with Andøya Space Centre and University of Oslo as partners.

ASIM

Since Atmosphere-Space Interactions Monitor (ASIM) was launched to the International Space Station (ISS) on April 2, 2018, the instruments have been in good health and have provided unprecedented measurements of lightning, Terrestrial Gamma-ray Flashes (TGFs) and Transient Luminous Events (TLEs). The ASIM payload consists of the "Modular X- and Gamma-ray Sensor" (MXGS) to image and obtain spectral measurements of Terrestrial Gamma-ray Flashes (TGF). The two detector layers and read-out electronics were designed and built by the BCSS instrumentation group *(Figure 8)*. MXGS will detect TGFs in two energy bands, 50-400 keV and 300keV-30MeV. 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. During spring 2019, an upgrade of the on-board software was performed. The most important part of this upgrade increased the relative timing accuracy between MXGS and MMIA from ±80 µs to ±5 µs.

The first papers with ASIM results was published in December 2019 and are described in the "Hard radiation from thunderstorms" section of this report.

BCSS is supporting the ASIM Science Data Center (ADSC) with a dedicated programmer/ researcher funded through ESA- PRODEX program.

Figure 9: Participants at a SXI Consortium meeting, September 2019, at University of Vienna. The goal of the meeting was to define suitable solutions to close any open actions from the PDR.

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 already existing research infrastructure that the BCSS is granted access to. 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 2019.

KJELL HENRIKSEN OBSERVATORY

KHO has now operated successfully for 11 years and is the largest facility of its kind for optical instruments that study the aurora. During the auroral winter season from November to the end of February, 28 optical instruments operate 24 hours a day. The 17 non-optical instruments run year-round, 24 hours a day. Instrumentation from 24 different institutions representing14 nations are present at KHO.

The observatory serves as the main laboratory for hands-on training and teaching of students in the space physics group at UNIS. Six courses have used it as part of field work, producing a grand total of 75 ECTS. One PhD student has graduated in our group.

In 2019, KHO actively supported 4 rocket campaigns in connection with the Grand Challenge Initiative (GCI). For these campaigns, KHO instrumentation and personnel provided each Principal Investigator (PI) critical feedback for determining the optimal time for launching into study the "dayside cusp aurora" that was the common goal of each campaign.

The first rocket, CAPER-2 (Cusp Alfven and Plasma Electrodynamics Rocket-2), was launched from Andøya Space Centre (ASC) on 4 January 2019 by PI James LaBelle from Dartmouth College, USA *(Figure 10)*. The rocket was launched from Andøya at 09:27 UT with a flight time of 8 minutes and 49 seconds to apogee at 774 km altitude above Svalbard.

During the moon-down period from late November to mid-December, geomagnetic activity was still low, with Kp indices of less than 3. Under these conditions the geomagnetic cusp is located north of Svalbard, and out of range for any rocket launched from SvalRak in Ny-Ålesund. These were the conditions in the early morning on 26 November.

But after a 15 minutes negative excursion of the B_Z component of the Interplanetary Magnetic Field (IMF) measured by the NASA Advanced Composition Explorer (ACE) satellite, dayside aurora were expected to expand south with a lead time of about one hour. As predicted, an auroral arc appeared in the zenith of Ny-Ålesund and the second rocket, ICI-5 (Ionospheric Cusp Irregularities-5) was launched at 07:43 UT headed by GCI PI Jøran Moen from the University of Oslo. The launch decision was a successful quick draw based on multi-site ground-based data support from Ny-Ålesund, KHO and the EISCAT Svalbard radar *(Figure 11)*.

In early December, the last two NASA rockets of the season, CHI (Cusp Heating Investigation) and CREX-2 (Cusp Region Experiment-2), were ready to launch from SvalRak and ASC, respectively. PIs of the campaign were Mark Conde (CREX-2) from University of Alaska and Miguel Larsen (CHI) from Clemson University in USA. These two rockets released Barium, Strontium and Tri-methyl aluminum clouds that, when illuminated by the Sun, are excellent tracers for the motion of charge particles in the ionosphere and for high altitude ionospheric winds through neutral particles. The clouds were tracked by ground-based optics from both Ny-Ålesund and KHO. In addition, a NASA King Air aircraft was used to track the artificial clouds from a third observational point.

Both weather and low activity space conditions forced us to wait almost the entire multi-week launch window. The northward located cusp was out of reach for the nominal trajectory of the CREX-2 rocket. But not for CHI, and finally, under launch conditions similar to ICI-5, the CHI rocket was launched on 10 December 09:30 UT. The weather was clear in Ny-Ålesund. A thin layer of clouds moved in and out of the field of view at KHO, but we managed to track the releases as shown in Figure 12.

The Aurora Forecast 3D app is rated at 4.28 and has reached over 9147 active installs on Google Play for Android. On Apple iOS

Figure 10: CAPER-2 rocket heading towards Svalbard. Photo by Lufttransport pilot Eivind Trondsen.

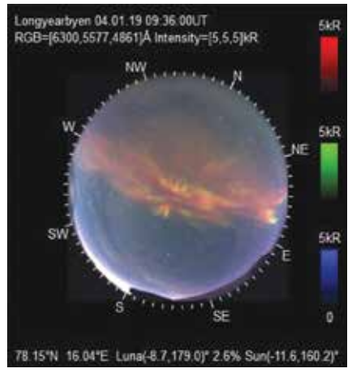


Figure 11: CAPER-2 target cusp aurora. Composite image by the NORUSCA II hyperspectral camera.

Ground-based instrumentation

phones, it is rated 4.4 with 958 active users. The Facebook page for KHO has 1475 followers.

NTNU GROUND-BASED INSTRUMENTS

NTNU's ground-based long-term monitoring program 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.

Data from NTNU's two local instruments have been used as a key component of two chapters (20 and 28) in the textbook, *Infrasound Monitoring: Challenges in Middle-atmosphere Dynamics and Societal Benefits* (A. Le Pichon , E. Blanc, and A. Hauchecorne (Eds.), 2nd Edition, Springer International, 2019). The chapters cover optical and radar techniques used to measure gravity wave activity in the middle atmosphere and the use of these instruments to produce calibrated standards against which model uncertainties can be assessed.

In June 2019, PhD student Christoph Franzen completed his PhD defense on "Aeronomy of Hydroxyl Airglow Variability by Means of High-Resolution Telescope Observations and Gravity Wave Simulations." This collaborative study program with the Nordic Optical Telescope focused on measuring small scale gravity wave activity in hydroxyl airglow data recorded by the ground-based astronomical telescope.

During 2019, Wim van Caspel, a new BCSS PhD student, started in the group. Wim will use NTNU's Skiymet meteor radar data in conjunction with the longitudinal chain of northern hemisphere SuperDARN radars to investigate tidal and planetary wave variability in the mid-latitude middle atmosphere.

Results from NTNU's instrumentation have been presented at international meetings run by the AGU, EGU, AOGS and JpGU during 2019 and have formed a core component of 3 master's theses 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. In 2019, this low-cost research infrastructure resulted in scientific publications on plasma irregularities associated with a reversed flow event in the cusp ionosphere, and a study on phase scintillation at the edge of polar ionospheric holes.

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. The combined use of ASIM and LINET data is included in a PhD project at BCSS, part of the SAINT project, that started in December 2017. SAINT is a Marie Curie network with 10 partners funding 15 PhD students in Europe.

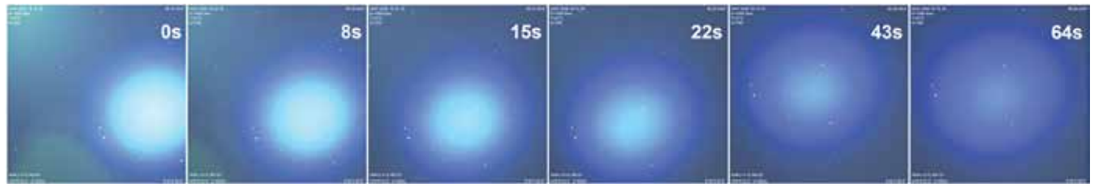


Figure 12: Snapshots from the BACC tracker camera at KHO of a Barium / Strontium cloud released from the CHI rocket launched from Ny-Ålesund 10 December 2019. Exposure time is 1 second. FOV is 8.2 degrees.

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

illustration: Mount Visual / Daniel Schmelling

Figure 13a: December 2019 web-based article in *Der Spiegel* on gamma ray flashes from thunderstorms
Figure 13b: January 2020 cover of *Science* magazine featuring ASIM instrument-derived research results

During 2019, BCSS researchers have contributed to 47 publications in scientific journals and more than 100 presentations (including 22 invited talks) at international conferences. The American Geophysical Union (AGU) also issued two press releases based on BCSS research, which led to BCSS being highlighted or mentioned in several hundred media news items this year.

ASYMMETRIC GEOSPACE

On January 24th, 2019, AGU issued a press release highlighting a breakthrough in the understanding of the asymmetric geospace. This press release was based on a paradigm shift in our understanding of the dynamics of near-Earth space, as outlined in two recent publications by *Østgaard et al. (2018)* and O*hma et al. (2018)*. The results presented in these two papers explain both how asymmetries are created and how they are removed. They represent the culmination of 15 years of research, comprising 4 PhD theses, 11 master's theses and 22 publications, that have sought to understand our asymmetric geospace. This new understanding of our near-Earth neighborhood generated a great deal of media attention throughout the world, including an article in the *New York Times*.

NEW FINDINGS BY ASIM INSTRUMENT

A slew of new discoveries, based on ASIM measurements, about the mysterious gamma ray flashes that come from Earth's thunderclouds were unveiled by BCSS leader Nikolai Østgaard during his talk on December 10 at the 2019 AGU Fall Meeting in San Francisco. These findings were published in three new publications in *Science* and *JGR*. AGU also issued a press release entitled "Scientists unveil new discoveries about gamma ray flashes coming from thunderstorms." The new findings from the ASIM instrument alone resulted in almost 100 news items, including one in *Der Spiegel (Figure 13a)*. The new findings by the ASIM instrument also found their way to the front cover of *Science (Figure 13b)*.

BCSS HOSTS RESEARCH SCHOOL

In 2019, we started the Birkeland Centre Research School with two week-long intense lectures for master's and early career scientists. The first one's focus was on "Solar Impact on the Winter Polar Atmosphere – from space to surface" (11-15 March). Seventeen master's students and early career scientists attended.

Photo: Georgi Genov

Figure 14: Attendees, May 2019 Reseach School

The second school was held on May 20-24 and focused on "Atmospheric Electricity and Hard Radiation from Thunderclouds." It was attended by 32 students from 22 institutions in 14 countries *(Figure 14)*.

The feedback we received from participants was extremely positive:

"All the presenters were excellent. They were able to communicate to a spectrum of backgrounds – from master's-level students to postdocs – in a very inclusive way. Dr. Cooray, for example, very elegantly included basic-level information without losing the attention of more advanced students among the attendees."

"The presenters were very approachable but it would have been good to have more time for questions and answers."

NEXT STEP

The Next Step concert series – a collaborative effort between the Bergen Philharmonic Orchestra and the University of Bergen (Bjerknes Centre for Climate Research and the Birkeland Centre for Space Science) – seeks to unite science and art. The series includes concerts on the themes of space, ocean, climate and humanity.

On the evening of September 12, the first concert of the series, Space, was hosted by Birkeland Centre's Arve Aksnes and UiB doctoral student Susanne Flø Spinnangr *(Figure 15a)*. The two gave a brief introduction to space science with accompanying visuals on a big screen behind them. The presentation ended with a surprise greeting from astronaut Luca Parmitano from aboard the International Space Station *(Figure 15b)*.

YOUNG CAS FELLOWSHIP

In February this year, the Centre for Advanced Study (CAS) of the Norwegian Academy of Science and Letters awarded Hilde Nesse Tyssøy of BCSS *(Figure 16)* the Young CAS Fellowship. Created in partnership with the Young Academy of Norway (YAN), the Young CAS Fellow program gives researchers the opportunity to grow their professional networks and create a foundation for collaboration at a critical point

> "The atmosphere was very friendly and welcoming and the size of the group was optimal. It was easy to connect to other attendees and lecturers." (Attendee, Hard Radiation Research School)

Video: European Space Agency

Figure 15a: "Space" concert presenters Arve Aksnes (top) and Susanne Flø Spinnangr

Figure 15b: Luca Parmitano, astronaut aboard the International Space Station, made a surprise "visit" at the Bergen Philharmonic Orchestra's Next Step "Space" concert.

Photo: Kavitha Østgaard

Figure 16: Dr. Hilde Nesse Tyssøy, winner of the 2019 Young CAS Fellowship

Education and public outreach

Photo: Kavitha Østgaard

Figure 17: Karl Laundal, one of three winners of the 2019 Trond Mohn Foundation(TMS) Starting Grant

in their careers. Each Young CAS Fellow receives up to NOK 175,000 in support from CAS. The funds are for the design of research projects, networking and three meetings over a period of a year.

TMS STARTING GRANT

On December 6th, Karl M. Laundal was announced as one of three winners of the prestigious TMS Starting Grant *(Figure 17)*. His winning proposal is entitled «What Shapes Space?». This grant will give him the necessary resources to make long-term plans for research on near-Earth space.

VISITING FULBRIGHT ARCTIC CHAIR

Prof. Mark Moldwin from the University of Michigan, Ann Arbor was chosen as the Fulbright Artic Chair for 2019-2020. This prestigious grant is only awarded to one U.S. scholar each year and provides a three to four month grant to do research and lecture at any institution of higher education or research in Norway *(Figure 18)*.

Prof. Moldwin, who conducts space physics research to understand the flow of energy, mass and momentum from the Sun through the Earth's space environment, chose BCSS as the site for his Norwegian sojourn. He spent this past fall, August 15-December 1, at the Birkeland Centre for Space Science .

PASSION FOR SCIENCE

On September 2, the Kavli Symposium: Passion for Science took place in the University Aula at UiB *(Figure 19)*. The symposium was organized to honor the three 2018 Kavli Prize winning scientistis with specialities in the fields of astrophysics, nanoscience and neuroscience. Accompanying this event was an exhibit on space and an astrophysics seminar with lectures by the Kavli winner for astrophysics, Dr. Ewine van Dishoeck, Dr. Holly Gilbert (NASA), previous Kavli winner Dr. Jane Luu (Draper Laboratory, USA), and Dr. Olga Malandraki (President, EGU Solar-Terrestrial Sciences Division). ●

Photo: Mark Moldwin

Figure 18: Prof. Mark Moldwin, Applied Physics, Univ. of Michigan, winner – Fulbright Arctic Chair, spent four months at BCSS.

Photo: Thor Brødreskift, UiB

Figure 19: NRK t.v. presenter Selda Ekiz interviews Dr. Ewine van Dishoeck, winner of the 2018 Kavli Prize for astrophysics.

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

2019-2020	Info from Swarm and other satellites will be used to fill knowledge gaps related to "energetic ion outflow"	**P.I.** Spencer Hatch **150 KEUR**

Norwegian Space Agency | DEEP | Project: VIT.02.19.7

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

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

2017-2020	**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**

Research Council of Norway | Project: 287427

2019-2022	Which types of particle precipitation matter in the middle atmosphere?	**P.I.** Noora Partamies **7 MNOK**

BTO / Research Council of Norway | Project: 295963

2019-2019	**ARAE - FORNY project** to explore the use of global models of ionospheric currents for navigation purposes	**P.I.** Karl Magnus Laundal **300 KNOK**

European Space Agency | ASDC | Project: 4000123438

2018-2019	**ASIM Science Data Centre** – Processing and analysis of ASIM data	**P.I.** Nikolai Østgaard **98 KEUR**

European Space Agency | Testing MHD | Project: 4000124903

2018-2019	**Testing** – MHD (Magnetohydrodynamics) model for geomagnetic applications	**P.I.** Michael Hesse **200 KEUR**

European Space Agency | SMILE Phase 1 | Project nr: 4000123238

2018-2019	**Design and building** – Radiation Shutter for SXI on SMILE	**P.I.s** N.Østgaard, Kjellmar Oksavik **669 KEUR**

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

2017-2019	**Full Range Energetic Particle Precipitation Impacting the Middle Atmosphere**	**P.I.** Hilde Nesse Tyssøy **3,52 MNOK**

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

2017-2018	**Production and visualization** – of a climatological model of high latitude ionospheric and field aligned current systems	**P.I.** Karl Magnus Laundal **100 KEUR**

Research Council of Norway Program for Space Research | Project: 255276/E10

2016-2019	**SOLENA** – Solar effects on natural climate variability in the North Atlantic and Arctic. Collaboration between the Bjerknes Centre for Climate Research, the Dept. of Geosciences, UiO, and the Geophysical Institute, UiB.	**P.I. Yvan Orsolini** **11,4 MNOK**

Research Council of Norway Program for Space Research | Project: 246725/E10

2015-2019	Multi-Instrument Studies of High Latitude Atmospheric Turbulence and Wave Processes	**P.I.** Lisa Baddeley **1,5 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**

Atmosphere-Space Interaction Monitor (ASIM) | ESTEC Contract Ref. 40000101107/10/NL/BJ | Terma-DTU Contract TER-SPACE-CON-DTU_SPACE-002_rev2

2010-2019	**Phase C and D, sub-sub-contract between DTU Space and University of Bergen** 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 Monitor (MXGS). ASIM is a payload for the International Space Station and is planned for launch in 2016.	**P.I.** Nikolai Østgaard **3,75 MEUR**

PERSONNEL

Summary

	TOTAL	UiB	NTNU	UNIS	MEN	WOMEN
Professors	10	6	2	2	10	-
Associate Professors	4	2	-	2	2	2
Professors Emeriti	2	2	-	-	2	-
Researchers	10	10	-	-	7	3
Research Asst.	1	1	-	-	-	1
Postdocs	10	7	1	2	7	3
PhD Candidates	14	9	2	3	10	4
Technicians	8	7	-	1	7	1
Administration	4	4	-	-	1	3
Master's Students	17	9	-	8	8	9
Sum	80	57	5	18	54	26

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 *(on leave)*	UiB
	Massara Chaari *(replacement)*	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
	Harald Ellingsen, *Managing Director*	UNIS
	Grete K. Ersland, *Head of Admin., Secretary, IFT Board*	UiB

Technical and Administrative Team

Arve Aksnes, *Advisor*	M	UiB
Torstein Frantzen, *Chief Eng.*	M	UiB
Georgi Genov, *Senior Eng.*	M	UiB
Jon-Thøger Hagen, *Chief Eng.*	M	UiB
Therese Jørgensen, *Sr. Advisor*	F	UiB
Thomas Poulianitis, *Chief Eng.*	M	UiB
B.H. Qureshi, *Chief 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
Michael Hesse	Professor	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	Postdoc	M	NTNU
Lindis Bjoland	Postdoc	F	UNIS
Emma Bland	Postdoc	F	UNIS
Brant Carlson	Researcher II	M	UiB
Sara Gasparini	Research Assistant	F	UiB
Stein Haaland	Researcher II	M	UiB
Spencer Mark Hatch	Postdoc	M	UiB
Pavlo Kochkin	Researcher	M	UiB
Norah Kwagala	Researcher	F	UiB
Karl Magnus Laundal	Researcher	M	UiB
Nikolai Lehtinen	Researcher	M	UiB
Ville Aleksi Maliniemi	Postdoc	M	UiB
Andrey Mezentsev	Researcher	M	UiB
Astrid Cecilia Norgren	Postdoc	F	UiB
Anders Ohma	Postdoc	M	UiB
Yvan Orsolini	Researcher II	M	UiB
Jone Petter Reistad	Postdoc	M	UiB
David Sarria	Postdoc	M	UiB
Christine Smith-Johnsen	Researcher	F	UiB
Paul Tenfjord	Postdoc	M	UiB
Hilde Nesse Tyssøy	Researcher	F	UiB
Eldho Midhun Babu	PhD candidate	M	UiB
Kjetil Albrechtsen	PhD candidate	M	UiB
Nina Kristine Eriksen	PhD candidate	F	UNIS
Christoph Franzen	PhD candidate	M	NTNU
Are Haslum	PhD candidate	M	UiB
Katie Herlingshaw	PhD candidate	F	UNIS
Håkon Midttun Kolstø	PhD candidate	M	UiB
Anders Lindanger	PhD candidate	M	UiB
Carolina Maiorana	PhD candidate	F	UiB
Anders Ohma	PhD candidate	M	UiB
Chris A. Skeie	PhD candidate	M	UiB
Susanne Flø Spinnangr	PhD candidate	F	UiB
Fasil Tesema	PhD candidate	M	UNIS
Wim van Caspel	PhD candidate	M	NTNU

MAJOR ACHIEVEMENTS

December 2019

Media coverage: Almost 100 news items were published around the world in the wake of new findings by the ASIM instrument. The new discoveries were first presented in three publications in *Science* and the *Journal of Geophysical Research*. In addition, AGU issued a press release entitled "Scientists unveil new discoveries about gamma ray flashes coming from thunderstorms."

Award: Leader of the Dynamics of the Asymmetric Geospace group at BCSS, Dr. Karl M. Laundal, was one of three winners of the prestigious TMS (Trond Mohn Foundation) Starting Grant. His winning proposal was entitled "What Shapes Space?"

October 2019

New PhD: Anders Ohma successfully defended his PhD thesis *(How Asymmetries in Geospace Evolve During Increased Tail Reconnection)*. His research advisor was UiB Professor Nikolai Østgaard, Head of BCSS.

Award: BCSS master's student Elise Knutsen (NTNU) won the International Astronautical Federation (IAF) Interactive Presentation Award in Washington, D.C. for her thesis *(Dynamical-Chemical Coupling in the Polar Middle Atmosphere: Effects of Energetic Particle Precipitation on the Middle Mesospheric Maximum)*. Her advisor was NTNU professor Patrick Espy, Co-leader of the Particle Precipitation group at BCSS.

September 2019

Public outreach: BCSS hosted a concert named *Space* in collaboration with the Bergen Philharmonic Orchestra and the University of Bergen. This concert was the first in the "Next Step" concert series whose goal is to unite science and art and to celebrate the 50th anniversary of the first moon landing.

New PhD: Christoph Franzen successfully defended his PhD thesis *(Aeronomy of hydroxyl airglow variability by means of high-resolution telescope observations and gravity wave simulations)*. His research advisor was NTNU professor Patrick Espy.

Instrument milestone: The Soft X-ray Imager (SXI) instrument, which is part of the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) spacecraft mission, passed the Instrument Preliminary Design Review. BCSS will deliver the radiation shutter mechanism and electronics for the SXI instrument.

May 2019

Research School: 32 students (master's and early career scientists) from 22 institutions in 14 countries attended a research school that was conducted by BCSS. The topic of this research school was "Atmospheric Electricity and Hard Radiation from Thunderclouds".

April 2019

TV interview: NRK Dagsrevyen interviewed BCSS Leader Nikolai Østgaard one year after the ASIM instrument was launched to the International Space Station (April 2018). In this interview, Østgaard presented ASIM data revealing that visible lightning comes after terrestrial gamma-ray flashes.

March 2019

Research school: The BCSS workshop on "Solar Impact on the Winter Polar Atmosphere – from space to surface" took place between 11-15, March. The school was attended by 17 master's and early career students.

New spacecraft mission: The European Space Agency (ESA) gave a green light to move ahead with SMILE. Launch is now scheduled for 2023.

February 2019

Award: Leader of the Particle Precipitation group at BCSS, Hilde Nesse Tyssøy, won the Young CAS Fellowship.

January 2019

Media coverage: More than 100 news articles were published in media all over the world (including *The New York Times*) after AGU issued a press release entitled "New study presents surprising explanation for differences in southern and northern lights". This press release was based on a paradigm shift in our understanding of the dynamics of near-Earth space, as outlined in two recent publications by *Østgaard et al. (2018)* and *Ohma et al. (2018)*.

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