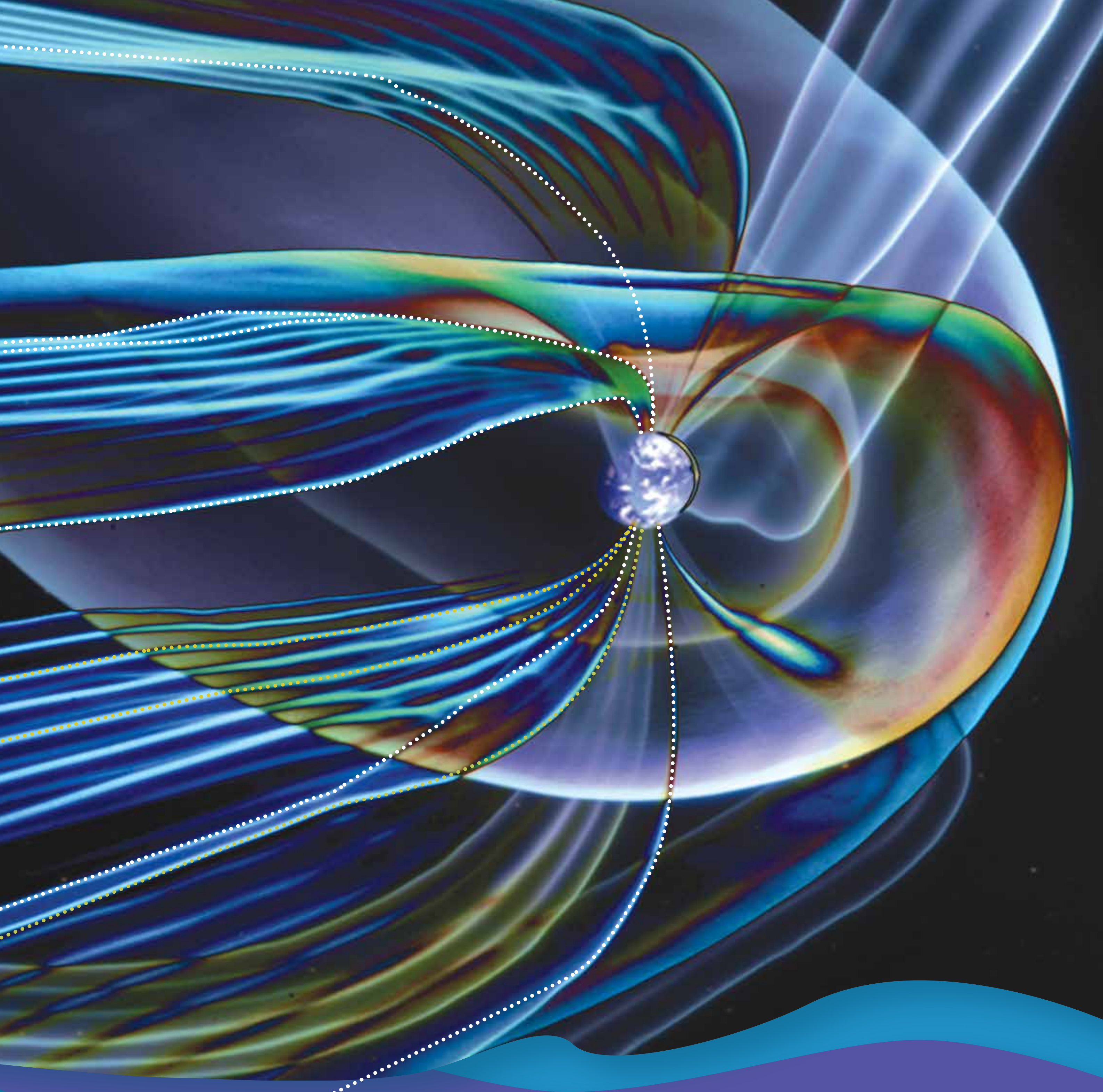


annual report 2018

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) started in March, 2013. It is led from the Department of Physics and Technology at the University of Bergen (UiB) with nodes at NTNU and UNIS. The overarching scientific objective of the BCSS is to understand "How the Earth is coupled to space". The Centre is organized in four research groups:

G1. Dynamics of the Asymmetric Geospace
G2. Theory and Modeling
G3. Particle Precipitation
G4. Hard Radiation from Thunderstorms

In addition, we have two groups that design, build and operate state of the art instrumentation, one for space- and one for ground-based research. We also have a group for education and public outreach.

From the centre leader

This annual report covers the year 2018.

SCIENCE & RECOGNITION

2018 has been the most productive year since we started the Centre. We published 74 peer-reviewed papers and, as of the end of 2018, our papers have been cited more than 2000 times. The six-year old Centre has an H-index of 18.

Several results merit highlighting here:

At the end of the year, a paper by *Ohma et al., 2018* was highlighted through an American Geophysical Union (AGU) press release. This press release led to more than 110 news stories worldwide, including articles in *The New York Times* and *Scientific American*, with interviews with both Anders Ohma and the Centre leader. This paper summarizes to a large degree the efforts of Group 1 since the start of BCSS in explaining why and how asymmetric auroras are produced, and also how and why symmetry is restored. An animation of the results has been viewed more than 10 000 times.

Another highlight is a *Science* paper, with Prof. Michael Hesse from BCSS as a co-author, focusing on "the small scales of magnetic reconnection". An additional paper about the role of instabilities in magnetic reconnection, with Michael Hesse as first-author, was highlighted as editor's pick in *Physics of Plasma*.

At the AGU fall meeting, the first results from Atmosphere-Space Interactions Monitor (ASIM) were presented in three invited talks (one by the Centre leader) and six other presentations. After only six months of operation, ASIM has already provided several "firsts": the first simultaneous Terrestrial Gamma-ray Flashes (TGF) measurements by two spacecraft, the first image of a TGF, the first simultaneous observations of TGF and Transient Luminous Events, and our solution of the temporal sequence of TGF and optical pulse from lightning on a microsecond time scale. This is just the beginning for ASIM.

NEW PROJECTS

Five new projects were initiated in 2018.

Noora Partamies at UNIS received funding from the Norwegian Research Council for a new project in Group 3: "Which types of particle precipitation matter in the middle atmosphere?"

Three new projects are funded through the ESA PRODEX program. One is a Space Weather program led by Michael Hesse and another is for supporting the ASIM data processing. The PRODEX funding for SMILE was also established and extended with additional funding to cover costs until the end of 2019.

The "Distribution of Energetic Electrons and Protons" (DEEP) project has received funding from the Norwegian Space Centre.

AWARDS

In December 2018, the leader of Group 3, Hilde Nesse Tyssøy, won a Fulbright stipend to work with researchers at the University of Colorado, USA and the National Center for Atmospheric Research (NCAR) in 2019 for an extended time.

INSTRUMENTS

In April 2018, the Atmosphere-Space Interactions Monitor (ASIM) was successfully launched to the International Space Station. This was a big milestone after 14 years of hard work. The ASIM team from BCSS, as well as our main collaborators, attended the launch in Florida. The event was picked up by media all over the world in more than 400 news stories. We were even featured prominently on national television. All instruments on ASIM are performing, as expected, at a high level.

The Soft X-ray Imager (SXI) instrument, which is the instrument on the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) in which we are involved, passed the Instrument System Requirement Review in September 2018. The SMILE mission, which is a joint effort of the European Space Agency (ESA) and the Chinese Academy of

Highlights

Sciences (CAS), is planned for ESA adoption during the spring of 2019. The SMILE team at BCSS is now preparing for the SXI Instrument Preliminary Design Review in 2019, which is another major milestone.

The DEEP instrument team is now developing a breadboard version. We have been offered an opportunity to fly a prototype of the instrument on the next ICI-5 rocket in the fall of 2019.

LEADERSHIP

In May 2018, Michael Hesse and Group 2 organized the Magnetospheric Multi-Satellite (MMS) workshop in Bergen, with more than 80 international attendees. During the week of the MMS workshop, a co-sponsored event with VilVite united space scientists and space enthusiasts.

Michael Hesse also became a member of ESA's Space Situational Awareness Advisory Group (SAA AG). The SSA AG advises the ESA Director responsible for the SSA program on operational, scientific and technical aspects of SSA activities, and ensures a close collaboration between ESA and the SSA-related expert communities.

As of 2018, Therese Moretto Jørgensen from BCSS is serving on two panels: "Candidate Earth Explorer 10 Mission Advisory Group (MAG) for the Daedalus Mission" and science advisory board for "AIDA", a Horizon 2020-Enabling exploitation of space data.

The Centre leader is continuing to serve as national representative in the steering committee of SCOSTEP and ISWI. Hilde Nesse Tyssøy is serving as deputy national representative for IAGA.

As usual, we organized scientific sessions at both EGU and AGU. At the EGU meeting, the session "Meet the Experts: The Future of Solar Terrestrial Research" was organized by the Solar-Terrestrial Early Career Scientists team and led by Jone Reistad.

ORGANIZATION

In 2018 we made some changes in the BCSS organization. Most important was the establishment of a new group, led by Michael Hesse, which focuses on theory and modelling (now Group 2). The other change was to merge what were previously Group 1 and 2 into a new group named "Dynamics of the Asymmetric Geospace". This is now Group 1 and is led by Therese Moretto Jørgensen and Karl Magnus Laundal.

EDUCATION

Last year, three PhD students (Alexander Broberg Skeltved, Norah Kaggwa Kwagala, Annet Eva Zawedde) and three Master's students received their degrees.

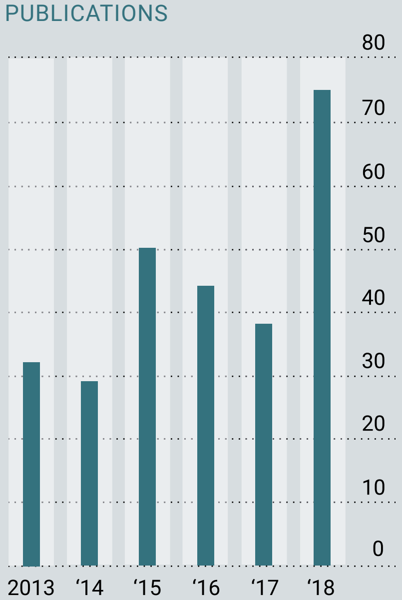
Following the vision we presented at the Midterm Review, we established a BCSS Research School in 2018. The two first one-week long intensive schools, "Solar Impact on the Winter Polar Atmosphere – from space to surface" and "Atmospheric Electricity and Hard Radiation from Thunderclouds," will take place in Spring 2019.

I want to take this opportunity to thank all the members of BCSS for making 2018 such a productive and successful year.

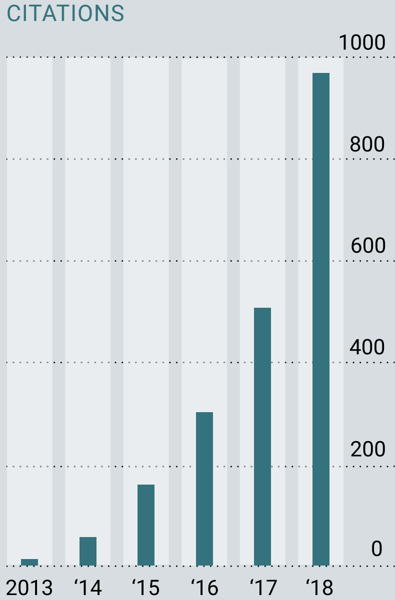
Nikolai Østgaard,
Leader of BCSS

Dissemination data

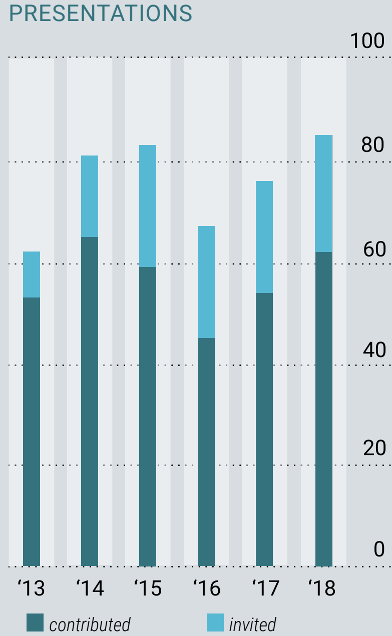
PUBLICATIONS



CITATIONS



PRESENTATIONS



Highlights in images

ASIM LAUNCH

Image: SpaceX

1. *ASIM inside the Dragon capsule*

Image: NASA/Kim Shiflett

2. *Dragon capsule ready for launch on the SpaceX rocket*

Image: NASA

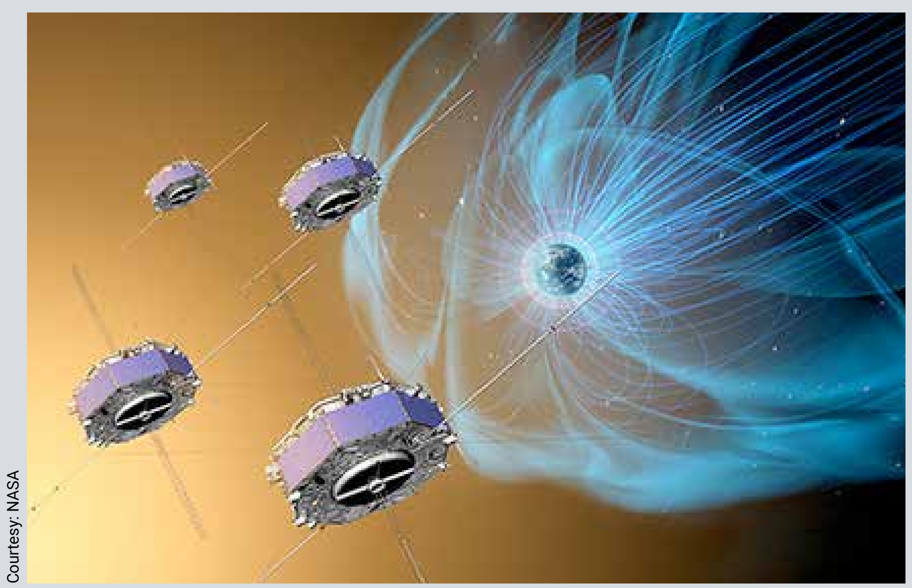
3. *Liftoff of the SpaceX rocket at 16:30 local time on April 2, 2018 from Cape Canaveral , Florida*

Image: NASA

4. *The robotic "Canada" arm of the ISS captures the Dragon capsule and mounts it on the space station on April 4, 2018.*

MMS WORKSHOP IN BERGEN

Courtesy: NASA



Artist's conception of the MMS mission

G1> Dynamics of the asymmetric geospace

A major breakthrough in our understanding of the asymmetric geospace has been achieved. Over the last several years, the group has developed a new explanation for how the asymmetry is generated. It starts with the fact that when the interplanetary magnetic field (IMF) has a predominant east-west orientation, magnetic coupling on the dayside between the earth magnetic field and the IMF happens in an asymmetric fashion between the northern and southern hemispheres. This "asymmetric" reconnection geometry leads to an asymmetric buildup of pressure inside the magnetosphere with associated asymmetries in the flows and resulting in a tilting of the earth magnetic field. *Tenfjord et al.* provided further confirmation for this explanation, showing that it applies also to conditions of northward pointing IMF. They showed that even though the reconnection geometry on the dayside is completely different from that of the southward IMF case, the magnetic energy is added to the magnetosphere in a similar way, building up asymmetric pressure, which induces a tilt. The time-scale involved was also found to be similar.

Figure 1: Screen shot from the animation video "Introduction to asymmetric geospace" created to visualize how the east-west orientation of the solar magnetic field leads to asymmetric forcing of the system between the two hemispheres and how it is removed again

The prevailing alternative explanation for the asymmetries, namely that they are induced by reconnection taking place also in the tail of the magnetosphere, is largely ruled out by the timing involved. New results indicate not only that magnetotail reconnection is unlikely to cause the asymmetry, but that magnetotail reconnection apparently restores symmetry in the system. This surprising new notion is so far corroborated by two independent studies. Using a large database of ionospheric plasma convection measurements from the SuperDARN network, *Reistad et al.* produced high-latitude convection maps sorted by season, IMF, and geomagnetic activity. The maps showed the magnetospheric flow from the nightside toward the dayside becoming more symmetric between the dawn and dusk sides with increasing levels of activity in the tail. This result suggests a large-scale reconfiguration of the nightside magnetosphere toward a more symmetric system due to tail reconnection. In the most recent study, *Ohma et al.* (Figure 2) analyzed the simultaneous evolution of auroral features in both polar regions during 10 tail reconnection events that occurred under conditions with a significant east-west component in the IMF. The results displayed a clear pattern of larger differences in the location of the aurora in the two hemispheres before the onset of tail reconnection followed by increasingly smaller differences as the tail reconnection events progressed.

In combination, the group's results offer a successful new paradigm for understanding

G1>

< **Therese M. Jørgensen, UiB**
Team Leader, Sr. Advisor

< **Karl M. Laundal**
Co-Leader, Researcher

Dag Lorentzen
Professor

Kjellmar Oksavik, UiB
Professor

Lisa Baddeley
Assoc. Professor

Jesper Gjerloev
Professor II

Steve Milan
Professor II

Stein Haaland
Researcher

Finn Søraas
Prof. Emeritus

Lindis Bjoland
Postdoc

Spencer Hatch
Postdoc

Jone Reistad
Postdoc

Katie Herlingshaw
PhD Candidate

Anders Ohma
PhD Candidate

the asymmetric geospace, the power of which was demonstrated in the study by *Østgaard et al*. The study showed how the features and dynamics of the asymmetric system during a major geomagnetic storm in August of 2001 were well explained within this new framework of understanding that has been developed by the group. The new understanding was heralded as a major advance in geosciences research in a press release issued by the AGU, further illustrating the importance and broad impact of this major accomplishment by the group. This press release led to more than 110 news stories worldwide, including *The New York Times* and *Scientific American*.

Several studies provided new insight related to understanding the time scales for changes in the global geospace system in response to changing solar wind or IMF conditions. *Milan et al.* determined the response in the Birkeland currents. They found that dayside currents responded promptly to reversals in the east-west component of the IMF, whereas the nightside response was delayed by up to an hour, or possibly even longer for northward IMF conditions. Consistent with the group's new paradigm for geospace asymmetry, interhemispheric asymmetry for the nightside currents were seen to grow during times when the IMF had a significant east-west component until the onset of tail reconnection. *Laundal et al.* presented an innovative new climatological model of the ionospheric current system and explored the effects of the radial component of IMF (B_x) and found differences in Birkeland currents of no more than 10%. In a complementary study, *Moretto et al.* showed that the Birkeland currents undergo exponential decay with a generic time constant of about 1 hour when the solar wind driving of the magnetosphere is effectively shut off. A seasonal variation in the decay parameter with faster decay observed in the winter than in the summer hemisphere was also reported. These findings are indicative of a fundamental behaviour of the magnetosphere-ionosphere system, which is crucial to fully understanding its dynamics.

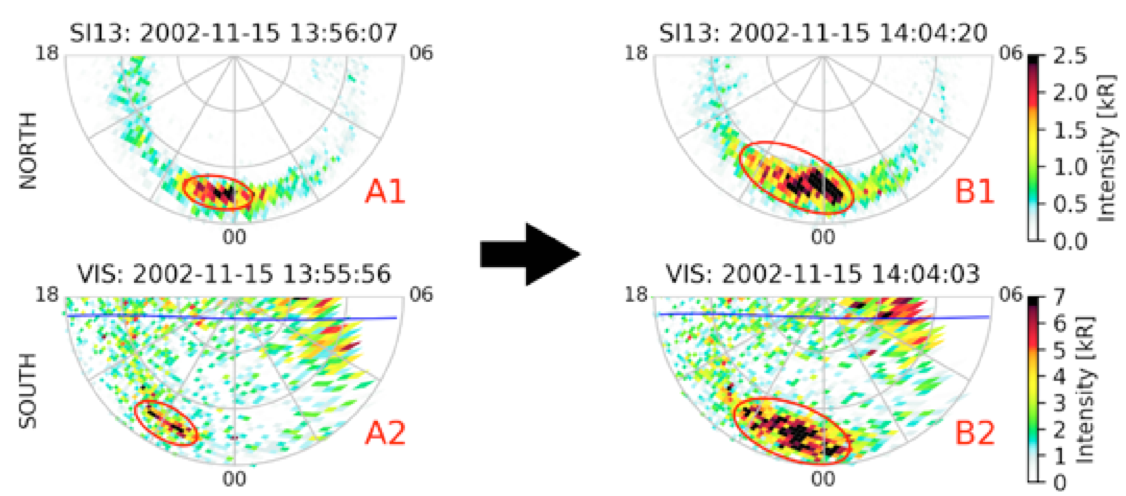
Studies of the aurora also produced several interesting results. Polar cycle and seasonal variations in thermally excited atomic oxygen emissions to red aurora was reported by *Kwagala et al.* Thermally excited emissions were found to maximize at solar maximum with peak occurrence rate of ~40% compared to ~2% at solar minimum and to have the highest occurrence at equinox. Their results pointed to solar wind-magnetosphere-ionosphere coupling as the dominant controlling process for the thermally excited emissions, underscoring the importance of taking into account this contribution in M-I coupling studies based on red line aurora observations. A detailed analysis in *Humberset et al.* of 4 events of pulsating auroral patches recorded in a high-resolution-all-sky imager movie revealed the surprising finding that the most consistent parameter seemed to be their shape. In contrast, the patches were not seen to fluctuate in intensity in a coherent fashion, the energy deposition was highly variable from one fluctuation to the next, and the fluctuations were highly irregular. These results have great implications for determining the generation mechanism and source region for pulsating aurora, indicating a source region closer to Earth than previously assumed and that ionosphere-magnetosphere coupling processes are important in their generation.

Research from the group was featured in more than 40 presentations worldwide, including more than 10 invited talks and seminars. The group gave presentations at more than 15 international conferences, had a strong presence at the main geophysics meetings of the field (EGU and AGU), and important roles at the SuperDARN, EISCAT, Cluster, SWARM, and GEM science community meetings.

New international collaborations were initiated during the last year with several groups in China. As part of his sabbatical, Prof. Oksavik visited Shandong University at Weihai, Tongji University in Shanghai, and the Polar Research Institute of China. These efforts have proven very fruitful, having already produced a number of publications with several others under preparation.

Over the last year, scientists in the group took part in the organization of major events for the geospace community, including, notably, serving as lead convener (Dr. Haaland) for the Europlanet 2018 Workshop on Ion outflow and atmospheric erosion. Another prominent example is the session: "Meet the Experts: The Future of Solar Terrestrial Research", which was held during the EGU meeting and organized by the Solar-Terrestrial Early Career Scientists team led by postdoctoral researcher Reistad. ◊

Figure 2: From *Ohma et al., 2018:* Asymmetric aurorae in the northern (top row) and southern (bottom row) hemispheres are asymmetric at substorm onset (left). They become symmetric due to tail reconnection during the substorm expansion phase (right).



G2> Theory and modeling

The Theory and Modeling group at BCSS is engaged in forefront, theory and modeling-based research of magnetospheric dynamics on large and small scales. Research methodologies range from analytical theory to, for large scales, magnetohydrodynamic modeling and comparisons to spacecraft observations.

Special research foci here include the kinetic physics foundations of magnetic reconnection, the generation of currents in the magnetosphere, and the mechanisms behind asymmetries of auroral patterns of the northern and southern hemispheres. An emerging research target is modeling for the purpose of physical understanding of space weather phenomena, as well as for the generation of space weather products relevant to ESA as well as to Norwegian space weather interests. The group was newly formed in 2018 to provide a theory and modeling focus within BCSS.

We contributed to 16 papers in international, peer-reviewed journals (4 first-author) on the above topics, with papers published in *Science* and in *Nature Communications*. We gave 27 presentations, 3 tutorial talks, and 5 invited talks at international scientific conferences.

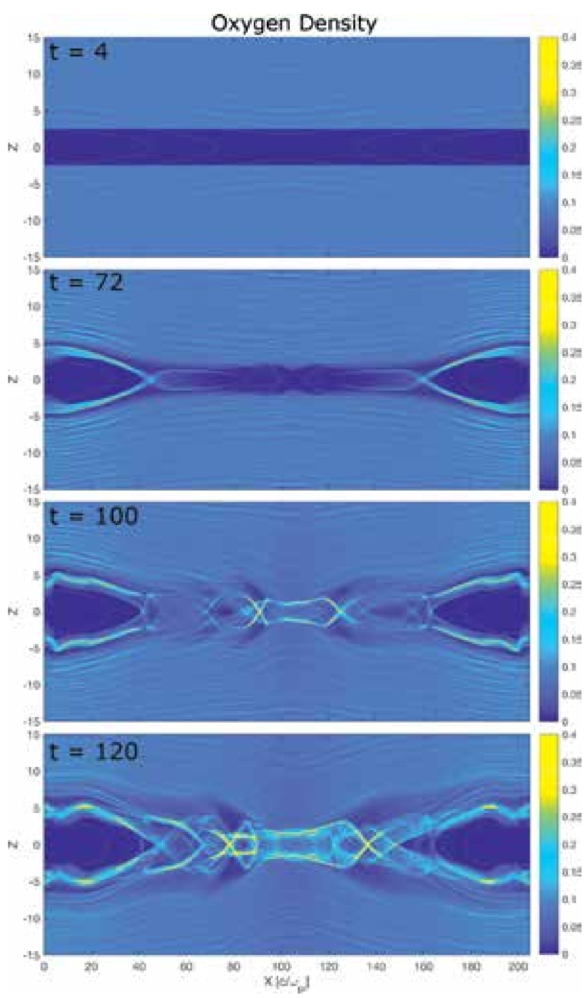
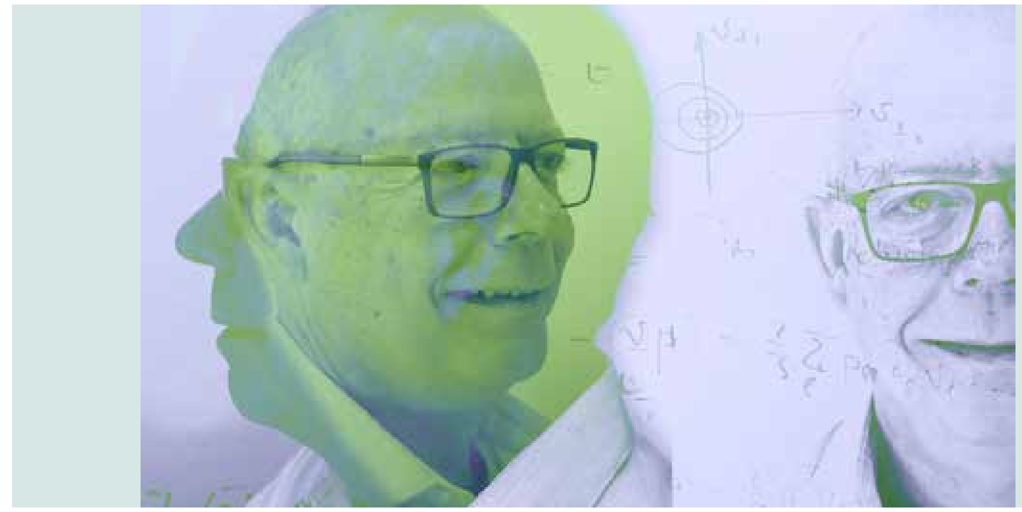


Figure 3: Oxygen density as foreground and magnetic field as background at four different stages of the simulated evolution *(Tenfjord et al.)*. The panels display the formation of evolving layers of enhanced cold oxygen density as the simulation progresses. The evolution of these newly discovered structures as well as the distribution of involved oxygen provide specific predictions for space mission.

RECONNECTION RESEARCH

Magnetic reconnection is recognized to be the most important plasma transport and energy conversion process in space physical plasmas. Magnetic reconnection contributes to the formation and ejection of coronal mass ejecta and to coronal heating, and it facilitates the entry of solar wind plasma and electromagnetic energy into the magnetosphere by either low- or high-latitude magnetopause reconnection. In the magnetosphere, reconnection converts stored magnetic energy to particle energy. It is also believed to play a role in the formation of the auroral acceleration region.

Oxygen of ionospheric origin is a ubiquitous particle species in magnetospheric dynamics. *Tenfjord et al.* investigated how an oxygen population influences magnetic reconnection and how it is energized. The oxygen population is inserted initially in the inflow region, and as time evolves it is captured by the reconnection process. As the oxygen gets involved, we discovered the formation of wave-like layers of high-oxygen density (Figure 3). These density striations consist of a quasi-steady horizontal layer and a dynamic, inclined, wavefront-like layer. Oxygen acceleration is dominated by electric forces, as the oxygen remains too cold to be significantly affected by the magnetic field. We discovered a key acceleration mechanism that leads to these two different structures. The oxygen population responsible for the density striations is accelerated ballistically when the Hall electric field comes into contact with the background population, forming an oxygen wave. Our results provide a detailed prediction of oxygen structures, which should be observable by magnetospheric missions. Finally, we suggested that the energy spent on the oxygen population reduces the energy available for reconnection, leading to a reduction of the reconnection rate.



< Michael Hesse, UiB
Team Leader, Professor

The electron dynamics within thin current sheets plays a key role both for the process of magnetic reconnection and other energy transfer mechanisms but is not well understood. *Norgren et al.* reported observations of a reconnecting current sheet with intermediate guide field BG=0.5Bin, where Bin is the magnetic field amplitude in the inflow regions. The current sheet width is comparable to electron spatial scales. We found a bifurcated structure embedded within the magnetopause current layer with thickness of several ion scales. Using comparisons between test particle simulations and electron data, we showed that electrons approaching from the edge of the largest magnetic curvature are scattered to perpendicular pitch angles in the center of the current sheet while electrons entering from the opposite side remain close to field aligned. The comparison also shows that an observed depletion in phase space at antiparallel pitch angles can be explained if an out-of-plane electric field is included. This electric field would be consistent with the reconnection electric field, and we therefore interpret the depletion of electron phase space density as a manifestation of ongoing reconnection.

The intensity of the magnetic reconnection process is measured by the reconnection electric field. *Hesse et al.* conducted computer simulations and developed corresponding analytic theory to provide a self-consistent understanding of the role of the reconnection electric field, which extends substantially beyond the simple change of magnetic connections. We found that the reconnection electric field is essential to maintaining the current density in the diffusion region, which would otherwise be dissipated. Candidates for current dissipation are the convection of current carriers away from the reconnection region by the reconnection outflow, or the average rotation of the current density by the magnetic field reversal in the vicinity. Instead, we found that the current dissipation is the result of thermal effects, underlying the statistical interaction of current-carrying particles with the adjacent magnetic field. This interaction serves to dissipate the directed acceleration of the reconnection electric field to thermal motion. This thermalization manifests itself in form of quasi-viscous terms in the thermal energy balance. This quasi-viscosity acts to increase the average thermal

G2>

Cecilia Norgren
Postdoc

Paul Tenfjord
Postdoc

Norah Kwagala
Researcher

Håkon Kolstø
PhD Candidate

Susanne Flø Spinnangr
PhD Candidate

energy. Our predictions already triggered investigations by NASA's Magnetospheric Multiscale mission.

Hesse et al. further investigated instabilities at the reconnection outflow separatrix and their role in heating the electron population in the outflow region. Electron heating in the transition from reconnection inflow to outflow is one important piece of reconnection energy conversion but previously not understood. We found a beam-beam instability, enabled by finite Larmor radius effects, to be operating at the interface between oppositely directed electron jets in the separatrix region. We found a close co-location of this type of turbulence and a substantial temperature increase moving from the inflow regions to the outflow jet (Figure 4). The heating occurred in the area with the turbulent features mentioned earlier. This association was confirmed in a detailed analysis of the individual terms of the quasi-viscous contribution. Here we found that the term involving the derivative of the electron bulk flow normal to the bulk flow direction provided by far the largest contribution. Instabilities of the type seen in our model can provide critical electron heating and a possible solution to the inflow-to-outflow heating problem.

SPACE WEATHER

G2 remains actively involved in NASA's Magnetospheric Multiscale mission (MMS) through research, attendance at MMS team meetings, leadership of the MMS Theory and Modeling group, and mission leadership team membership. In 2018, G2 organized an MMS-focused community science workshop in Bergen, which was attended by more than 80 scientists from the international research community.

FLIGHT MISSION INVOLVEMENT

G2 also translates scientific and technical capabilities developed in BCSS toward space weather applications. Here, G2 succeeded in winning an ESA proposal to initiate a global MHD-based modeling activity, and to test the capability of the model in reproducing observed geomagnetic signatures in northern Europe. This project started in the latter part of 2018. ◊

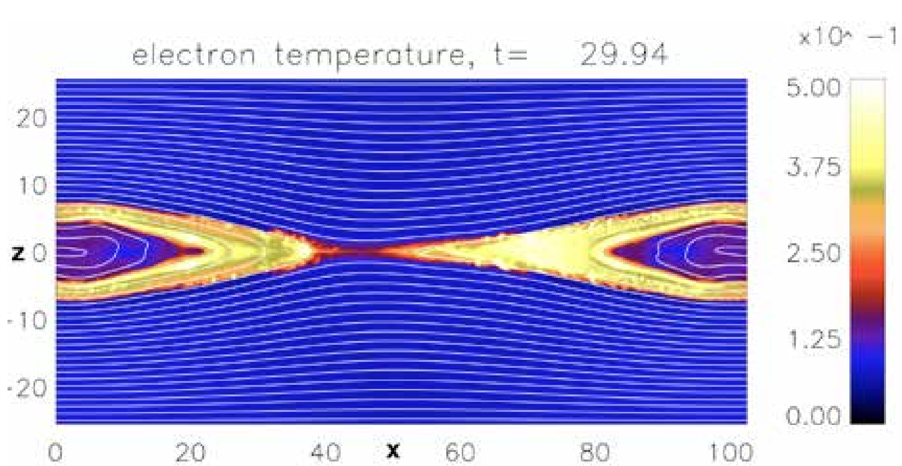


Figure 4: Global plot of the electron temperature in a reconnection simulation *(Hesse et al.)*. The figure shows a strong temperature increase at a boundary, which also features significant spatial variations. We succeeded in proving that this dramatic temperature change is caused by the effect of plasma instabilities at the reconnection inflow-outflow interface.

G3> Particle precipitation

Precipitating energetic protons and electrons, ionizing the polar thermosphere and mesosphere, have long been known to initiate a series of chemical reactions increasing the production of NOx and HOx gasses in the atmosphere. HOx and NOx gasses destroy ozone in catalytic reactions. As ozone plays a key role in the middle atmospheric energy budget, it is speculated that the subsequent change in temperature might alter stratospheric winds and wave propagation initiating a top-down mechanism which could impact regional surface level climate at high latitudes during winter. In order to extend the understanding of the middle atmospheric ozone variability and its potential link to the surface climate, one has to improve on quantifying the energetic particle precipitation (EPP) input at different altitude levels of the atmosphere. There is a need to understand the general variability of the atmospheric parameters. Further, atmospheric models must have the capability of reproducing the associated chemistry impact, which can be validated in comparison with observations. Group 3 brings together space and atmospheric scientists with the expertise to unravel the complex relationship between EPP and its atmospheric effects applying both observations and models.

Understanding the background variability of ozone is also essential in order to understand the potential impact EPP-produced OH might have on tertiary ozone maximum in the polar winter mesosphere. *Smith-Johnsen et al. (2018a)* used observations from satellites and a ground-based station to construct a global data set for investigating the tertiary ozone maximum in the winter mesosphere for the period August 2004 to June 2017. These give a comprehensive picture of the ozone maximum in latitude, pressure, and time and indicate that planetary wave activity in the northern hemisphere can alter the altitude and latitude distribution of the tertiary ozone.

At the end of 2018, team member Annet Eva Zawedde successfully defended her PhD on the impact of energetic electron

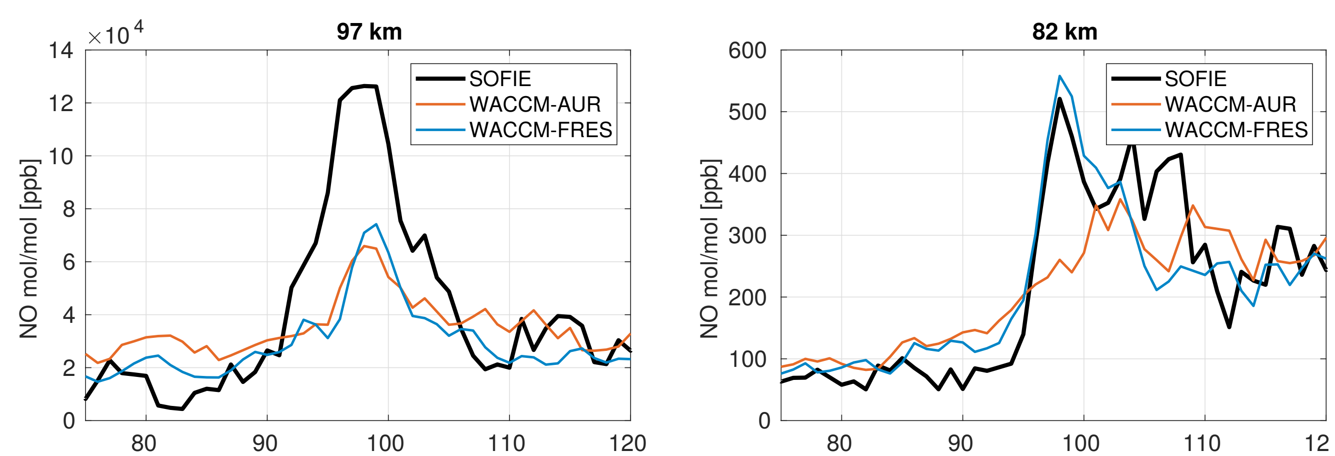


Figure 5: Adapted from *Smith-Johnsen et al. (2018a)*: Time evolution of NO volume mixing ratio for two different altitudes. The black line represents SOFIE observations of NO VMR. The orange line represents NO VMR from the Standard run while the blue line is from the POES-FRES run with D region chemistry. SOFIE = Solar Occultation For Ice Experiment; POES = Polar Orbiting Environmental Satellites; FRES = full range energy spectrum.

G3 >

< **Hilde Nesse Tyssøy, UiB**
Team Leade, Researcher

Patrick Espy, NTNU
Co-Leader, Professor

Robert Hibbins, NTNU
Professor

Noora Partamies, UNIS
Associate Professor

Johan Stadsnes, UiB
Prof. Emeritus

Yvan Orsolini
Researcher

Christine Smith-Johnsen
Researcher

Stefan Bender
Postdoc

Emma Bland
Postdoc

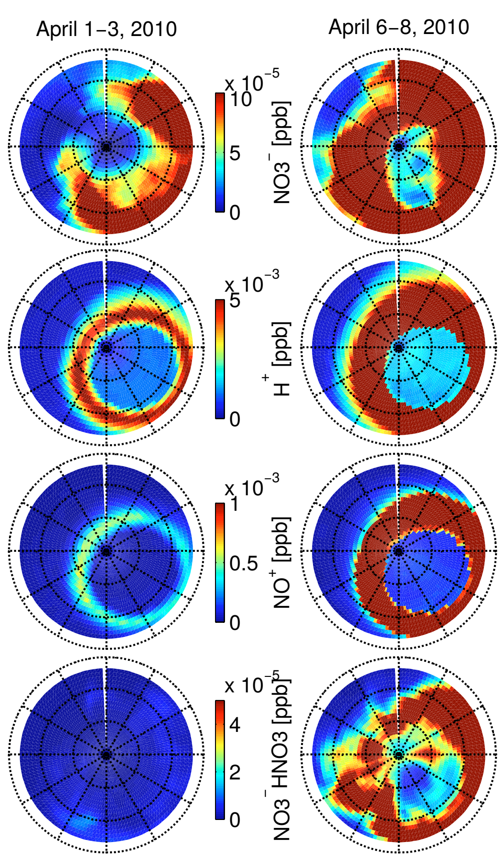
Eldho Midhun Babu
PhD Candidate

Christoph Franzen
PhD Candidate

Annet Eva Zawedde
PhD Candidate

precipitation (EEP) on mesospheric hydroxyl radical. One of the outstanding questions in this respect has been the relative importance of the large, but scarce, solar proton events to the frequent, but weak EEP events to OH and subsequent ozone reduction. *Zawedde et al. (2018)* investigated the OH variability in respect to both atmospheric background variability and EEP and found that OH variability is mainly driven by changes in temperature and water above 70 km and by EPP below 70 km. Protons dominate over electrons below 70 km, but the electron impact is comparable to that of protons above 70 km altitude.

Figure 6: Geographic maps of some key ion clusters at 70 km (in ppb) over the southern hemisphere in April 2010, contrasting quiet (left column for April 1-3) from active conditions (right column for April 6-8) following a geomagnetic storm. The simulations were performed with WACCM-D, a variant of the WACCM model valid for the D-layer, with an extensive mesospheric ion chemistry. The simulations included forcing from medium-to-high energy electron (MEE) precipitation. From *Orsolini et al. (2018)*.



The relative importance of different types of particle precipitation is also the topic of a newly funded program by the Research Council of Norway, with Assoc. Prof. Noora Partamies as the project manager: "Which types of particle precipitation matter in the middle atmosphere?" The progress and evaluation of the results will be closely linked to an ongoing project: "Full Range Energetic Particle Precipitation Impacting the Middle Atmosphere (FREPPIMA)" also supported by the NRC. While the proposed project from UNIS will partly share the science objectives of FREPPIMA, the ground-based database of riometers, SuperDARN, and EISCAT offers better spatial and temporal resolution and coverage as compared to the space-borne observations. Hence, the two projects are complementary and will offer a mutual validation of the results. In particular, new methods of characterizing the spatial impact of EPP using SuperDARN *(Bland et al., 2018)* might offer insight into their relative importance globally and over decadal time scales.

The Whole Atmosphere Community Climate Model (WACCM) is one of few high-top climate models parameterizing EPP. The standard WACCM EEP parametrization only includes auroral electrons (with a characteristic energy of 2keV). *Smith-Johnsen et al. (2018b)* studied the atmospheric NO response to a geomagnetic storm in April 2010 using WACCM. Modeled NO was compared to mesospheric observations in the southern hemisphere. By combining low and high electron energy measurement from the TED and MEPED onboard the NOAA POES satellites, *Smith-Johnsen et al. (2018a)* obtained a continuous energy spectrum ranging from 1 to 750 keV, which corresponds to atmospheric altitudes of 60-120 km. In this study, we showed that including the high energy electrons and *D* region ions (WACCM-D) increased the directly produced NO in agreement with observations between 60 and 80 km. However, all model runs showed a persistent deficit in NO between 90 and 110 km, a deficit influencing the indirect effect of downward transport of NO from the lower thermosphere. This is currently the focus for ongoing studies.

We also used WACCM-D to investigate ion chemistry and its impact on nitric acid, an important minor species in the middle atmosphere *(Orsolini et al., 2018)*. Both WACCM and WACCM-D simulations are performed with and without forcing from medium-to-high energy electron precipitation, allowing a better representation of the energetic electrons penetrating into the mesosphere. We demonstrated the effects of the strong particle precipitation events which occurred during April and May 2010 on nitric acid and on key ion cluster species, as well as other relevant species of the nitrogen family. The 1-year-long simulation allows the event-related changes in neutral and ionic species to be placed in the context of their annual cycle. We especially highlighted the role played by medium-to-high energy electrons in triggering ion cluster chemistry and ion-ion recombination in the mesosphere and lower thermosphere during the precipitation event, leading to enhanced production of nitric acid and raising its abundance by two orders of magnitude.

During 2018, Group 3 has published 12 papers. We have given more than 20 presentations at international conferences, five of which were invited talks. In particular, at the 7th International HEPPA SOLARIS workshop in Virginia, USA, two of our young researchers, Drs. Emma Bland and Christine Smith-Johnsen, presented solicited talks. The visibility and presence in the Scientific Organization Committee has led to BCSS being the host of the 8th International HEPPA SOLARIS workshop in June 2020. Dr. Yvan Orsolini organized a session at the 2018 COSPAR General Assembly (C2.3), and Dr. Patrick Espy organized a session at the 2018 Asia Oceania Geosciences Society 15th annual meeting (AS-30).

In the frame of the SPARC SOLARIS-HEPPA Working Group 5 (www.sparc-climate.org/activities/solar-influence/), Hilde Nesse Tyssøy is co-leading a model-measurement intercomparison experiment aimed at the impact of medium-energy electrons (>30 keV). In September 2018, we hosted a working group meeting including participants from multiple universities and research organizations from both Europe and US.

With two active NRC research projects focusing on understanding the nature of EPP, we are becoming a group with unique expertise and state of the art analysis techniques in both ground- and satellite-based observations. ◊

G4> Hard radiation and thunderstorms

< **Nikolai Østgaard, UiB**
Team Leader, Professor

< **Martino Marisaldi, UiB**
Co-Leader, Associate Professor

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 to 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 the sub-milliseconds Terrestrial Gamma-ray Flashes (TGFs) to the 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 4.

A large fraction of the group's activities is devoted to the Atmosphere Space Interaction Monitor (ASIM) mission onboard the International Space Station (ISS). ASIM is a mission of the European Space Agency (ESA) dedicated to the study of lightning, Transient Luminous Events (TLEs) and TGFs. ASIM was launched on April 2, 2018, on a Space-X rocket and installed on the external facility of the Columbus module of the ISS. The ASIM scientific payload consists of two main instruments: The MXGS, a hard-X and gamma-ray detector designed to study TGFs, and the MMIA, an array of cameras and photometers operating in different bands (optical and UV) to observe lightning and TLEs. The MXGS instrument consists of two detector layers: the Low-Energy Detector (LED), sensitive in the 20 – 400 keV range, and the High-Energy Detector (HED), sensitive in the 0.3 - >30 MeV range. The LED, with a coded mask system, provides direct imaging of TGFs in the hard-X rays with a source location accuracy of about 7 km at ground level. The HED provides accurate energy measurements in the band where most of the TGF energy is emitted. ASIM's main 'first-of-its-kind' characteristics are: (i) TGF imaging capabilities in hard-X rays via first-time application of a technique widely employed in high-energy astrophysics to Earth observation; (ii) the simultaneous optical and X- gamma-ray observation of the same field of view.

Following the ASIM installation onboard the ISS, the team was heavily involved in the so-called 'commissioning phase', where the initial check of all the instrument's functionalities and performance was done, as well as the tuning of all the configurable parameters, including instruments thresholds, gain, and trigger logic parameters. It was a hectic but highly rewarding period, resulting in a good understanding of the instrument's behavior in orbit, and in the optimization of the configuration to be implemented during nominal operations, which started in June 2018. In parallel, all software tools needed to analyze the data were developed, in collaboration with the ASIM Science Data Center (ASDC). This resulted in a pipeline for the identification of TGFs running in near-real time at BCSS.

The ASIM scientific results after the first six months of operations were presented at the Fall Meeting of the American Geophysical Union (AGU) in Washington DC. ASIM detects about one TGF per day with an unprecedented counts statistic. More than 25% of the events have more than 100 counts, making them suitable for individual spectral analysis. Two TGFs were simultaneously observed by ASIM and the Fermi satellite, resulting in potential insight into the TGF emission geometry at the source. Many TGFs consist of multiple peaks, suggesting periodicity at the millisecond level that needs to be explained by production scenarios. Many TGFs have TLEs closely associated in time coming from the same thunderstorm system. More than 40 TGFs have concurrent optical and UV measurements by the photometers, showing that TGFs are produced during the upward lightning leader propagation. This scenario, suggested by previous studies based on a much smaller number of events, is now confirmed thanks to the peculiarities of the ASIM payload, allowing for the first time simultaneous optical and high-energy measurements.

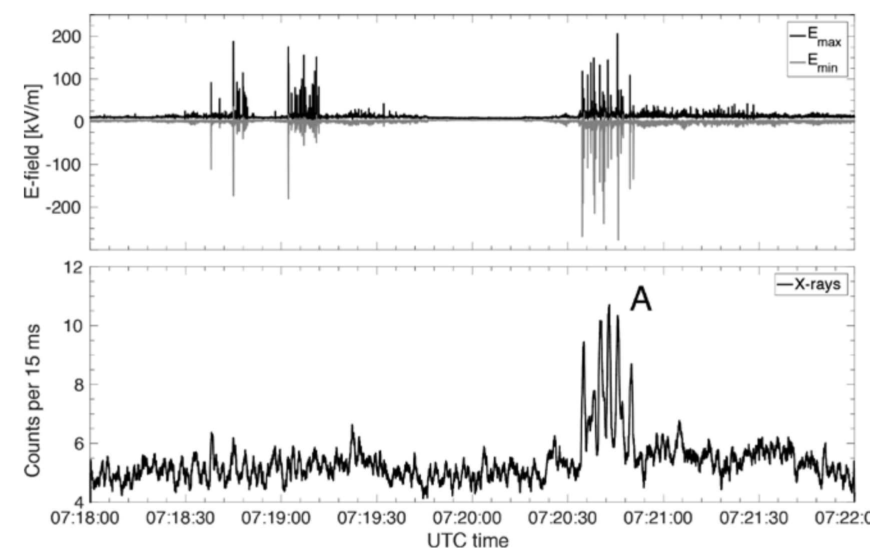
In addition to the activities related to ASIM, we also highlight four papers published by our group in 2018:

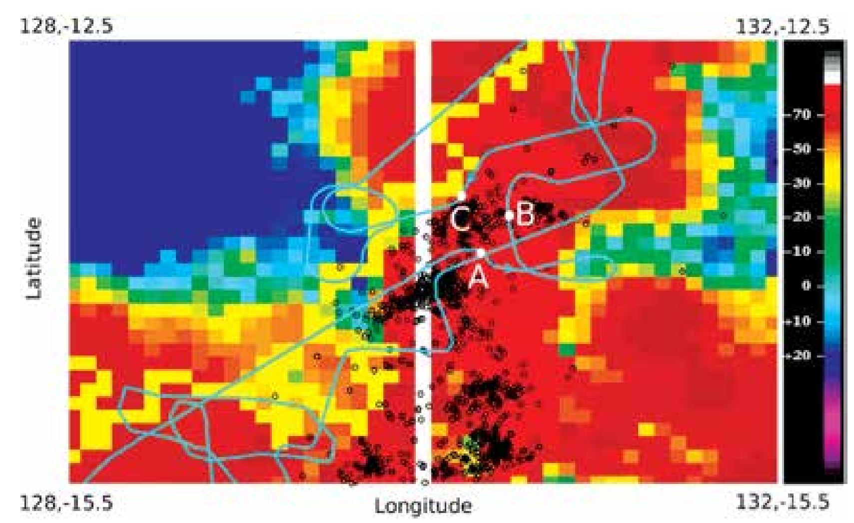
TGFs and gamma-ray glows are not the only high-energy atmospheric physics phenomena we observed so far. *Kochkin et al. (2018)* report, for the first time, gamma-ray enhancements of about one second duration observed by detectors onboard an aircraft (Figure 7). These bursts are closely associated to static discharges from the aircraft wings and exhibit a large fraction of 511 keV photons that can only be produced by a significant level of positron annihilation in the vicinity of the aircraft. These observations cannot be explained by any available model and strongly push for additional experimental and theoretical efforts in this direction.

Based on all the years of RHESSI data (~12 years), combined with World Wide

Figure 7a: Zoomed view of the electric fields and gamma- rays peaks with enhanced 511 keV lines during A *(Kochkin et al., 2018).*

Figure 7b: Flight trajectory (blue) over Australia. Gamma-ray glows were observed at A, B and C. Colorscale is degree Celsius from HIMAWARI-8 satellite. The red regions with t≤ −70° correspond to the Cloud Top Height ≥ 15 km. World Wide Lightning Location Network sferics are shown from moment A to C as black circles.





G4>

Brant Carlson
Researcher

Nikolai Lehtinen
Researcher

Andrey Mezentsev
Researcher

Pavlo Kochkin
Postdoc

David Sarria
Postdoc

Kjetil Albrechtsen
PhD Candidate

Anders Lindanger
PhD Candidate

Carolina Maiorana
PhD Candidate

Chris Alexander Skeie
PhD Candidate

Lightning Location Network (WWLLN) data, *Albrechtsen et al.*, found a large population of weak TGFs that cannot be found by even the most sophisticated search algorithms (Figure 8). A continuous distribution down to only 3 counts within a 250 microsecond bin was identified, giving a new ratio of TGF versus WWLLN of about 1%.

Sarria et al. compared three different Monte Carlo codes for modeling Relativistic Runaway Electron Avalanches (RREA). They found a good overall consistency between the three codes, but also provided advice and examples on how to properly set up the Geant4 in this context. Taking into account precise modeling of interactions below 10 keV (as suggested by *Skeltved et al., 2014*) produces only minor differences in the simulations results. Therefore, a threshold energy of 10 keV or more can be used, allowing for fast simulations.

Lehtinen et al. used a three-species fluid model of electric discharge in air to simulate streamer evolution from the avalanche-to-streamer transition to the collision of opposite-polarity streamers to explore whether such a mechanism could be responsible for the observed X-rays in laboratory experiments. They concluded that this fluid model is insufficient in explaining X-ray observations and discussed other possible mechanisms not included in this or previous modeling. How X-rays are produced in laboratory experiments is still a mystery.

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.

In June of 2018, two Master's students (Anders Lindanger and Chris Alexander Skeie) completed their dissertations; both started as PhD students within Group 4 in September. Two new Master's students (Ingrid Bjørge Engeland and Ragnar Landet) have also joined the group. ◊

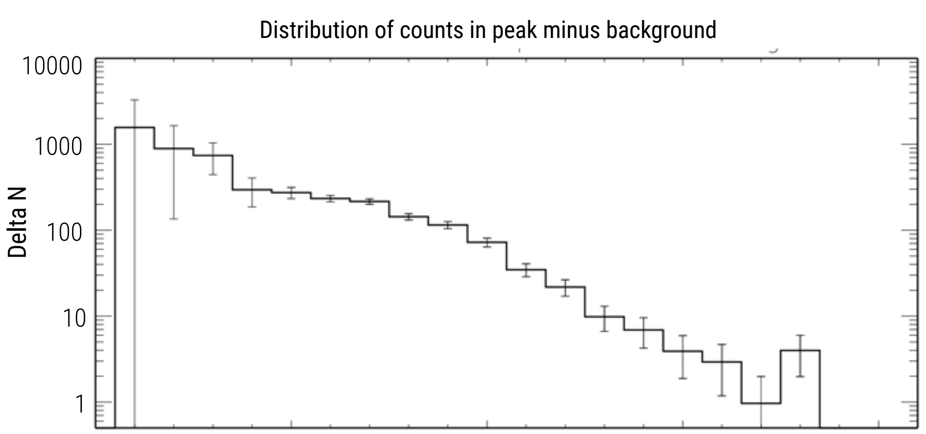


Figure 8: Distribution of very weak TGFs down to only three counts in 250 microsecod bin *(Albrechtsen et al., 2018).*

SI> Space instrumentation

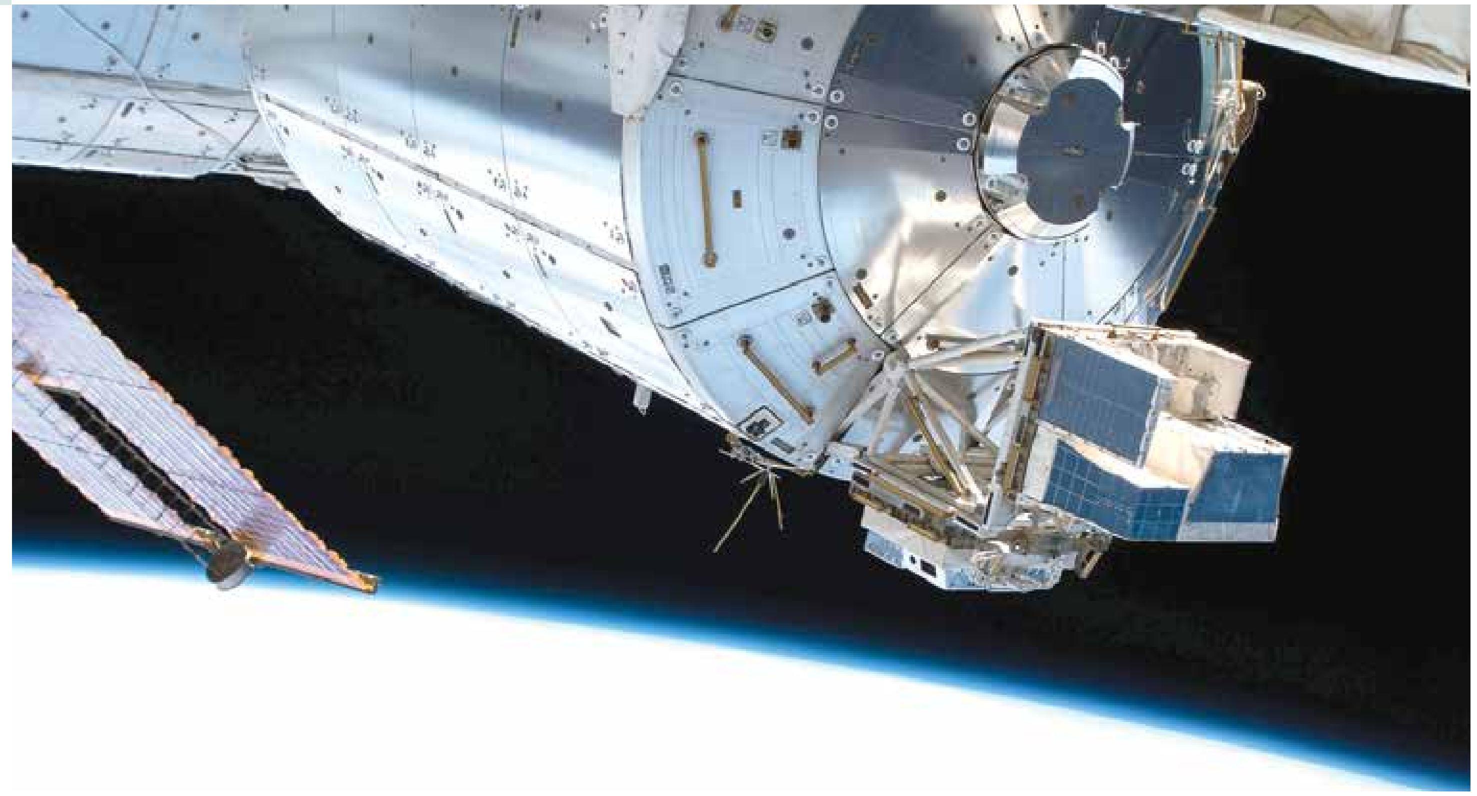


Figure 9: The ASIM instrument aboard the Columbus module of the International Space Station *(Courtesy: NASA)*

ASIM

Atmosphere-Space Interactions Monitor (ASIM) was launched by Elon Musk's SpaceX to the International Space Station (ISS) on April 2, 2018. This was a big milestone for the BCSS ASIM team, who attended the launch from Kennedy Space Centre, Florida. After the SpaceX payload arrived at ISS, the Canadian robotic arm took control and mounted the ASIM payload on the starboard side of the Columbus module. Eleven days later (April 13), the two ASIM instruments were switched on. The 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 UIB. MXGS detects 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, Denmark. MMIA has three photometers and two cameras to image and obtain spectral measurements of lightning and Transient Luminous Events.

After the successful switch-on of instruments, a two-month commissioning phase started. The purpose of this phase was to check that all parts were working and to also tune all the various settings of the instrument. This was an intense and hectic period, but by early June, ASIM was ready for full operation. MXGS was adjusted to have an acceptable background from all parts of the orbit and an acceptable number

SI>

< **Maja Elise Rostad, UiB**
Team Leader, Chief Engineer

Kjetil Ullaland, UiB
Professor

Georgi Genov
Senior Engineer

Shiming Yang
Senior Engineer

Torstein Frantzen
Chief Engineer

Jon Thøger Hagen
Chief Engineer

Thomas Poulianitis
Chief Engineer

Bilal Hasan Qureshi
Chief Engineer

of false triggers. After only a few days in operation, we could see that ASIM had unprecedented sensitivity and measured many very bright TGFs. At the AGU fall meeting in Washington, we could present both MMIA measurements and the results from the first half year of ASIM observations, which included at least three "ASIM firsts" (described in the G4 section of this Annual Report).

We hosted both an ASIM Science Data Centre (ASDC) meeting and an ASIM Science meeting in Bergen in 2018.

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), which will be adopted as an ESA mission in the spring of 2019. Launch is planned towards the end of 2023.

One of the instruments onboard SMILE is the Soft X-ray Imager (SXI) that will provide unprecedented images of the entry of plasma from the Sun into the Earth's magnetosphere, (Figure 10). The University of Leicester leads the SXI project, which is a collaboration between several European universities, research institutes, and industrial partners. SXI completed its System Requirement Review in September 2018, and preparations are now underway for the Preliminary 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 one MCU-based breadboard RSE, one FPGA-based elegant breadboard RSE, and one breadboard RSM. The latter two units were assembled in December 2018 and are currently being tested (Figures 11 and 12). In 2018 the project also resulted in one Master's thesis (Ove Lylund).

An initial contract with the ESA PRODEX office was signed in February 2018. In October 2018 the contract was amended to cover additional work packages in 2019 on the RSE and RSM engineering qualification models. A follow-up application will be submitted in 2019 to cover work from 2020 until launch. Our total involvement in SMILE will add up to around 29 MNOK, including in-kind assistance from UiB.

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 to determine 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 make it possible to determine the electron fluxes absorbed by the atmosphere, as well as the fluxes back-scattered from the atmosphere.

In 2018, while developing a breadboard prototype, we were granted financial support from the Norwegian Space Centre to increase the TRL of DEEP. At the end of 2019, we will be given an offer to launch a prototype of DEEP on ICI-5, one of 12 rockets that are part of the "Grand Challenge Initiative – Cusp" with Andøya Space Centre and University of Oslo as two of the partners. ◊

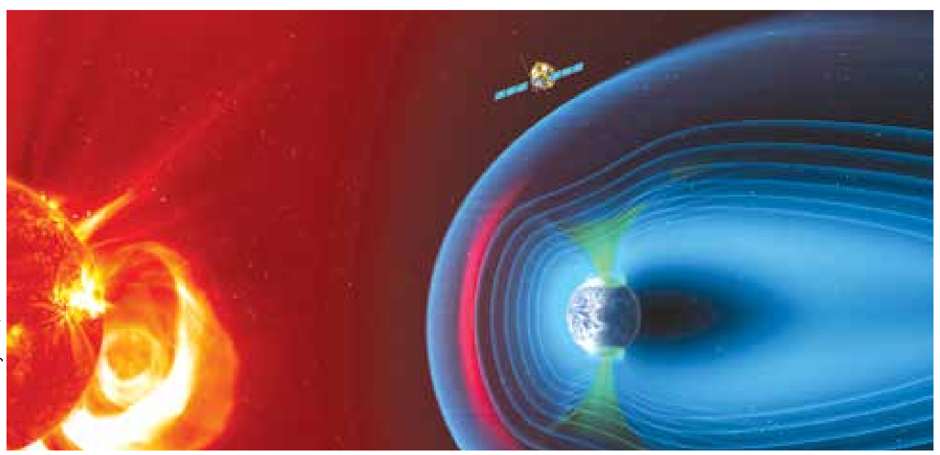
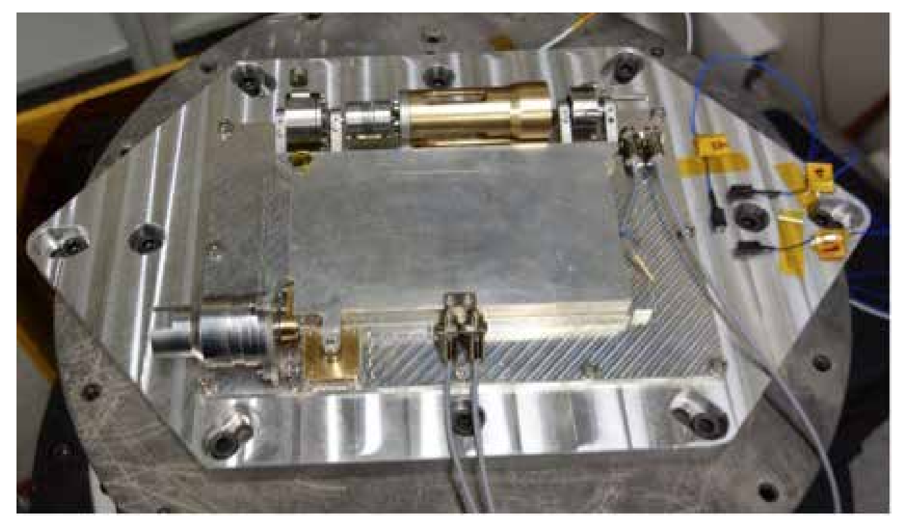


Illustration by ESA/ATG medialab

Figure 10: (Left) From its vantage point, Smile will observe the solar wind interaction with the magnetosphere, gathering simultaneous images and video of the dayside magnetopause.

Figure 11: (Below) Test set-up of the elegant breadboard model of the Radiation Shutter Electronics (RSE).

Figure 12: Breadboard model of the Radiation Shutter Mechanism (RSM) mounted on a jig ready for vibration testing.



G-BI> Ground-based instrumentation

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

KJELL HENRIKSEN OBSERVATORY

KHO has now operated successfully for 10 years and is the largest facility of its kind for optical instruments studying the aurora. The history of the observatory dates back to 1978 with the first station in Adventdalen. During the auroral winter season from November to the end of February, 26 optical instruments operate 24 hours a day. The 17 non-optical instruments run all-year-round 24 hours a day. 24 different institutions from 14 nations are present at KHO. Only 6 domes out of 30 are currently not in use.

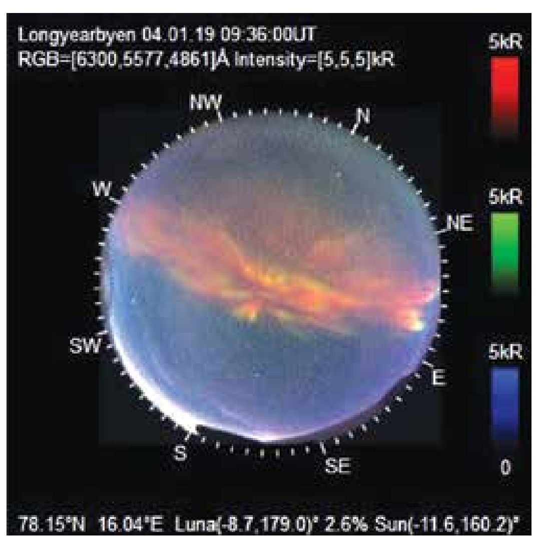


Figure 13: CAPER-2 target cusp aurora.

The observatory serves as the main laboratory for hands-on training and teaching 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 successfully defended a dissertation based only on KHO data.

Activity at KHO was high in 2018. Five sounding rockets were launched as part of the Grand Challenge Initiative (GCI). The first two rockets were launched from Ny-Ålesund on December 7, 2018. The NASA campaign was named VISualizing Ion Outflow via Neutral atom Sensing-2 (VISION-2). The following day two more rockets were launched from Andøya Space Centre (ASC). The Twin Rockets from the University of Iowa designed to investigate Cusp Electrodynamics-2 (TRICE-2) launched only 2 minutes apart. On January 4, 2019, the weather was clear over KHO, and the CAPER-2 (Cusp Alfven and Plasma Electrodynamics Rocket-2) launched from ASC by Dartmouth College, flew into perfect cusp conditions over Svalbard (Figure 13).

The target of the GCI sounding rockets is the dayside cusp aurora.

Three more instrumental groups have joined KHO in 2018. The Meridian Imaging Svalbard Spectrograph (MISS) is now in full operation. The Boreal Auroral Camera Constellation (BACC) continues to grow.

Our knowledge of spectroscopy is about to be space-borne through the project named HYPSO in cooperation with NTNU AMOS.

The Aurora Forecast 3D app has a 4.22/5 rating and has reached over 6109 active installs on Google Play for Android and

< **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

599 active users on iOS apple phones. The Facebook page for KHO has 1291 followers.

SVALBARD SUPERDARN HF RADAR

The SuperDARN HF radar at Breinosa is operated by the Space physics group at UNIS. Routine operations for the SuperDARN radar started in the late autumn of 2016, and the radar has been running successfully with 24 hours/day coverage up to October 2018.

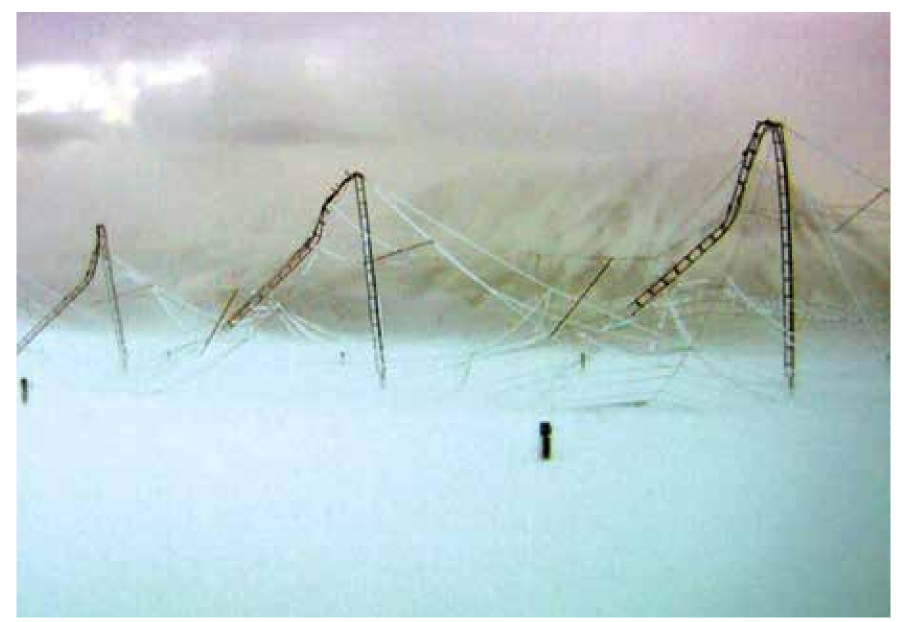
On October 23, 2018, an unfortunate incident occurred where all masts in both the main and interferometer array broke down due to high winds and ice loading. Having withstood two Svalbard winters, the masts were nevertheless brought down by combined icing and wind conditions (Figure 14). The space physics group at UNIS will rebuild the SuperDARN radar, and the planning for the new radar antenna system has already started. This includes the purchase of a new antenna, as well as ice and wind load calculations/modelling that will be conducted by an external company. A new type of mast will then be constructed based on the results from the ice and wind load calculations.

NTNU GROUND-BASED INSTRUMENTS

In addition to maintaining the long-term monitoring program with the meteor radar and optical instruments, NTNU staff has led a wide variety of projects using ground-based instrumentation in collaboration with international groups. The innovative collaboration with the Nordic Optical Telescope continues through the PhD project of Christoph Franzen. He has recently published a paper in the *Journal of Geophysical Research (JGR)* based on a series of observations made at the telescope last year. In this new paper, Franzen presents evidence of very small scale quasi-periodic structures in the OH airglow measured on scales of less than 100m. He demonstrates for the first time that in the Mesosphere and Lower Thermosphere (MLT) region, such small scale features satisfy a Kolmogorov type of energy cascade model of turbulence. Such observations of the OH layer in the MLT are only possible due to the very high spatial resolution spectroscopic observations afforded by the telescope.

The northern hemisphere chain of SuperDARN radars continues to be a fruitful source of new data for the group. Utilizing hourly mean horizontal winds derived from meteor ablation trails observed by a series of near-identical radars spread over a wide range of longitudes has provided

Figure 14: The Svalbard SuperDARN on the day of collapse: 23 October, 2018



G-BI>

the group with a number of recent projects on MLT dynamics that are not possible to conduct with single-station observations. Most recently, a paper on the variability of the semidiurnal tide during sudden stratospheric warmings (SSWs) has been submitted to *JGR*. Meteor winds from the radars are used to extract time series of the migrating and non-migrating components of the tide (only possible due to the wide longitudinal spread of the radars) for comparison with previous modelling studies on the modulation of the tide due to the changes in the underlying wind field associated with SSW events.

Data from NTNU's Skiymet momentum flux meteor radar and hydroxyl airglow temperatures and radiances derived from the co-located high resolution infrared spectrometer have been used in two Master's theses during 2018 and presented at six international conferences.

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 2018 this low-cost research infrastructure resulted in scientific publications on atmospheric gravity waves, traveling ionospheric disturbances, and severe disruption to navigation signals during a major geomagnetic storm.

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 is run by the University of Munich. The combined use of ASIM and LINET data is the focus of 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. ◊

Photo: Emma Bland

Figure 15: Students in the AGF-301 course at UNIS (Upper Polar Atmosphere)

EPO> Education and public outreach

The focus for the dissemination of BCSS research results is on publications in renowned international scientific journals and presentations at international scientific meetings and workshops. Outstanding results were achieved during the past year based on these criteria. In addition, a variety of highly successful efforts aimed at promoting BCSS science and achievements to students and the general public were carried out during 2018.

SUCCESSFUL ASIM LAUNCH

The Centre and its scientists were featured prominently in the media on several occasions during the past year. On April 2, the ASIM instrument was launched to the International Space Station on a SpaceX rocket (Figure 16) from Cape Canaveral, Florida. BCSS scientists who had been working on the ASIM project since 2004, were part of the Norwegian delegation eagerly awaiting the launch (Figure 17).

The ASIM project has generated a great deal of media interest throughout the world, resulting in more than 400 news items so far.

Photo: Gunnar Mæhlum, IDEAS

Figure 16: *(Above right)* A SpaceX rocket carrying the ASIM instrument in a Dragon capsule launches to ISS.

Figure 17: From left, UiB President Dag Rune Olsen, Centre Leader Nikolai Østgaard, BCSS Sr. Consultant Kavitha Østgaard, Sr. Manager at the Norwegian Space Centre Marianne Vinje Tantillo, Monica Ullaland and BCSS Prof. Kjetil Ullaland, and CEO at IDEAS Gunnar Mæhlum. Sitting: Sr. Engineer at BCSS, Georgi Genov.

EPO > Education and public outreach

Therese Jørgensen
Team Leader

Arve Aksnes, PhD
Advisor

Kjartan Olafsson
Assoc. Professor, Advisor

Kavitha Østgaard
Senior Consultant

THE ASYMMETRIC GEOSPACE

Another major media story to report relates to the great effort BCSS scientists have invested over several years in understanding the asymmetric geospace. Through the research published by *Østgaard et al. (2018)* and *Ohma et al. (2018)* (which continue a series of BCSS papers by *Tenfjord et al. ((2015, 2016, 2018), Reistad et al. (2016, 2018),* and *Laundal et al. (2018))*, BCSS scientists are now able to explain both how differences in southern and northern lights occur, and also how this asymmetry is removed. This has led to a joint press release issued by the American Geophysical Union on January 24, 2019, resulting in more than 100 news stories. Among these are an article from *The New York Times* entitled "The Northern and Southern Lights are Asymmetric Dancers in the Dark" (Figure 18) and a feature article in *Scientific American*.

To visualize the large-scale physics in our near-Earth neighborhood, an animaton entitled "An Introduction to Asymmetric Geospace" was developed by BCSS and uploaded to AGU's YouTube channel as part of the joint press release, resulting in more than 10,000 views during its first 3 weeks.

SCIENTIFIC AMERICAN

EARTH

Why Do the Nort
Southern Light

Scientists have discovered the culprit: how the sun

The New York Times

TRILOBITES

The Northern and Southern Lights Are Asymmetric Dancers in the Dark

Our planet's auroras do not mirror one another, and their varying shapes result from the interplay of the sun and Earth's magnetic fields.

Aurora borealis, the northern lights, seen near Rovaniemi, Finland, in October.

Figure 18: Media coverage of "Asymmetry" research findings

MMS WORKSHOP IN BERGEN

In June of 2018, BCSS/UiB hosted Norway's first MMS (Magnetospheric Multiscale Mission) Workshop (Figure 19). The scientific organizers of the workshop were Prof. Michael Hesse (BCSS) and Dr. Tai Phan (Space Science Laboratories, UC Berkeley).

The MMS Mission is a four-satellite team that was launched by NASA in 2015. MMS investigates how the Sun's and Earth's magnetic fields connect and disconnect, explosively transferring energy from one to the other in a process that is important at the Sun, other planets, and everywhere in the universe, known as magnetic reconnection.

Photo: Dr. Guan Le, NASA GSFC

Figure 19: Attendees of the MMS Workshop in Bergen

EPO>

BRINGING SPACE SCIENCE DIRECTLY TO THE PUBLIC

Throughout 2018, BCSS has participated in several public outreach events at the Bergen Science Centre, VilVite. For example, during the MMS Workshop, BCSS co-hosted a program with Prof. Patricia Reiff of Rice University, Texas who presented a planetarium show (Figures 20-22).

BCSS has also contributed to a VilVite learning program aimed at gifted youth. On two occasions during the Fall of 2018, BCSS provided lectures and learning activities for the young science talents, giving them insight into our near-Earth space.

During the annual Research Days 2018 in September, the BCSS stand generated much attention (Figure 23). ◊

Figure 20: *(Far left)* Dr. Pat Reiff of Rice University, Texas

Figure 21: *(Left, below)* Prof. Michael Hesse with a curious youngster at the VilVite exhibit

Figure 22: *(Left)* Space enthusiasts at the VilVite MMS exhibit

Figure 23: *(Below)* Assoc. Prof. Kjartan Olafsson oversees the building of a model at Research Days 2018.

Project Funding

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

European Space Agency | ASDC | Project nr: 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 nr: 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**
EU-MCSA SAINT | Grant nr: 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 KEURO**
Norwegian Research Council | FREPPIMA | Project nr: 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 nr: 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 KEURO**
Norwegian Research Council 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**
Norwegian Research Council 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**
European Research Council Advanced Grant | TGF Meppa | Grant Agreement Nr. 320839		
2013-2018	**Terrestrial Gamma Flashes–the Most Energetic Photon Phenomenon in our Atmosphere** A 5 year project to support TGF research. The project comprises both data analysis, modeling and experiments. The goal is to understand what processes are involved in the TGF production. The experiments were performed from space, balloons, aircraft and in the laboratory. The project was finished by March 2018.	P.I. Nikolai Østgaard 2.49 MEUR Additional 623 kEUR (25%) funding was given by the University of Bergen
Norwegian Research Council 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**

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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	-	-	6	4
Postdocs	10	7	1	2	7	3
PhD Candidates	14	11	1	2	10	4
Technicians	8	7	-	1	7	1
Administration	4	4	-	-	1	3
Master's Students	6	6	-	-	4	2
Sum	68	55	4	9	49	19

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*	UiB
	Erik Wahlström, *Head, Dept. of Physics*	NTNU
	Harald Ellingsen, *Managing Director*	UNIS
	Grete K. Ersland, *Head of Admin., IFT Board Secretary*	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
Kjartan Olafsson, *Assoc. Prof.*	M	UiB
Thomas Poulianitis, *Chief Eng.*	M	UiB
B.H. Qureshi, *Chief Eng. (Til 3/18)*	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
Steve 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
Stein Haaland	Researcher II	M	UiB
Spencer Mark Hatch	Postdoc	M	UiB
Pavlo Kochkin	Postdoc	M	UiB
Norah Kwagala	Researcher	F	UiB
Karl Magnus Laundal	Researcher	M	UiB
Nikolai Lehtinen	Researcher	M	UiB
Andrey Mezentsev	Researcher	M	UiB
Cecilia Norgren	Postdoc	F	UiB
Yvan Orsolini	Researcher II	M	UiB
Jone Petter Reistad	Postdoc	M	UiB
Marit Sandanger	Researcher	F	UiB
David Sarria	Postdoc	M	UiB
Christine Smith-Johnsen	Researcher	F	UiB
Kristian Snekvik	Postdoc	M	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
Christoph Franzen	PhD candidate	M	NTNU
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
Alexander Skeltved	PhD candidate	M	UiB
Susanne Flø Spinnangr	PhD candidate	F	UiB
Fasil Tesema	PhD candidate	M	UNIS
Wim van Caspel	PhD candidate	M	NTNU
Annet Eva Zawedde	PhD candidate	F	UiB

Major Achievements

December 2018	**New PhD:** Annet Eva Zawedde successfully defended her PhD thesis *(The Impact of Energetic Electron Precipitation on Mesospheric Hydroxyl Radical)*. Her research advisor was Dr. Hilde Nesse Tyssøy. **Rocket launch:** BCSS members helped launch several NASA rockets from Svalbard. Two VISIONS-2 rockets were launched from Ny-Ålesund and, on the following day, the same BCSS team helped with the launch of two TRICE-2 rockets from Andøya Space Center. **Award:** Group 3 Leader Dr. Hilde Nesse Tyssøy won the prestigious Fulbright Stipend. Dr. Nesse Tyssøy will spend four months in the US at the Univ. of Colorado, Boulder and the National Center for Atmospheric Research.
October 2018	**Recognition:** The 50th anniversary of the beginning of Norway's space exploration was celebrated in Tromsø. The anniversary celebrated the launch of ESRO-1A on October 3, 1968. Representatives from ESA, the Norwegian Space Centre, Andøya Space Center, the Kongsberg Satellite Services, and several others, including UiBs Profs. Finn Søraas *(Emer.)* and Kjellmar Oksavik, were present at the celebration.
September 2018	**Lecture:** Kjetil Ullaland, professor of microelectronics and technical lead of the ASIM instrument project at BCSS, gave a presentation at the Society for the Advancement of Science in Bergen (Selskapet til Vitenskapenes Fremme) on the events leading up to the launch of the instrument. **Instrument milestone:** The Soft X-ray Imager (SXI) instrument, which is part of the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) project in which BCSS is involved, passed the Instrument System Requirement Review.
August 2018	**New PhD:** Norah Kaggwa Kwagala successfully defended her thesis *(Thermally excited 630.0 nm emissions in the polar Ionosphere)*. Norah's PhD advisor was Prof. Kjellmar Oksavik. **TV interview:** TV2 interviewed BCSS leader Nikolai Østgaard on the outcome of the ASIM mission. Calling the mission "an unqualified success", Østgaard explained that the ASIM instrument on the International Space Station was functioning as hoped.
July 2018	**Video blog (vlog):** UiB President Dag Rune Olsen interviewed BCSS leader Nikolai Øsgaard as part of a series of vlogs. Østgaard discussed the value of basic research and what it takes to conduct world-class research.
June 2018	**Public outreach:** BCSS and VilVite were co-sponsors of an event that united space scientists and enthusiasts on the weekend of June 9. Among the planned activities was the presentation of Prof. Patricia Reiff's *(Rice Univ. Dept.of Physics & Astronomy, Houston, Texas)* planetarium show to wide-eyed spectators. **International meeting:** BCSS/UiB hosted Norway's first MMS Workshop in June. MMS (Magnetospheric Multiscale Mission) is an unmanned NASA space mission to study the Earth's magnetosphere, using four identical spacecraft flying in a tetrahedral formation. The scientific organizers of the workshop were Prof. Michael Hesse (BCSS) and Dr. Tai Phan (Space Science Laboratories, UC Berkeley, USA).
April 2018	**Installation of instrument:** The ASIM instrument was turned on after retrieval from the Dragon capsule and installation on the Columbus module on the International Space Station (ISS) as planned. **Launch:** The ASIM instrument was launched to ISS on a SpaceX rocket at GMT 20:30 (16:40 local time) from the Kennedy Space Center at Cape Canaveral, Florida. **Media coverage:** Over 400 news outlets around the world covered the launch of the SpaceX rocket bearing BCSS' ASIM instrument to ISS.
February 2018	**New PhD:** Alexander B. Skeltved successfully defended his PhD thesis *(Evaluating the production scenarios of terrestrial gamma-ray flashes)*. Alexander's advisor was Prof. Nikolai Østgaard.