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#### 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". Under this title we have formulated four main questions where we have identified fundamental gaps in our knowledge:

- 1. When and why is the aurora in the two hemispheres asymmetric?
- 2. How do we get beyond the static large-scale picture of the ionosphere?
- 3. What are the effects of particle precipitation on the atmospheric system?
- 4. What is the role of energetic particles from thunderstorms in geospace?

The BCSS is organized in four scientific groups focusing on each of these questions. In addition, we have two groups to design, build and operate state-of-the art instrumentation, one for space and one for ground-based instrumentation. We also have a group for education and public outreach.

Cover image: An illustration of the ASIM instrument on the Columbus module of the International Space Station



#### From the centre leader

This annual report covers the year 2017.

#### SCIENCE

The Birkeland Centre for Space Science had another productive year in 2017. The publication rate in peer-reviewed journals was high (38), we gave 19 invited talks and 86 contributed presentations at international meetings. As usual, we organized sessions at the two largest annual international meetings: EGU and AGU.

In the fall of 2017, Dr. Karl Magnus Laundal (co-leader of Group 1) won a bid to ESA to produce a new climatological model of the ionospheric current systems. More information on this model, which is the first model of its kind, can be found in the Group 1 section of this report. The model will be publicly available in 2018.

In October, Dr. Stein Haaland and co-editors (Andrei Runov and Colin Forsyth) published a volume of AGU monographs that is a comprehensive and updated overview of current knowledge about dawn-dusk asymmetries.

#### **NEW PROJECTS**

2017 also marked the kick-off of the SAINT project, which is a EU-funded Marie Skłodowska-Curie actions of which we are a part. SAINT is a European collaboration funding 15 PhD students to study atmospheric electricity and support the ASIM mission.

In October, the NRC-funded project – Full Range Energetic Particle Precipitation Impacting the Middle Atmosphere (FREP-PIMA) – started with Hilde Nesse Tyssøy as Pl.

#### AWARDS

Professor Kjellmar Oksavik was awarded the prestigious Fulbright Arctic Chair stipend for 2017 and visited Virginia Tech from August to December 2017.

On June 13, Professor Michael Hesse was honored by NASA for his "exemplary service to NASA leading Goddard Space Flight Center's Heliophysics Science Division" and commitment to space physics.

#### RECOGNITION

In recognition of our scientific achievements, the Centre leader was invited to the United Nations, Office of Outer Space Affairs to give a presentation to one of the Scientific and Technical Subcommittees (UNCOPUOS/STSC) in Vienna (January 2017) on the Norwegian contribution to SCOSTEP/

In March, Karl Magnus Laundal's results based on SWARM data were highlighted on ESA's homepage.

#### **INSTRUMENTS**

The ASIM project, in which we have been involved since 2004, received the final approval by ESA in 2017 and in November the payload was transported to Kennedy Space Center in Florida, USA. The launch to the International Space Station is scheduled for April 2, 2018.

In April-May, 2017, we flew a spare model of the high-energy gamma-ray detector for ASIM on one of NASA's ER-2 aircraft in order to detect gamma-rays from above the thunderclouds. This was the first time a dedicated campaign from this altitude (20 km) was carried out. The first results from this campaign were presented at the AGU December meeting.

The EISCAT\_3D (E3D) project was officially started with an opening event on 7 September, 2017. As BCSS has played an active role in making this project possible, we were represented by several key persons at this event.

The SMILE project is now rapidly progressing and funding for the first three years was secured through the ESA PRODEX program.

#### LEADERSHIP

Dr. Lisa Baddeley of BCSS will take on a new responsibility within the EISCAT community as the Norwegian representative to the EISCAT Science Oversight/Advisory Committee (SAC).

#### **Highlights**

#### **NEW POSITIONS**

From January 2017, Michael Hesse, previously Director of the Heliosphysics Division at NASA Goddard Space Flight Centre, ically evaluated, in the so-called midterm joined the BCSS as a professor.

From May 2017, Therese Jørgensen, previously Senior Head of the Geospace Section of the Atmospheric and Geospace Sciences Division at the National Science Foundation, USA, joined the BCSS as a Senior Advisor and started as the new leader of Group 2 changes other than the ones we had sugas well as the EPO group.

#### **EDUCATION**

Last year, 3 PhD students (Beate Krøvel Humberset, Xiangcai Chen and Paul Tenfjord) and 5 Master's students received their degrees.

#### MIDTERM EVALUATION

2017 was also the year when all the Centres of Excellence established in 2013 were critevaluation, to determine whether funding for the last 5 years (2018-2023) of the 10year Centre-period should be given. I am extremely pleased to report that we passed this evaluation with the highest possible score of "Exceptional". We were the only centre that was not guided to make any gested ourselves. The message was simply: keep up the good work.

#### THE FUTURE

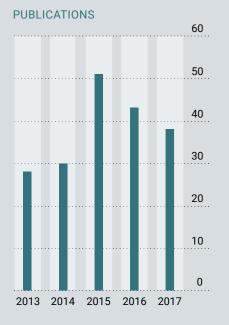
With the arrival of professor Michael Hesse, a renowned scientist in the theory and modelling of space plasma, we have a unique opportunity to build one of the strongest 
There is an exciting future ahead of us. modelling groups in Europe. We started this in 2017 and by summer 2018 we will have a separate modelling/theory group in BCSS. This is one of the cornerstones of the vision we laid out in the midterm evaluation for the next five years of the Centre. That is, we wish to develop our quantitative

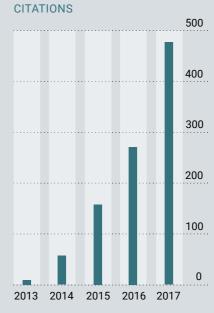
understanding of the system, which will enable accurate predictions of space phenomena. Our vision is also to branch out to neighbouring scientific disciplines, like particle physics and solar physics, as exemplified by our space-climate collaboration. This vision was very well received by the midterm evaluation committee whose own words best predict the future of BCSS (from

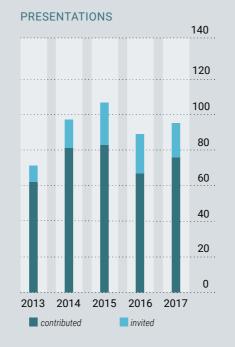
The Centre is likely to become an even stronger international player, with real cross-disciplinary activities and expertise covering the atmosphere, ionosphere, magnetosphere, particle physics and astrophysics from an experimental, analytical and modeling perspective.

Nikolai Østgaard, Leader of BCSS

#### Dissemination data







#### Instrumentation highlights

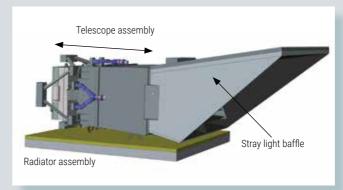


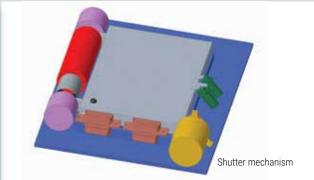


(Above) ASIM: In Florida, ready for launch



(Left) ALOFT: Picture of aircraft and instrument





(Above) SMILE project



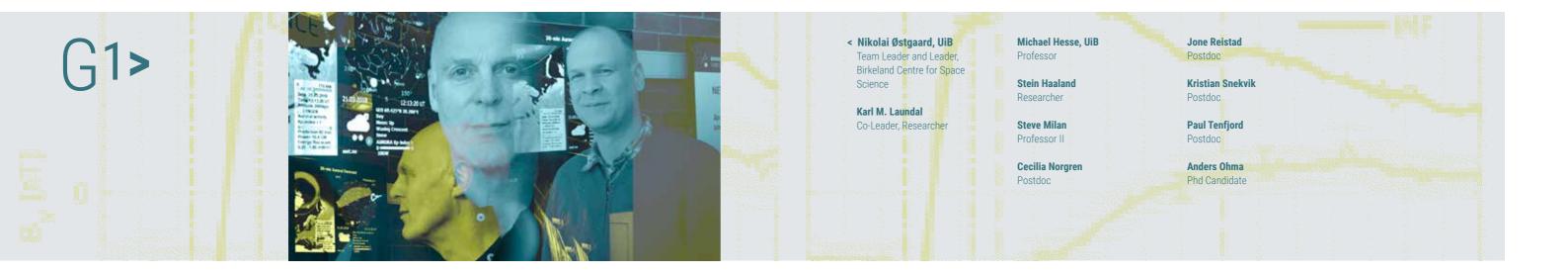
# G1> when and why is the aurora in the two hemispheres asymmetrical?

In the past few decades, several satellite observations have revealed that the Earth's magnetosphere tends to have an east-west magnetic disturbance in the same direction as the highly variable interplanetary magnetic field (IMF). Different mechanisms have been suggested to explain why this happens. Early works refer to "penetration", suggesting an immediate propagation from the IMF to the Earth's closed magnetic field lines. More recently, two ideas have emerged which, more realistically, involve finite propagation times: One idea, put forth in the 90's, implies that the travel time of the magnetic perturbation is the same as the travel time of the plasma from the interplanetary magnetic field to closed magnetic field lines. This would take about 1 hour or more. The other idea, described in detail by Tenfjord et al. (2015), is that magnetic energy is added to the magnetosphere asymmetrically, and that the asymmetric pressure distribution sets up asymmetric flows which bend the field lines. The predicted propagation time of this mechanism is just a few minutes.

In 2017, Group 1 researchers published two papers – which directly address the question of propagation time – showing that the magnetic perturbations propagate much faster than plasma travel times. *Tenfjord et al.* presented an observational study based on measurements of the magnetic field at geosynchronous orbit. Geosynchronous orbit is in the inner magnetosphere, and it takes typically more than 1 hour for solar

wind magnetic flux and plasma to reach this region. Nevertheless, the observations presented by *Tenfjord et al.* show clearly that effects of interplanetary magnetic field rotations are seen in only ~10 minutes (see *Figure 1*). The rapid response is followed by a longer period, of around 40 minutes, during which the magnetic field adapts to the new IMF orientation and stabilizes. This is a strong indication that the process described in the 2015 paper is of fundamental importance for how asymmetries are induced in the magnetosphere.

Snekvik et al. also addressed the time scales in geospace associated with changes in the solar wind and interplanetary magnetic field. They investigated the magnetic field perturbations in the ionosphere, measured at 800 km altitude by the fleet of 66 Iridium satellites. Using a sophisticated statistical technique, they show an initial response in the ionospheric magnetic field almost immediately following a change in the solar wind. This immediate response was observed globally, indicating that the signal travels quickly with a compressional wave. After the immediate response, the ionospheric magnetic field continues to reconfigure during 10-20 min. Snekvik et al. proposed that the reconfiguration is controlled by simultaneous changes in the outer magnetosphere as magnetic field lines are folded into the magnetotail on the nightside of the Earth.



The group has also contributed substantially to a book, called Earth's Magnetic Field: the Earth's Interior and its Environment, published by Springer in 2017 as part of a series from the International Space Science Institute in Bern, Switzerland. Karl Laundal is lead author on two review papers in this book on magnetic coordinates and the impact of north-south differences in Earth's magnetic field on geospace. Steve Milan is lead author on a review paper about solar wind-magnetosphere-ionosphere-atmosphere coupling and the generation of electric currents in the magnetosphere. Michael Hesse and Laundal also contributed to a paper by Eigil Friis-Christensen on magnetic disturbances during times, which are ostensibly "quiet".

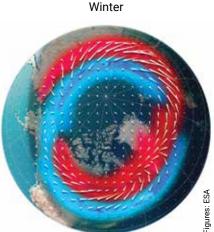
In the fall of 2017, the Birkeland Centre for Space Science won a bid to produce a new climatological model of the ionospheric current system, determined from magnetic measurements taken by the CHAMP and Swarm satellites (see Figure 2). The model is commissioned by the ESA Swarm Data, Innovation and Science Cluster (DISC), and will be published as a Swarm data product in 2018. The model will provide ionospheric current values at any location as continuous functions of solar wind speed, interplanetary magnetic field (IMF), dipole tilt angle, and the F10.7 solar flux index. It will be the first model of its kind to include the total horizontal ionospheric current system, without any assumptions or measurement other than of the magnetic field in space. The model will also allow for precise comparisons of the current systems in the two hemispheres. These new qualities are made possible by taking advantage of recent work by Karl Laundal and collaborators from the geomagnetism group at the Technical

University of Denmark. They demonstrated how to take into account irregularities in the Earth's magnetic field, which distort ionospheric currents differently in the two hemispheres and at different longitudes. Laundal presented early results of north-south comparisons at the 2017 Swarm science meeting in Banff, Canada, which were highlighted in an ESA press release during the meeting. He also gave two invited presentations about the model at the IAGA general assembly in August 2017.

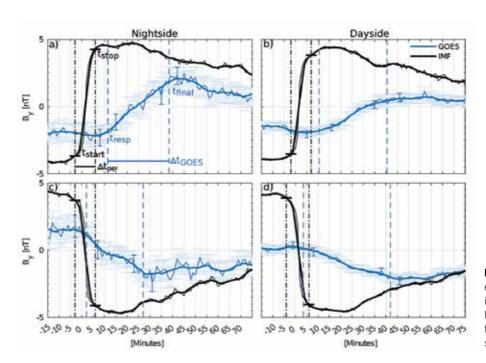
At the start of 2017, BCSS initiated a new research direction into collisionless magnetic reconnection. We pursued a number of topics in this general direction. Investigating the complexity of distribution functions just downstream of the reconnection X-line, we explained apparent two-component distributions by a combination of patching together of distributions from the two inflow regions, time-of-flight effects, parallel electric field acceleration, and finite Larmor radius effects. These results were published in Phys. Rev. Letters. Further published results include an investigation of the electron dynamics in reconnection with a moderate guide field, an investigation of electron heating, and a theoretical explanation and prediction of the structure of electron distributions in the inner electron diffusion region. New research initiatives involve the inclusion of cold oxygen, such as expected to originate from the ionosphere in the reconnection process, reconnection in high-beta plasmas in the magnetosheath, and a study addressing the role of the reconnection electric field in maintaining the current density and in powering a quasi-viscous heating process. We also revived earlier research activities based on large-scale MHD modeling. The two

directions here are targeting the structure of the guiet magnetosphere and the role of a number of magnetospheric features play in establishing north-south asymmetries in expected auroral features. Results from all of these studies were presented at a number of international scientific assemblies, including the AGU and EGU annual meetings. BCSS was also involved prominently in MMS science meetings, in the US-Japan workshop on magnetic reconnection, and in an international team at the International Space Science Institute in Bern, Switzerland. Finally, an outlook of the future of magnetospheric research was presented in the context of a memorial event honoring Kristian Birkeland at the Norwegian embassy in Tokyo. ◊





**Figure 2:** Snapshot of the global ionospheric current system, from a new climatological model produced at the BCSS. The model is based on magnetic field measurements in space, from the Swarm and CHAMP satellites, and it will be published as a Swarm data product in 2018.



**Figure 1:** *Tenfjord et al. (2017)*: A superposed epoch analysis of IMF By polarity changes and the induced By component at geosyncronous orbit. First response after 5-15 minute and final reconfiguration after 30-45 minutes, consistent with the scenario proposed by *Tenfjord et al.* (2015).

# how do we get beyond the large-scale picture of the ionosphere?



During 2017, researchers in the ionospheric dynamics group have contributed to ten papers in international, peer-reviewed journals on a wide variety of findings related to ionospheric dynamics and magnetosphere-ionosphere coupling.

Auroral structure and dynamics provide important information on small and mesoscale magnetosphere-ionosphere coupling. During the last year, researchers in Group 2 successfully completed several significant studies based on auroral observations. Assoc. Prof. Lisa Baddeley (Baddeley et al., 2017) together with colleagues from BCSS, USA, Russia, and China published a rare occurrence of a prolonged sequence of equatorward moving arc structures in the dusk-side auroral oval over Svalbard, which was captured in unprecedented detail. Simultaneous observations of the event were obtained from several optical instruments on the ground, from Incoherent Scatter Radar measurements, and from particle, magnetic field, and auroral emission instruments on board a low-altitude satellite passing overhead. The findings support the interpretation of the arcs as resulting from a resonant wave structure on the Earth magnetic field generated by a compressional wave propagating earthward from the magnetotail. The detailed analysis provides the first direct assessment of the energy loss suffered by the wave field due to both ionospheric heating and particle precipitation, something which will serve as important quantitative validation for theoretical models of magnetosphere-ionosphere coupling (Figure 3).

Dr. Xiangcai Chen successfully completed his PhD with this group last year. In his latest publication (Chen et al., 2017), which he produced together with colleagues from BCSS, UiO and China, a sequence of northsouth aligned arcs near local noon and equatorward of the pre-existing auroral oval boundary captured over Svalbard was carefully studied in relation to complementary observations of ionospheric convection and particle precipitation. This is an example of so-called throat aurora. The dynamic features of the movement, brightening, and dimming of the arcs were examined in unprecedented detail. The results support the interpretation that throat aurora is the signature of the fine-structure of the openclosed field-line boundary in the cusp region of the Earth magnetic field caused by modulations of the merging of the interplanetary and Earth magnetic fields during times when cold magnetospheric plasma is present at the magnetopause. The latter is a topic, which is currently attracting intense interest within the magnetospheric physics community and finding ionospheric signatures of this process, and thus, is immensely valuable (Figure 4).

Dr. Beate Krøvel Humberset also successfully completed her PhD with the group last year. In her latest publication (*Humberset et al.*, 2017), which she produced with colleagues from BCSS and JHU/APL in USA, she reported on a novel analysis of a high-resolution all-sky imager movie, which revealed scale-size dependent variability of the nightside aurora. The largest scale sizes are stable on timescales of minutes

while the small scale sizes are more variable. The result is remarkably similar to the spatiotemporal characteristics reported previously by BCSS researchers for the nightside field-aligned currents, suggesting that this behaviour is an inherent feature of the M-I coupling system.

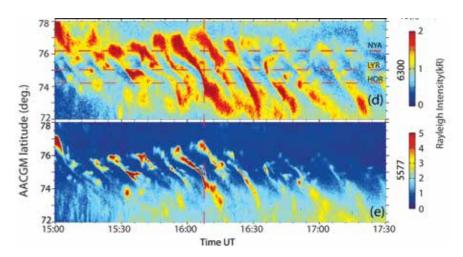
Continuing her research for the PhD, Norah Kwagala, together with colleagues at BCSS and UiT, published the first-ever statistical investigation of the contribution from thermally excited atomic oxygen emissions (630.0 nm red aurora), which confirms its importance in the dayside polar and cusp ionosphere (Kwagala et al., 2017). More than 400,000 measurements from the EISCAT Svalbard radar over a 15-year period (2000-2015) are included in the study. Strong thermal emission is found to be most likely around noon local time and associated with high electron temperatures and nominal electron densities, in agreement with theoretical predictions. However, strong thermal emission is also found to occur at lower temperature and slightly enhanced electron density. This surprising result seems to be related to enhanced neutral atomic oxygen density indicative of neutral upwelling, the confirmation of which makes an interesting subject for a future

Structuring of the ionospheric plasma observed both in density patches and enhanced flow channels in the polar cap is the other main topic of current interest for research in this group. A number of activities within this area were carried out over the last year. A Master's thesis that investigated a set of reversed flow events in the polar cap observed in the SuperDARN radars was successfully completed under

the supervision of Prof. Oksavik. As the recipient of the prestigious Fulbright Arctic Chair exchange grant, Prof. Oksavik continued his work on flow channel events in SuperDARN observations in collaboration with colleagues at Virginia Tech for 4.5 months during the 2017 fall term. The visit has already resulted in four papers in international peer-reviewed journals, eight presentations at international conferences, two invited guest lectures, and strengthening of the collaboration between BCSS and SuperDARN researches in the USA (Figure 5).

New experimental techniques have been developed in the group to better capture the details, dynamics, and global context of the flow channel and polar patch structures. As part of her PhD research at UNIS, Katie Herlingshaw has conceived a method for combining measurements from the EISCAT Svalbard incoherent scatter radar and the newly built Svalbard SuperDARN radar to investigate flow channels. By running the radars in specially designed synchronized

**Figure 3:** From *Baddeley et al.*, 2017: Auroral intensities in the (d) 630.0 nm and (e) 557.7 nm wavelengths as measured by the meridian scanning photometer (MSP).



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Jesper Gjerloev Professor II

**Lisa Baddeley** Associate Professor

Finn Søraas Prof. Emeritus

Pål Ellingsen Postdoc

**Beate Krøvel Humberset** 

**Katie Herlingshaw** Phd Candidate

Norah Kwagala

Figure 5: Prof. Kjellmar Oksavik received the prestigious Fulbright Arctic Chair exchange

patterns and having them study the flow channels simultaneously, she will be able to study the flow structures in more details than ever seen before. The first set of joint measurements was completed successfully with more planned for the future. Similarly, for the investigation of the dynamics of polar patches, Assoc. Prof. Baddeley designed and carried out a World Day experiment involving a large set of international radar systems and other instrumentation in the northern polar region.

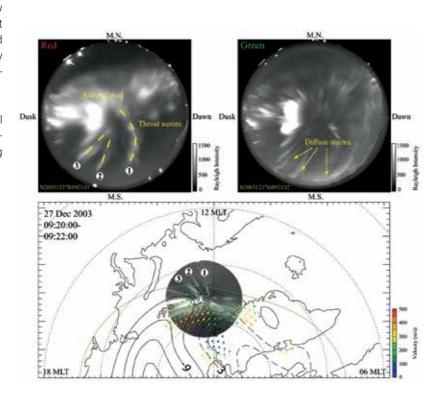
The SuperDARN system is our most important tool to monitor ionospheric convection globally. A new approach for deriving global convection maps from the SuperDARN measurements was developed by Prof. Jesper Gierloev in collaboration with colleagues in Australia and USA. The new model overcomes some of the inherent limitations in the existing approach and delivers vastly improved results, especially in capturing the dynamics of the convection systems.

International collaboration is an essential component in the successful scientific activities of the group. This is promoted, among

Figure 4: Chen et al., 2017: (top row) A snapshot of the throat aurora in the red and green lines observed by all-sky imagers. Magnetic north, south, west (dawn), and east (dusk) are marked on each image. (bottom) Simultaneous measurements of the dayside ionospheric plasma convection from SuperDARN in MLAT/MLT coordinates are presented (the Sun is to the top). The field of view of the red line aurora is overlaid, using an assumed emission altitude of 200 km and a cutoff at 80° zenith angle.

many international collaborative projects and attendance at meetings and workshops around the world. The scientists in the group are well renowned in the worldwide science community and receive many invitations to speak or organize special sessions. Research from the group contributed to more than 30 presentations worldwide, including more than ten invited talks, seminars, and guest lectures. The group was represented at more than 15 international conferences-including a strong presence at the main geophysics meetings of the field (EGU and AGU)-and also served in important roles at the SuperDARN, EISCAT, and SWARM science community meetings. •

other things, through the participation in



# G3>

## what are the effects of particle precipitation on the atmospheric system?

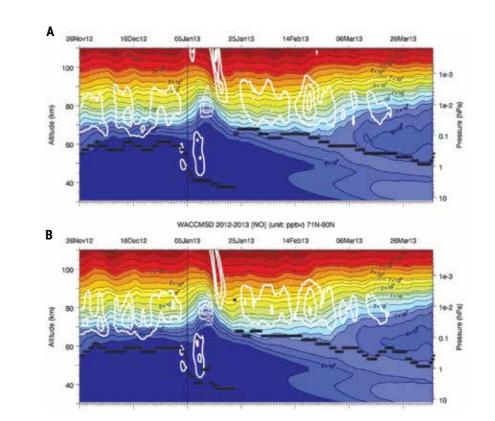
Figure 6: Orsolini et al. (2017) compares the nitric oxide (NO) in two WACCM simulations with Specified Dynamics during the January 2013 elevated stratopause event, using standard (Prandtl number 4) or enhanced eddy diffusion (Prandtl number 2). The thick black line is the approximate stratopause. Very little difference is seen between the two runs in the upper mesosphere, and comparison with satellite observations indicates that the descent of NO is still underestimated. The total wave forcing (white contours) indicates an important contribution from planetary waves in the upper mesosphere, just prior to the stratopause jump.

Precipitating electrons and protons deposit their energy at various altitudes throughout the lower thermosphere down to the stratosphere depending on their initial energy. The subsequent ionization, dissociation, and excitation initiate a series of chemical reactions, which increases the production of NOx and HOx gasses. In the absence of sunlight, for example during polar winter, the NOx-gas has a long lifetime and will be transported both horizontally and vertically by the background winds and waves. When reaching the lower mesosphere and stratosphere, NOx participates in a catalytic cycle of ozone destruction in the presence of sunlight. As ozone plays a key role in the

energy budget here, a good estimate of the particle energy input and its altitude distribution are crucial for determining the role of energetic particle precipitation (EPP) in affecting the temperature and dynamics. Hence, to unravel the effects of particle precipitation on the atmospheric system, we need to understand both the nature of the incoming particles, as well as the atmospheric dynamics. Group 3 brings together space and atmospheric scientists with the expertise needed to unravel the complex relationship between EPP and its atmospheric effects.

The dynamics of the winter polar mesosphere region is dominated by the polar vortex and the downwelling within, which transport NOx from upper mesosphere into the stratosphere, while upwelling prevails aloft. Transport of sufficient NOx from its mesosphere-lower thermosphere (MLT) reservoir into the stratosphere is a central feature of a chemistry-climate model that represents the EPP effect on stratospheric composition and dynamics. Orsolini et al. (2017) examined the sudden stratospheric warming (SSW) of January 2013. They showed that the downwelling initiates in the MLT following the stratopause reformation that is driven by planetary wave activity. They analyzed the transport of NO in WACCM and found that despite doubling the model eddy diffusion, the model underestimates the large descent of NO from the MLT compared to observations (Figure 6).

Identifying how deep the NO direct production penetrates during EEP events is an important issue, as it will affect the timing and strength of its indirect effect. NOAA's multiple POES satellites enable us to construct polar maps of the precipitating





electrons. By combining the low and high energy electron measurements, Smith-Johnsen et al. (2017) obtained a continuous energy spectrum ranging from 1 to 750 keV, which corresponds to atmospheric altitudes of 60-120 km. In the Antarctic fall of 2010, an event causing both low and high energy electrons precipitating into the atmosphere occurred. The energy deposition height profiles of the incoming electron fluxes was compared to NO number density observation where they found evidence of direct production of NO down to 60 km. The medium-energy electrons (>10 keV) also contribute significantly to the indirect effect at these altitudes (Figure 7).

Correlation

Figure 7: From Smith-Johnsen et

al. (2017): The correlation between

SOFIE measurements of NO (relative

change compared to climatology) and

estimates of accumulated NO based

during a geomagnetic storm period in

April 2010. (Only correlation with 95%

on POES electron measurements

significance is shown.)

The above case study was a geomagnetic storm driven by a combination of a Corotating Interaction Region (CIR) and two Coronal Mass Ejections. CIR storms are often associated with medium to relativistic electron precipitation despite weak geomagnetic signatures, and might be an underestimated source of EPP. Based on the superposed epoch analysis of 41 isolated weak to moderate CIR storms, Ødegaard et al. (2017) suggested the solar wind velocity and the corresponding electric field as candidates to single out storms that cause increased EEP (> 292 keV) deep into the mesosphere (Figure 8).

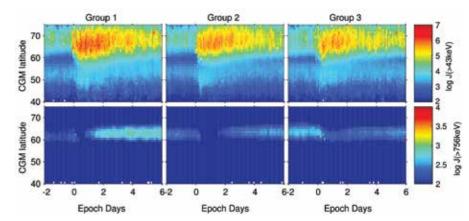
CIR storms are often associated with substorms and pulsating auroras. Recent event studies and modeling efforts on pulsating aurora conclude that the precipitation energy during these events is high enough to cause significant chemical changes in the mesosphere. Motivated by this, Partamies et al. (2017) investigated the bulk behavior of auroral pulsations. Based on about 400 pulsating aurora events, they showed that the auroral peak emission height decreases by about 8 km at the start of the pulsating aurora interval. This brings the hardest 10% of the electrons down to about 90 km altitude. The median duration of pulsating aurora is about 1.4 hour, which is a conservative estimate since in many cases the end of event is limited by sunrise or the aurora drifting out of the camera field of view. The longest durations of auroral pulsations are observed during events, which start within the substorm recovery phases. As a result, the geomagnetic indices are not able to describe pulsating aurora.

The application of atmospheric dynamics is not limited to the impacts of the

ionosphere on the neutral atmosphere. The table can be turned such that the expertise in Group 3 is relevant for Group 2: How can the ionospheric variability be driven by the dynamics of the neutral atmosphere? By using a longitudinal chain of ionosondes at high northern latitudes (520-650 N), Stray and Espy (2017) observed planetary wave-like structures in the peak electron density in the ionosphere. The observed wave activity in wave number one and two does not show any significant correlation with indices of geomagnetic activity, suggesting that this is not the primary driver. Further, the time delay between the motions of wave structures in the mesosphere and the ionosphere would indicate an indirect coupling mechanism.

During 2017, Group 3 has produced 11 publications. We have given more than 20 presentations at international conferences, two of which were invited talks. PhD student Christoph Franzen received the best presentation award at the Network for the Detection of Mesospheric Change meeting. Patrick Espy was the main convener of session Passive and Active Remote Sensing of the Chemistry and Dynamics of the Middle and Upper Atmosphere, at the 14th Annual meeting of the Asia Oceania Geosciences Society (AOGS). Hilde Nesse Tyssøy was a co-convener for the session "Energetic Particle Precipitation into the Atmosphere: Sources and Atmospheric Impacts" at the 2017 Joint IAPSO-IAMAS-IAGA Assembly.

The Group 3 UNIS node continues to be part of the science collaboration Chemical Aeronomy in the Mesosphere and Ozone in the Stratosphere (CHAMOS). Hilde Nesse



Tyssøy is co-leading the HEPPA-SOLARIS working group activity on "Medium Energy Electrons (MEE) Model measurement inter comparison", and is now also part of the HEPPA scientific organizing committee. In October, the NRC-funded project "Full Range Energetic Particle Precipitation Impacting the Middle Atmosphere" (FREPPIMA) started with Hilde Nesse Tyssøy as PI. 6

Figure 8: From Ødegaard et al. (2017): Superposed epoch analysis of 41 CIR/HSSWS storms from 2006 to 2010 divided into three groups based on the increase of precipitating relativistic electron fluxes. Ødegaard et al. (2017) propose the solar wind velocity and the corresponding electric field as candidates to single out storms that cause increased EEP (> 300 keV) deep into the mesosphere.

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# **G4>** what is the role of energetic particles from thunderstorms in geospace?



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 speeds and producing photons of energies up to several tens of Mega-electronvolts. more than ten times the maximum photon energy that is associated with natural radioactivity. In addition to electrons and photons, positrons and neutrons have also been observed in association with thunderstorms. All this energetic radiation is emitted at very different timescales, from the sub-milliseconds-long Terrestrial Gamma-ray Flashes (TGFs) to the minute-long Gamma-ray Glows. The emerging research field dedicated to the understanding of this variety of energetic phenomena and their impact on the surrounding environment definitely deserves the name of 'high-energy atmospheric physics', and is the core focus of BCSS Group 4.

Although there is a general consensus on the basic theoretical framework, several fundamental questions are still open: how much of the thundercloud energy is dissipated as high-energy radiation? Do these high-energy phenomena have any influence on atmospheric chemistry and dynamics? How common are TGFs and gamma-ray glows? The very definition of TGF is debated. Moreover, the observational scenario is hampered mostly by sparse observations: space observations have global coverage but are limited to bright transient events (TGFs), ground observations are limited to specific spots on Earth equipped with suitable instrumentation, and subject to peculiar thunderstorm characteristics, in situ observations by aircraft are still very rare, and experimental activities in a controlled laboratory environment cannot achieve the electric field and voltage conditions at play in thunderclouds. BCSS Group 4 addresses this complex scenario by means of a synergic approach including observations, theoretical modeling and experimental activities.

Here we want to highlight three papers published by our group in 2017:

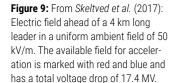
In order to accelerate electrons to relativistic energies, strong electric fields are needed. These can either be large-scale electric fields between main charge regions or they can be local fields created when lightning channels, called leaders, form. The latter was the focus of a modeling effort by *Skeltved et al.* (2017) (*Figure 9*). By modeling the potential at the tips of a conductive leader that forms in an extended uniform field between main charge regions, they estimated the electric field as well as the potential available for free electrons to be

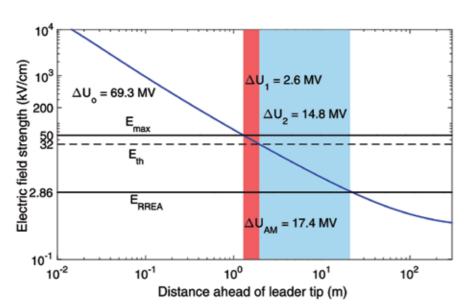
accelerated to relativistic energies. They carefully considered boundary conditions and assumptions in order to make them as realistic as possible. They also took into account that the very strong field close to the leader tip would not be available, as ionization would immediately lead to the formation of a large number of streamers in this region. Considering maximum length (6 km) and altitude of the upper leader tip (11 km) of a leader not attached to any of the charge regions, they found that less than 30 MV were available for acceleration of electrons. If they allowed for the positive end of the lower leader tip to develop inside the negative charge layer, 52 MV were available. This is not sufficient to account for the energies observed in TGFs, and further studies to explore the role of streamer region ahead of leaders are needed to resolve this.

Gamma-ray glows take place on a much longer time scale than TGFs but up to now, only sparse observations have been available, either from aircrafts or on the ground. Given the spatial extent of these phenomena (kilometers) and their duration (tens of seconds), it is important to assess how common they are, and how much energy is radiated. In the paper by Kochkin et al. (2017), we report on a gamma-ray glow observed onboard an Airbus A340 aircraft over Australia during a test flight within the ILDAS project. The glow exhibits a flux 20 times the normal background rate, and was abruptly terminated by a lightning flash. Observations are compatible with the scenario suggesting that the glow is produced in the high-electric field regions inside the thunderclouds.

Gjesteland et al. (2017) revisited the results from Østgaard et al. (2013), where simultaneous measurements of optical signals from lightning, terrestrial gamma-rays and radio were available (Figure 10). In this paper, one more of such a serendipitous event was presented. They concluded that with the limited time resolution of the various measurements we cannot resolve which of the processes, the optical flash or the production of gamma-rays, occurred first. The results underpin the need to have better time resolution for optical signatures from lightning.

The team was actively involved in the ALOFT aircraft campaign aimed at the validation of the lightning imager onboard the geostationary GOES-R satellite and the concurrent observation of energetic radiation from thunderstorms. BCSS was responsible for one of the two high-energy radiation detectors. During the campaign the NASA ER-2 aircraft cruised at an altitude of 20 km for about 70 flight hours over the continental USA, of which 45 hours were above active thunderstorms. Observation of thunderstorm radiation from such an altitude has never been performed before, and should lead to the best observational conditions for the detection of TGFs. Our ultimate goal was to contribute to the still open question: how many TGFs are there? Surprisingly, no TGF was detected, but, conversely, a few gamma-ray glows were observed for which the most extensive set of concurrent observations (onboard gamma-rays, optical and electric field measurements, ground-based lightning location with 3D capabilities) is available. Understanding the TGF non-detection, and the characterization of this gamma-ray glow, are some of the group's current main focuses (Figure 11). The





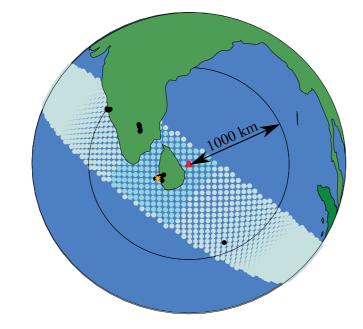
# Brant Carlson Researcher Nikolai Lehtinen Researcher Postdoc Andrey Mezentsev Postdoc David Sarria Postdoc Alexander Broberg Skeltved Phd Candidate

# **SI>** space instrumentation

team is also actively leading this effort by the organization of a dedicated workshop at UiB with our ALOFT partners from USA (University of Alabama at Huntsville, Naval Research Laboratory).

The team is also strongly committed to contributions to the Science Data Center for the ASIM mission, the first space experiment specifically designed for TGF science. ASIM is scheduled for launch and installation on the International Space Station in April 2018. For the Data Center, Group 4 will contribute with dedicated software for TGF identification and analysis, finalized to the commissioning and the scientific exploitation of the mission.

As in the past years, team members were actively involved as conveners of topical sessions, reference for the community, 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 17 presentations.



At the end of 2017, team member Alexander B. Skeltved finished his PhD on modeling of TGF production scenarios. David Sarria joined the team as Postdoc, and Carolina Maiorana started her PhD activity within the group under the auspices of the Marie Skłodowska-Curie Innovative Training Network SAINT. •

Figure 10: From *Gjesteland et al.* (2017): A map of the location of the TGF on 25 October 2012. The LIS orbits field of view in grey and the field of view at the time of the TGF in blue. The red triangle is the location of RHESSI. Black dots are WWLLN locations, and the asterisk is the location of the TGF.

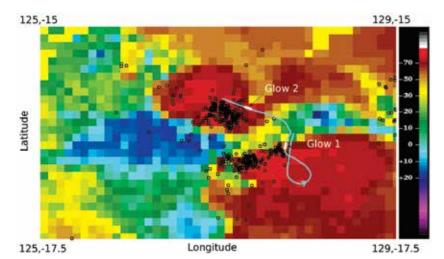


Figure 11: From Kochkin et al. (2017): Flight trajectory of Airbus (light blue) over thundercloud (temperature in color bars), with lightning activity marked with black squares. Glows were seen during the white regions.

The space instrumentation group is currently involved in four instrument projects: ASIM, ALOFT, SMILE and DEEP. In addition, we are part of the LINET network and operate one of their VLF receivers in Bergen.

#### A SIN

ASIM is a European Space Agency (ESA) mission to the International Space Station in which we have been involved since 2004. ASIM will measure optical (Transient Luminous Events: TLEs and lightning) and X -and gamma-ray emissions (Terrestrial Gamma-ray Flashes: TGFs). Our responsibility has been to develop the detector and readout electronics for MXGS (Figure 12), which consists of two X- and Gamma-ray detectors. The Low Energy Detector (LED) is a 1024 cm<sup>2</sup> pixelated detector of CZT (Cadmium Zink Telluride) with dedicated read-out electronics. LED will measure energies in the range of 20 keV up to 400 keV. With a coded mask, the LED (Figure 13) will enable imaging of the TGFs. The High Energy Detector (HED) is 900 cm<sup>2</sup> of BGO (Bismuth Germanate) crystals coupled to photomultiplier tubes with their dedicated read-out electronics. It extends the energy range up to 20 MeV.

MXGS was fully integrated on the CEPA platform (Figure 14) together with all other subsystems of ASIM in 2016. 2017 has mainly been devoted to approvals of the instrument and the final documentation packages. In February 2018, we received the excellent news that the ASIM PFM QAR was finalized. QAR is the Qualification Acceptance Review, which is the final approval of ASIM before launch. Launch is now scheduled for April 2, 2018.

ASIM is the largest project space instrumentation project ever undertaken by Norwegian academia.

The space instrumentation group will be involved in both the commissioning phase and support of the ASIM Science Data Center together with members of Group 4.

#### ALOF

The Airborne Lightning Observatory for FEGS and TGFs (ALOFT, where FEGS is Fly's Eye GLM Simulator) is a collaborative campaign with the University of Alabama in Huntsville with the main mission of calibrating the Global Lightning Monitor (GLM) which is flying on a geostationary satellite.

The BCSS contribution to ALOFT was to provide a spare BGO detector (225 cm²) from ASIM: UIB-BGO. New read-out electronics including power supply and a data processing unit was built for this instrument. UIB-BGO was mounted under the left wing of the ER-2 aircraft.

After a technical test flight in the fall 2016, two aircraft campaigns were carried out in April and May 2017. The first campaign was from the NASA Armstrong Flight Research Center in Palmdale, California, USA and the second campaign was from Warner Robins AFB in Georgia, USA. In the latter campaign, which included 16 flights with a total of about 70 flight hours at a cruise altitude of 20 km, 45 flight hours were over thunderstorm regions. These are the first observations ever of gamma-rays over thunderclouds at an altitude of 20 km.

The data from ALOFT are now being analyzed, and the first results, which include





< Maja Elise Rostad, UiB Team Leader

**Kjetil Ullaland, UiB** Professor **Georgi Genov** Senior Engineer

**Shiming Yang** Senior Engineer

**Thomas Bjørnsen** Chief Engineer **Torstein Frantzen**Chief Engineer

**Thomas Poulianitis**Chief Engineer

**Bilal Hasan Qureshi** Chief Engineer

unprecedented measurements of gamma-glows from 20 km, were presented at the AGU meeting in December 2017.

For future aircraft campaigns, probably in 2020, we plan to develop a new version of this instrument to fit inside the same thermally controlled box. The design of this version will be decided when the data from ALOFT have been analyzed, but a larger detector and faster electronics are probably part of such a design.



**Figure 13:** *(above)* ASIM: The integration of LED into MXGS FM

**Figure 14:** (*right*) The ASIM instrument mounted on CEPA. MXGS is on the right (silver cover), MMIA is on the left.

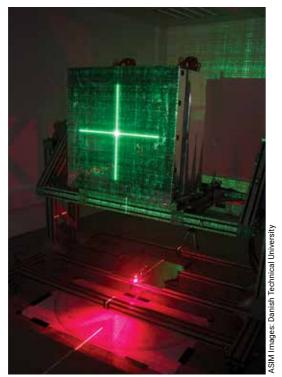
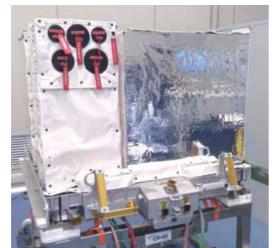


Figure 12: ASIM: The MXGS FM during calibration



#### SMILE

The Solar Wind Magnetosphere lonosphere Link Explorer (SMILE) mission is a joint mission between ESA and the Chinese Academy of Science (CAS). SMILE will investigate the interaction between the solar wind, the Earth's magnetosphere, and the ionosphere. The main instrument is a Soft X-ray Imager (SXI) which will provide unprecedented images of the entry of plasma from the Sun into the Earth's magnetosphere (Figure 15).

In 2016, we were invited to join the UK-led SXI team based on our experience and successful delivery of ASIM, our closely related expertise in ionosphere and magnetosphere physics, and our experience from the ESA Solar System Exploration Working Group (SSEWG). For SXI, we will deliver a mechanical Radiation Shutter door that protects the CCD camera against fatal exposure when the spacecraft traverses the Earth's radiation belts in each orbit.

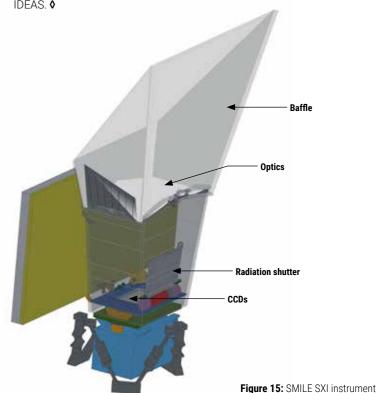
Launch is scheduled for 2021, and our involvement has a budget of around 16 MNOK, which is funded through the Norwegian ESA-PRODEX program.

#### DEEP

(Distribution of Energetic Electrons and Protons) Accurately quantifying the effect of energetic particle precipitation on the atmosphere requires a good estimate of the energy deposited in the atmosphere and understanding of how the energy is distributed globally. The design and/or orbits of the 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 not monitored by current satellites, but is essential to determine the particle loss to the atmosphere. We will design an electron-instrument consisting of three boxes, each including three detectors covering a field of view of more than 180°. This will give us information to determine the electron fluxes absorbed by the atmosphere, as well as the fluxes back-scattered from the atmosphere.

Our goal is to have this detector flying on one of the Norwegian micro-satellites or other small satellite initiatives. Silicon detectors have been developed at SINTEF. We are currently developing the read-out electronics for DEEP and are investigating possibilities of using pre-amplifiers from



## G-B|> ground-based instrumentation



< Fred Sigernes, UNIS
Team Leader

**Dag Lorentzen, UNIS**Professor & Co-leader

Robert Hibbins
Professor

**Mikko Syrjäsuo** Chief Engineer

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 Dragvoll campus in Trondheim. The Scintillation and Total Electron Content (TEC) network of BCSS is also included in the infrastructure. This section reports on the main activity in 2017.

#### KJELL HENRIKSEN OBSERVATORY-KHO

KHO has now operated successfully for ten 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, 25 optical

instruments operate 24 hours a day. The 15 non-optical instruments run all-year-round, 24 hours/day. 21 different institutions from 12 nations are represented at KHO. Only six domes out of 30 are currently not in use.

The observatory serves as the main laboratory for hands-on training and teaching of students in the space physics group at UNIS. Five courses have used it as part of field work, producing a grand total of 60 ECTS. One PhD student has graduated utilizing data from the KHO in his dissertation.

A large number of presentations, visits and interviews have been conducted at KHO. Visits from the local school in Longyearbyen and training of tourist guides have been popular activities. Two TV production teams visited us in December with focus on the Polar winter (NRK) and the Dayside aurora NHK (Nippon Hoso Kyokai) – Japan Broadcasting Corporation. The Aurora Forecast 3D app is rated as high as 4.2 and has reached over 12870 installs on Google Play for Android and 603 active users on iOS Apple phones. The Facebook page for KHO has 1190 followers.

The BACC (Boreal Aurora Camera Constellation) project is starting to grow, forming a constellation of low-cost, high-sensitivity all-sky color cameras monitoring the aurora oval at multiple sites. Two camera stations have already been tested at KHO (2015-2017) and in Ny-Ålesund (2016-2017) by UiO. Two new stations are under construction. These will be deployed by the Finnish Meteorological Institute (FMI) to Kevo and Muonio in northern Finland. The plan is to utilize existing auroral boreal infrastructure to create a constellation of cameras.

In cooperation with the Centre for Autonomous Marine Operations and Systems (AMOS) at NTNU, a Norwegian Centre of Excellence, a small, light weight, pushbroom Hyper Spectral Imager (HSI) has been constructed for drone operations. The next step is to design, develop and test a new prototype for CubeSat satellites aimed at detecting various oceanic targets.

KHO gives vital support and prepares for the Grand Challenge Initiative (GCI). Seven rockets will be launched into the cusp over Svalbard over the next 2-3 years. Groundbased data are essential for providing the Primary Investigators (PIs) with the right launch decision criteria.

#### SVALBARD SUPERDARN HE 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 with 24 hours/day coverage throughout 2017. The radar has performed very well in its first full year of operation, and has provided an extensive amount of good quality data.

The radar is a stereo radar, which means that it operates on two frequencies – or channels – simultaneously. It consists of a main antenna array, used to both send and receive, and an interferometer array, used for calculating the return-signal elevation angle. It has a 52 degree field of view looking North-East, with a typical range of more than 3000 km, thus covering a large portion of the Arctic Ocean. The radar is a part of a global network of similar radars, and data – apart from being stored locally – are streamed to two international servers

on a daily basis. One of these is located at the British Antarctic Survey (BAS) in Cambridge UK, and the other at Virginia Tech in Blacksburg, VA, USA. One of the main data products from the combined set of radars is global convection maps of the ionosphere.

#### NTNU GROUND-BASED INSTRUMENTS

The new generation of Skiymet momentum flux meteor radar based at NTNU has continued to monitor the temperature and dynamics of the MLT region over Trondheim. This instrument has provided key data for three journal articles on the descent of nitric oxide during the Elevated Stratopause Event of January 2013 (JASTP), a new high-altitude meteorological analysis system (JASTP), and a review paper on middle atmosphere dynamics (Surveys of Geophysics) (Figure 17). In addition, data from the radar have been used to illustrate key aspects of two chapters in a book on Infrasound Monitoring for Atmospheric Studies to be published by Springer. Two conference presentations at the ARISEII workshop in Prague and the European Geosciences Union annual meeting in Vienna have been based around results from the NTNU radar during 2017.

Hydroxyl airglow temperatures and radiances are also routinely monitored from NTNU's high resolution infrared spectrometer. Data on the diurnal variability of OH\* from this instrument have been presented at the 7th Network for the Detection of Mesospheric Change symposium in Grainau, Germany.

NTNU staff have been involved in a number of BCSS-related activities using other ground-based facilities, including long-term

**Figure 16:** The Sony A7S All-Sky camera at the KHO uses an extremely wide angle lens to capture the entire sky in one image.



# G-BI>

archive data from the global ionosonde and SuperDARN networks, as well as bespoke data from the Nordic Optical Telescope. This work has led to two additional publications in the journals Atmospheric Measurement Techniques and JASTP during 2017, and presentations at three conferences hosted by the Asia Oceania Geosciences Society, the European Geosciences Union and the Network for the Detection of Mesospheric Change.

#### GNSS RECEIVER NETWORK

BCSS operates four scintillation and total electron content receivers in Svalbard, which record signals from GPS, GLONASS and GALILEO. These receivers improve our affected by plasma irregularities and auroral Europe. activity in the Arctic ionosphere. GALILEO is now approaching full operational capability,

which has significantly improved the data coverage. In 2017, the satellite communication links at Hopen and Bjørnøya were also upgraded, which makes it easier to monitor the real-time data from the Norwegian mainland.

#### 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 Skłodowska Curie network with understanding of how navigation signals are 10 partners funding 15 PhD students in

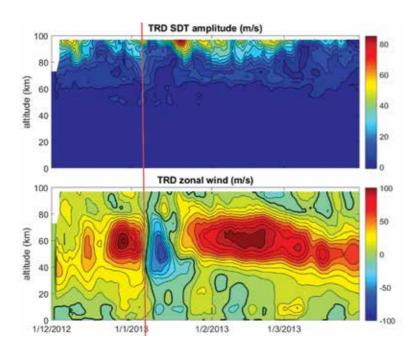


Figure 17: The evolution of the semidiurnal tide (upper panel) and zonal winds (lower panel) over Trondheim before, during and after the 2013 SSW derived from our radar merged with MERRA2 reanalysis data



# **EPO>** education and public outreach

Focus for the dissemination of research results from BCSS is on publications in well-renowned international scientific journals and presentations at international scientific meetings and workshops. Outstanding achievements in 2017 were defined based on both of 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 the past year.

The Centre and its scientists were featured prominently in the media on several occasions during the past year. Findings by BCSS researcher Dr. Laundal based on data from the Swarm satellite project was highlighted on the ESA website in March 2017. In June 2017, NASA announced that Prof. Michael Hesse was awarded the NASA Distinguished Service Medal, the highest honor bestowed by the agency (Figure 18). Also in June 2017, the United States Fullbright Program announced the selection of Prof. Kjellmar Oksavik as the 2017-2018 Fullbright Arctic Chair (Figure 4). The same month also saw the publication in Bergens Tidende of an article by Prof. Nikolai Østgaard on "Space Physics in Norway Today and the Heritage of Kristian Birkeland". An official opening of



Figure 18: Prof. Hesse (middle) receives the NASA Distinguished Service medal. On the left, Acting NASA Administrator Robert Lightfoot and on the right, Acting NASA Deputy Administrator Lesa Roe.

#### Therese Jørgensen

Team Leader

#### Arve Aksnes

AUVISUI

#### Kjartan Olafsson

Assoc. Professor, Advisor

#### Kavitha Østgaard

Senior Consultant

Auditorium

the EISCAT\_3D project held in Tromsø in September with the participation of several BCSS members was featured in local and international news coverage.

While most of the efforts in EPO are focused on creating and maintaining a strong media presence, we also acknowledge the value of engaging directly with people, not least for recruiting young students into the science fields. The Centre has a strong presence at the local Research Days in Bergen every year and is a major contributor to several of the activities (Figures 19-20). This was the case also for this year's event in September 2017. Several other individual events for school classes were hosted by BCSS scientists, including a poster session at the Institute for Physics and Technology at the UiB in December 2017, where thirty students from Langhaugen High School in Bergen presented their findings on how northern lights occur based on data they collected themselves and whether it is possible to use social media to chart occurrences of aurora.

In December 2017, students from Fusa High School attended a 1-day workshop at BCSS. They participated in lectures on lightning/ TGFs, spacecraft design and radioactivity experiments at UiB's Van de Graaf facility. The classes were taught by BCSS staff.



Figures 19-20: Phd candidate Anders Ohma (top) and postdoc Paul Tenfjord (bottom) give demonstrations to young space enthusiasts at Research Days.

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# EPO>

Many BCSS scientists contributed lec- on the Peaceful Uses of Outer Space week on Space Science at UiB that took PhD Research School: Development and Applications of Intelligent Detectors, collaboration.

Prof. Østgaard made a presentation on Norwegian and BCSS space science activ-

tures to the joint international lecture (COPUOS) (Figure 21). Since the beginning of the year, Prof. Hesse has served on place in September 2017 as part of the the European Space Weather Assessment and Consolidation Working Group, which forms part of the advisory structure of which is an ongoing German-Norwegian the European Science Foundation's Space Sciences Committee. In October 2017, Assoc. Prof. Baddeley was appointed to BCSS scientific expertise was called on serve as the Norwegian representative to as national and international representathe EISCAT Science Oversight/Advisory tives on committees on several occasions Committee. In November a group of scienduring the last year. In January 2017, at tist and engineers from BCSS participated the invitation of the SCOSTEP president, in an event at the Norwegian Space Centre where they presented two ideas for new small satellite space missions based on ities to the United Nations Committee instruments developed at BCSS. •



Figure 21: Prof. Nikolai Østgaard at the COPUOS meeting

## **Project Funding**

European Re	search Council Advanced Grant   Grant Agreement Nr. 320839	P.I. Nikolai Østgaard
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 will be performed from space, balloons, aircraft and in the laboratory.	2.49 MEUR Additional 623 kEUR (25%) funding was given by the University of Bergen
Atmosphere	-Space Interaction Monitor (ASIM)   ESTEC Contract Ref. 40000101107/10/NL/BJ   Terma-DTU Contract	t TER-SPACE-CON-DTU_SPACE-002_re
2010-2017	Phase C and D, sub-sub-contract between DTU Space and University of Bergen	P.I. Nikolai Østgaard
	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.	3,75 MEUR
Norwegian F	tesearch Council Program for Space Research   Project nr: 230956/F50	
2014-2017	The Norwegian Cluster studies A small project to support the Norwegian collaboration using Cluster data	P.I. Nikolai Østgaard 600 KNOK
Norwegian	Research Council Program for Space Research   Project: 255276/E10	
	SOLENA - Solar effects on natural climate variability in the North Atlantic and Arctic. Collaboration	P.I. Yvan Orsolini
		P.I. Yvan Orsolini 11,4 MNOK
2016-2019	<b>SOLENA</b> – 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	
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.  AINT   Grant nr: 722337 – SAINT (Science and Innovation with Thunderstorms)  SAINT – project with a multidisciplinary and inter-sectorial training platform for 15 ESRs. The platform	
2016-2019 EU-MCSA SA	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.  AINT   Grant nr: 722337 - SAINT (Science and Innovation with Thunderstorms)	11,4 MNOK
2016-2019 EU-MCSA S/ 2017-2020	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.  AINT   Grant nr: 722337 – SAINT (Science and Innovation with Thunderstorms)  SAINT – project with a multidisciplinary and inter-sectorial training platform for 15 ESRs. The platform	11,4 MNOK P.I. Nikolai Østgaard
2016-2019  EU-MCSA S/ 2017-2020  Norwegian F	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.  AINT   Grant nr: 722337 – SAINT (Science and Innovation with Thunderstorms)  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.	11,4 MNOK P.I. Nikolai Østgaard
2016-2019 EU-MCSA S/ 2017-2020	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.  AINT   Grant nr: 722337 – SAINT (Science and Innovation with Thunderstorms)  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.  Research Council   FREPPIMA   Project nr: 263008	11,4 MNOK  P.I. Nikolai Østgaard  268 KEURO
2016-2019  EU-MCSA SA 2017-2020  Norwegian F 2017-2020	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.  AINT   Grant nr: 722337 – SAINT (Science and Innovation with Thunderstorms)  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.  Research Council   FREPPIMA   Project nr: 263008	11,4 MNOK  P.I. Nikolai Østgaard 268 KEURO  P.I. Hilde Nesse Tyssøy
EU-MCSA S/ 2017-2020 Norwegian F 2017-2020	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.  AINT   Grant nr: 722337 – SAINT (Science and Innovation with Thunderstorms)  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.  Research Council   FREPPIMA   Project nr: 263008  Full Range Energetic Particle Precipitation Impacting the Middle Atmosphere	11,4 MNOK  P.I. Nikolai Østgaard 268 KEURO  P.I. Hilde Nesse Tyssøy

#### **Publications**

- 190) Kwagala N.K., K. Oksavik, D.A. Lorentzen, and M.G. Johnsen (2017) How often do thermally excited 630.0 nm emissions occur in the polar ionosphere?, J. Geophys. Res. Space Physics, 121, doi:10.1002/ 2017JA024744
- 189) Eastwood, J.P., R. Nakamura, L. Turc, L. Mejnertsen and M. Hesse (2017) The Scientific Foundations of Forecasting Magnetospheric Space Weather, Space Sci. Rev., doi:10.1007/s11214-017-0399-8
- 188) Tanskanen, E.I., K. Snekvik, J.A. Slavin, D. Pérez-Suárez, A. Viljanen, M.L., Goldstein, M.J. Käpylä, R. Hynönen, L.v.T., Häkkinen, K. Mursula (2017) Solar Cycle Occurrence of Alfvénic Fluctuations and Related Geo-Efficiency, J. Geophys. Res. Space Phys., doi: 10.1002/2017JA024385
- 187) Kochkin, P., A.P.J. van Deursen, M. Marisaldi, A. Ursi, A. I. de Boer, M. Bardet, C. Allasia, J.-F. Boissin, F. Flourens, N. Østgaard (2017) In-flight observation of gamma-ray glows by ILDAS, J. Geophys. Res., doi: 10.1002/2017JD027405, doi: 10.1002/2017JD027405
- 186) Stray, N.H., and P. J. Espy (2017) Planetary wave-like oscillations in the ionosphere retrieved with a longitudinal chain of ionosondes at high northern latitudes, J. Atmos. Sol. Terr. Phys., doi.org/10.1016/j. iastp.2017.10.011
- 185) Franzen, C., R.E. Hibbins, P. J. Espy, A.A. Djupvik (2017) Optimizing hydroxyl airglow retrievals from long-slit astronomical spectroscopic observations, *Atmos. Meas. Tech.*, 10, 3093–3101, https://doi. org/10.5194/amt-10-3093-201
- 184) Summers, D., Shi, R., Engebretson, M. J., **Oksavik, K.**, Manweiler, J. W., & Mitchell, D. G. (2017) Energetic proton spectra measured by the Van Allen Probes, *J. Geophys. Res.: Space Phys.*, 122, doi: 10.1002/2017.JA024484
- 183) Partamies, N., Weygand, J. M., and Juusola, L. (2017) Statistical study of auroral omega bands, Ann. Geophys., 35, 1069-1083,
- 182) Grandin, M., A. Kero, N. Partamies, D. McKay, D. Whiter, A. Kozlovsky, and Y. Miyoshi (2017) Observation of pulsating aurora signatures in cosmic noise absorption data, *Geophys. Res. Lett.*, 44, 5292–5300, doi:10.1002/2017GL073901
- 181) Oyama, S., A. Kero, C. J. Rodger, M. A. Clilverd, Y. Miyoshi, N. Partamies, E. Turunen, T. Raita, P. T. Verronen, and S. Saito (2017) Energetic electron precipitation and auroral morphology at the substorm recovery phase, J. Geophys. Res. Space Physics, 122, 6508–6527, doi:10.1002/2016JA023484
- 180) Søraas F., M. I. Sandanger, and C. Smith-Johnsen (2017) NOAA POES and MetOp particle observations during the 17 March 2013 storm, J. of Atm. and Solar-Terres. Phys., https://doi.org/10.1016/j.iastp.2017.09.004
- 179) Chen, L.-J., M. Hesse, et al. (2017), Electron diffusion region during magnetopause reconnection with an intermediate guide field: Magnetospheric multiscale observations, J. Geophys. Res. Space Phys., 122, 5235–5246. doi:10.1002/2017.JA024004
- 178) Wang, S., L.J. Chen, **M. Hesse**, et al. (2017), Parallel electron heating in the magnetospheric inflow region, *Geophys. Res. Lett.*, 44, 4384–4392, doi:10.1002/2017GL073404
- 177) Liu, Y.H., Hesse, M., Guo, F., Daughton, W., Li, H., Cassak, P.A. and Shay, M.A. (2017) Why does steady-state magnetic reconnection have a maximum local rate of order 0.1?, Phys. Rev. Lett. 118 (8), 085101, doi: 10.1103/PhysRevLett.118.085101
- 176) Friis-Christensen, E., C.C. Finlay, M. Hesse, K.M. Laundal (2017) Magnetic Field Perturbations from Currents in the Dark Polar Regions During Quiet Geomagnetic Conditions, Space Sci. Rev. 206 (1-4), 281-297, doi: 10.1007/s11214-017-0332-1

- 175) Hesse, M., L. J. Chen, Y.-H. Liu, N. Bessho, and J. L. Burch (2017) Population Mixing in Asymmetric Magnetic Reconnection with a Guide Field, Phys. Rev. Lett. 118, 145101, doi: https://doi.org/10.1103/Phys-RevLett.118.145101
- 174) N. Bessho, L.J. Chen, M. Hesse, S. Wang (2017) The effect of reconnection electric field on crescent and U-shaped distribution functions in asymmetric reconnection with no guide field, *Phys. Plasmas* 24 (7), 072903, doi: http://dx.doi.org/10.1063/1.498973
- 173) Jin, Y., J. Moen, K. Oksavik, A. Spicher, L. B. N. Clausen, and W. J. Miloch (2017), GPS scintillations associated with cusp dynamics and polar cap patches, J. Space Weather Space Clim., doi: 10.1051/ swsc/2017022
- 172) Gjesteland, T., N. Østgaard, P. Bitzer and H. J. Christian (2017) On the timing between terrestrial gamma ray flashes, radio atmospherics, and optical lightning emission, J. Geophys. Res. Space Phys., doi: 10.1002/2017.JA024285
- 171) Skeltved, A.B., N. Østgaard, A. Mezentsev, N. Lehtinen and B. Carlson (2017), Constraints to do realistic modeling of the electric field ahead of the tip of a lightning leader, J. Geophys. Res. Atmos., doi: 10.1002/2016.ID026206
- 170) Ursi, A., C. Guidorzi, **M. Marisaldi**, D. Sarria, F. Frontera (2017) Terrestrial gamma-ray flashes in the BeppoSAX data archive, *J. Atm. Solar-Terrest. Phys.*, doi:10.1016/j.jastp.2017.02.014
- 169) Smith-Johnsen, C., Tyssøy, H. N., Hendrickx, K., Orsolini, Y., Kumar, G. K., Ødegaard, L.-K. G., Sandanger, M. I., Stordal, F. and Megner, L. (2017) Direct and indirect electron precipitation effect on nitric oxide in the polar middle atmosphere, using a full range energy spectrum, accepted in J. Geophys. Res., doi:10.1002/2017JA024364
- 168) Partamies, N., D. Whiter, A. Kadokura, K. Kauristie, H. Nesse Tyssøy, S. Massetti, P. Stauning, and T. Raita (2017) Occurrence and average behaviour of pulsating aurora, accepted in J. Geophys. Res. Space Physics, doi: 10.1002/2017JA024039
- 167) H. Kim, M. R. Lessard, S. L. Jones, K. A. Lynch, P. A. Fernandes, A. L. Aruliah, M. J. Engebretson, J. I. Moen, K. Oksavik, A. G. Yahnin, and T. K. Yeoman (2017) Simultaneous Observations of Traveling Convection Vortices: Ionosphere-Thermosphere Coupling, J. Geophys. Res. Space Phys., 122, doi:10.1002/2017JA023904
- 166) L. J. Baddeley, D. A. Lorentzen, N. Partamies, W. Denig, V. A. Pilipenko, K. Oksavik, X. Chen, and Y. Zhang (2017) Equatorward Propagating Auroral Arcs Driven by ULF Wave Activity: Multipoint Ground and Space Based Observations in the Dusk Sector Auroral Oval, J. Geophysi. Res. Space Phys., 122, doi:10.1002/2016JA023427
- 165) Herland, E. V., Finlay, C. C., Olsen, N., Edvardsen, I., Nordgård-Hansen, E., Laundal, K. M., and Waag, T. I. (April 5, 2017) The CHAOS-X Model and Uncertainty Values for Magnetic Directional Surveying. J. Soc. Petrol. Eng. doi:10.2118/185895-MS
- 164) Sagi, K., K. Pérot, D. Murtagh, Y. Orsolini (2017) Two mechanisms of stratospheric ozone loss in the Northern Hemisphere, studied using data assimilation of Odin/SMR atmospheric observations, Atmos. Chem. Phys., 17, 1791-1803, doi:10.5194/acp-17-1791-2017
- 163) Snekvik, K., N. Østgaard, P. Tenfjord, J. P. Reistad, K.M. Laundal, S. E. Milan, and S. E. Haaland (2017) Dayside and nightside magnetic field responses at 780 km altitude to dayside reconnection, J. Geophys. Res. Space Phys., doi: 0.1002/2016JA023177
- 162) Yvan J. Orsolini, Varavut Limpasuvan, Kristell Pérot, Patrick Espy, Robert Hibbins, Stefan Lossow, Katarina Raaholt Larsson, Donal Murtagh (2017) Modelling the descent of nitric oxide during the elevated stratopause event of January 2013, J. Atm. Sol.-Terr.Phys., http://dx.doi.org/10.1016/j.jastp.2017.01.006

(continued on next page)

- 161) Ødegaard, L.-K. G., H. N. Tyssøy, F. Søraas, J. Stadsnes, and M. I. Sandanger (2017) Energetic electron precipitation in weak to moderate corotating interaction region-driven storms, J. Geophys. Res. Space Physics, 122, doi:10.1002/2016JA023096
- 160) Zhou, X., G. Haerendel, J. I. Moen, E. Trondsen, L. Clausen, R. J. Strangeway, B. Lybekk, and D. A. Lorentzen (2017) Shock-Aurora: Field-Aligned Discrete Structures Moving along the Dawnside Oval, J. Geophys. Res. Space Physics, 122, doi:10.1002/2016JA022666
- 159) Chen, X.-C., D.-S. Han, D. A. Lorentzen, K. Oksavik, J. I. Moen, and L. J. Baddeley (2017) Dynamic Properties of Throat Aurora Revealed by Simultaneous Ground and Satellite Observations, J. Geophys. Res. Space Physics, 122, doi:10.1002/2016JA023033
- 158) Dods, J., S. C. Chapman, J.W. Gjerloev (2017) Characterising the lonospheric Current Pattern Response to Southward and Northward IMF Turnings with Dynamical SuperMAG Correlation Networks, J. Geophys. Res., doi:10.1002/2016JA023686
- 157) Shore, R. M. Freeman, J. Wild, J. Gjerloev (2017) A high-resolution model of the external and induced magnetic field at the Earth's surface in the northern hemisphere, J. Geophys. Res. Space Phys., doi: 10.1002/2016JA023682
- 156) Humberset, B. K., J. W Gjerloev, M. Samara, R. G. Michell (2017) Scale Size-Dependent Characteristics of the Nightside Aurora, J. Geophys. Res. Space Physics, doi: 10.1002/2016JA023695
- 155) W. Longley , P. Reiff, J. Reistad, N. Østgaard (2017) "Magnetospheric Model Performance During Conjugate Aurora", Geophysical Monograph 222: Magnetosphere-Ionosphere Coupling in the Solar System, First Edition, Edited by C. R. Chapell, R. W. Schunk, P. M. Banks, J. L. Burch and R. M. Thorne, AGU, Published by John Wiley & Sons, Inc.
- 154) Haaland, S., B. Lybekk, L. Maes, K. Laundal, A. Pedersen, P. Tenfjord, A. Ohma, N. Østgaard, J. Reistad and K. Snekvik (2017), Northsouth asymmetries in cold plasma density in the magnetotail lobes: Cluster observations, J. Geophys. Res. Space. Phys., doi:10.1002/ 2016JA023404
- 153) Haaland, S., M. André, A. Eriksson, K. Li, H. Nilsson, L. Baddeley, C. Johnsen, L. Maes, B. Lybekk and A. Pedersen (2017) "Low-energy lon Outflow Observed by Cluster: Utilizing the Spacecraft Potential" in Magnetosphere-lonosphere Coupling in the Solar System, Editor(s): Charles R. Chappell, Robert W. Schunk, Peter M. Banks, James L. Burch, Richard M. Thorne, Geophysical Monograph Series, doi: 10.1002/9781119066880

## Personnel

Summary	TOTAL	UiB	NTNU	UNIS	MEN	WOMEN
Professors	10	6	2	2	10	0
Associate Professors	4	2	-	2	2	2
Professors Emeriti	2	2	-	-	2	-
Researchers	6	6	-	-	5	1
Postdocs	12	8	2	2	9	3
PhD Candidates	10	8	1	1	5	5
Technicians	8	7	-	1	7	1
Administration	4	4	-	-	1	3
Master's Students	7	3	2	2	5	2
Sum	63	46	7	10	46	17

#### Science Advisory Board (SAB)

Alan Rodger, Former Director of British Antarctic Survey	UK
Kristi Kauristie, PhD, Finnish Meteorological Institute	FIN
Hermann Opgenoorth, Professor, Uppsala University	SWE

#### **BCSS Team**

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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	UiB
	Board Secretary	

#### **Technical and Administrative Team**

Arve Aksnes, Advisor	М	UiB
Thomas Bjørnsen, Chief Eng.	М	UiB
Torstein Frantzen, Chief Eng.	М	UiB
Georgi Genov, Senior Eng.	М	UiB
Therese Jørgensen, Sr. Advisor	F	UiB
Kjartan Olafsson, Assoc. Prof.	М	UiB
Thomas Poulianitis, Chief Eng.	М	UiB
Bilal Hasan Qureshi, Chief Eng.	М	UiB
Maja Rostad, Chief Eng.	F	UiB
Mikko Syrjäsuo, Head Eng.	М	UNIS
Shiming Yang, Senior Eng.	М	UiB
Kavitha Østgaard, Sr. Consultant	F	UiB

#### Scientific Team

Lica Paddolov	Assoc. Professor	F	UNIS
Lisa Baddeley Patrick Espy	Professor	М	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
*	Assoc. Professor	M	
Kjartan Olafsson	Assoc. Professor	F	UiB
Noora Partamies			UNIS
Fred Signernes	Professor	M	UNIS
Johan Stadsnes	Professor Emeritus	M	UiB
Finn Søraas	Professor Emeritus	M	UiB
Kjetil Ullaland	Professor	М	UiB
Nikolai Østgaard	Professor	М	UiB
Stefan Bender	Postdoc	М	NTNU
Emma Bland	Postdoc	F	UNIS
Brant Carlson	Researcher II	М	UiB
Pål Ellingsen	Postdoc	М	UNIS
Kishore Kumar Grandhi	Postdoc	М	UiB
Stein Haaland	Researcher II	М	UiB
Pavlo Kochkin	Postdoc	М	UiB
Sven Olav Kühl	Postdoc	М	NTNU
Karl Laundal	Researcher	М	UiB
Nikolai Lehtinen	Researcher	М	UiB
Andrey Mezentsev	Postdoc	М	UiB
Cecilia Norgren	Postdoc	F	UiB
Yvan Orsolini	Researcher II	М	UiB
Jone Petter Reistad	Postdoc	М	UiB
Marit Sandanger	Postdoc	F	UiB
Kristian Snekvik	Postdoc	М	UiB
Paul Tenfjord	Postdoc	М	UiB
Hilde Nesse Tyssøy	Researcher	F	UiB
Kjetil Albrechtsen	PhD candidate	М	UiB
Christoph Franzen	PhD candidate	М	NTNU
Katie Herlingshaw	PhD candidate	F	UNIS
Beate Humberset	PhD candidate	F	UiB
Norah Kwagala	PhD candidate	F	UiB
Carolina Maiorana	Phd candidate	F	UiB
Anders Ohma	PhD candidate	М	UiB
Alexander Skeltved	PhD candidate	М	UiB
Paul Tenfjord	PhD candidate	М	UiB
Annet Eva Zawedde	PhD candidate	F	UiB
/ unice Eva Zavreade	The candidate		OID

## **Major Achievements**

November 2017	<b>Instrumentation</b> : The ASIM payload is transported to Kennedy Space Center in Florida, USA. The launch to the International Space Station is scheduled for April 2, 2018.
	<b>Evaluation:</b> BCSS passes its mid-term evaluation by NRC (the Norwegian Research Council) with a an overall assessment of "exceptional". The Centre is to be funded for an additional five years.
October 2017	<b>New Phd:</b> Beate Krøvel Humberset successfully defends her PhD thesis "Scale size-dependent characteristics of the magneto-sphere-ionosphere system using auroral imaging".
	<b>Publication:</b> Stein Haaland and co-editors (Andrei Runov and Colin Forsyth) publish a volume of AGU monographs that is a comprehensive and updated overview of current knowledge about dawn-dusk asymmetries.
September 2017	<b>Opening:</b> The EISCAT_3D (E3D) project officially starts with an opening event on September 7, 2017. Several key BCSS members attend the ceremony, as the Centre has played an active role in making EISCAT_3D possible.
	<b>Research grant:</b> Karl Magnus Laundal wins a bid to ESA to produce a new climatological model of the ionospheric current systems. The model will be publicly available in 2018.
	<b>New role:</b> Assoc. Prof. Lisa Baddeley of BCSS takes on a new responsibility within the EISCAT community as the Norwegian representative to the EISCAT Science Oversight/Advisory Committee (SAC).
August 2017	<b>Award:</b> Prof. Kjellmar Oksavik visits Virginia Tech from August to December on the prestigious Fulbright Arctic Chair stipend for 2017.
June 2017	New Phd: Paul Tenfjord successfully defends his PhD thesis "Solar wind energy transfer and the asymmetric geospace"
	Award: Prof. Michael Hesse is honored by NASA for his "exemplary service to NASA leading Goddard Space Flight Center's Heliophysics Science Division" and commitment to space physics.
April - May 2017	<b>Campaign:</b> A spare model of the high-energy gamma-ray detector for ASIM is flown on one of NASA's ER-2 aircraft in order to detect gamma-rays from above thunderclouds. This is the first time a dedicated campaign from this altitude (20 km) has been carried out.
March 2017	Outreach: Dr. Karl Magnus Laundal's results based on SWARM data are highlighted on ESA's homepage.
February 2017	<b>New Phd:</b> Xiangcai Chen successfully defends his PhD thesis "A study of dayside open/closed field line boundary dynamics using simultaneous ground-based optical and HF radar observations".
January 2017	Special Invitation: In recognition of the scientific achievements of BCSS, the Centre leader Prof. Nikolai Østgaard is invited to the United Nations Office of Outer Space Affairs, Vienna to give a presentation to one of the Scientific and Technical Subcommittees (UNCOPUOS/STSC) on the Norwegian contribution to SCOSTEP/VarSITI.

