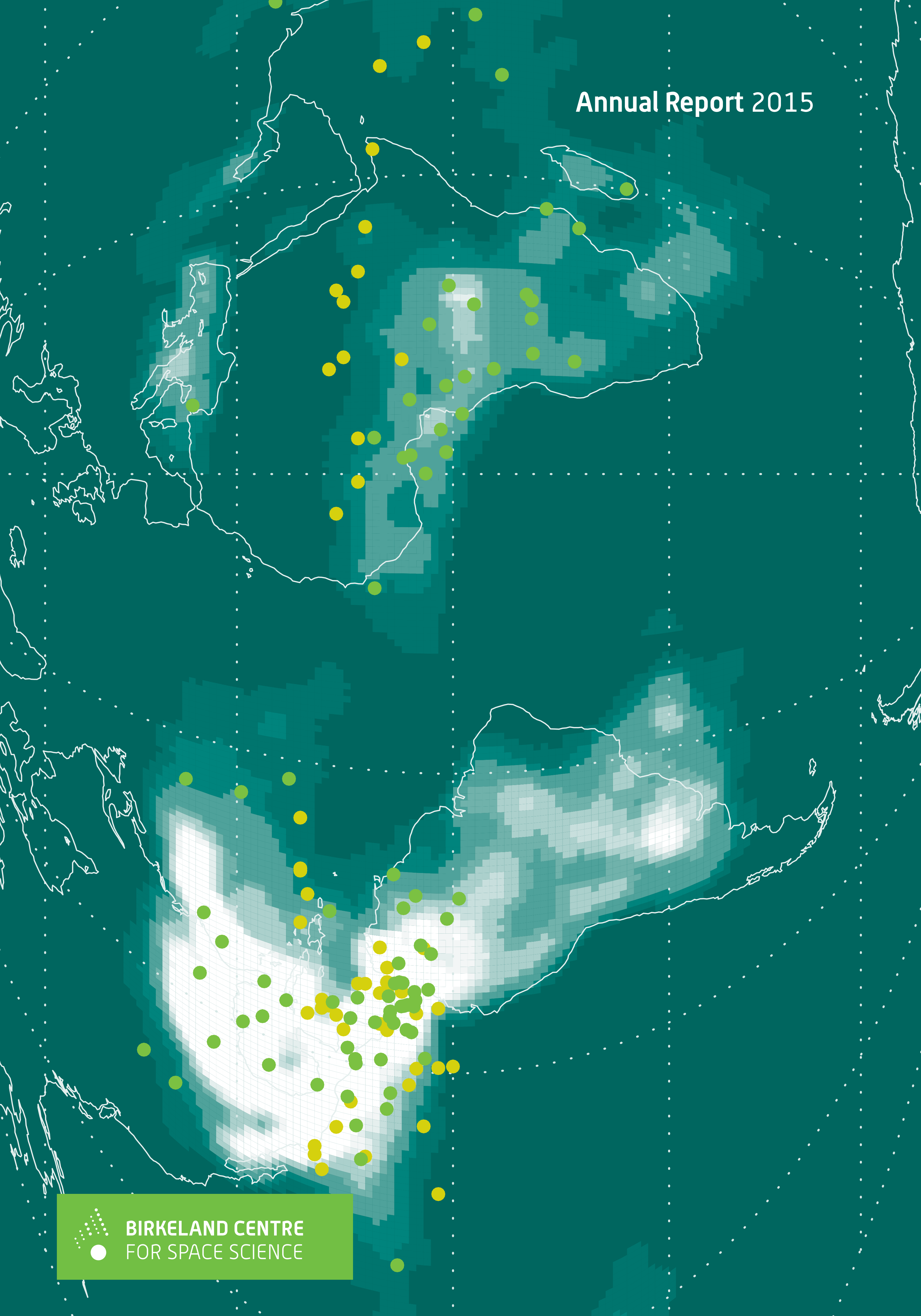
# Annual Report 2015



BIRKELAND CENTRE
FOR SPACE SCIENCE

# From the Centre Leader

**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 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:**

**Q1. When and why is the aurora in the two hemispheres asymmetric?**
**Q2. How do we get beyond the static large-scale picture of the ionosphere?**
**Q3. What are the effects of particle precipitation on the atmospheric system?**
**Q4. What is the role of energetic particles from thunderstorms in geospace?**

**The BCSS is organized in scientific groups focusing on these four 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 that is responsible for our visual identity.**

This annual report covers March 2015 until December 2015.

The summer of 2015 was an intense period for the ASIM project. Repairs and environmental tests were performed at various places all over Europe (Spain, UK and Denmark) and during the fall, our contribution to the MXGS instrument, the Low- and High-Energy Detectors were successfully integrated at INTA in Spain.

The SuperDARN radar on Svalbard was finalized in October 2015 and is now in operation.

In June 2015 the EISCAT_3D project was funded with 288 MNOK from the Research Council of Norway (RCN). The University of Tromsø is the host institution for the Norwegian proposal, and BCSS has contributed substantially to its success.

At the end of the year, we became involved in a new satellite project, SMILE, which is a collaboration between the European Space Agency and the Chinese Academy of Science.

Two new projects received funding in 2015. An ESA-funded project for SWARM and SuperMAG, with Jesper Gjerløv as Principal Investigator, and SOLENA. The latter is a collaboration between the Bjerknes Center for Climate Research, the Dept. of Geosciences, University of Oslo, Geophysical Institute, University of Bergen and BCSS, with Yvan Orsolini (BCSS and NILU) as Principal Investigator. SOLENA is funded by RCN.

This year we can report a record-high publication rate, 51 publications in peer-reviewed journals. Highlights are: *Han et al.* (2015), which was featured on the front cover of *Journal of Geophysical Research*. *Dods et al.* (2015) was highlighted in *Science Newsline,* reporting that SuperMAG magnetometers are a social network talking to each other through vectors. *Tenfjord et al.* (2015) is another highlight, which marks a milestone for our understanding of the dynamics of the interaction between solar wind-magnetosphere-ionosphere. At the end of the year, we reported that there are even more terrestrial gamma-ray flashes in existing data than formerly thought (*Østgaard et al., 2015*).

Also in 2015, BCSS was highly present at all the important international meetings, organizing sessions and giving 106 presentations, of which 24 were invited talks.

PhD student Christer van der Meeren won the EGU Outstanding Student Poster award in April 2015. Martino Marisaldi was awarded a Fulbright research stipend at Duke University in North Carolina. Annet E. Zawedde was awarded the Martin Landrøs Prize for outstanding master's thesis. Twelve master's students graduated.

During the solar eclipse in March 2015, the UNIS team contributed with instruments and expertise to a live broadcast that was aired all over the world.

I would like to thank all members of the Birkeland Centre for Space Science for making 2015 a successful year.

Nikolai Østgaard,
Leader of BCSS

# Q1 When and why is the aurora in the two hemispheres asymmetric?

**The mechanisms producing the aurora are closely linked with the Birkeland currents, electric currents that flow along magnetic field lines. Birkeland currents flowing upward are largely carried by downward electrons, which can also excite auroral emissions if their energy is high enough. Interhemispheric asymmetries in Birkeland currents have been proposed as explanations for observations of differences in the auroras in two hemispheres *(Laundal and Østgaard, 2009; Reistad et al., 2013)*. For this reason, the Q1 group is currently working to understand asymmetric Birkeland currents and convection patterns.**

**Prof. Nikolai Østgaard, UiB**
Team Leader and
Leader, Birkeland Centre for Space Science

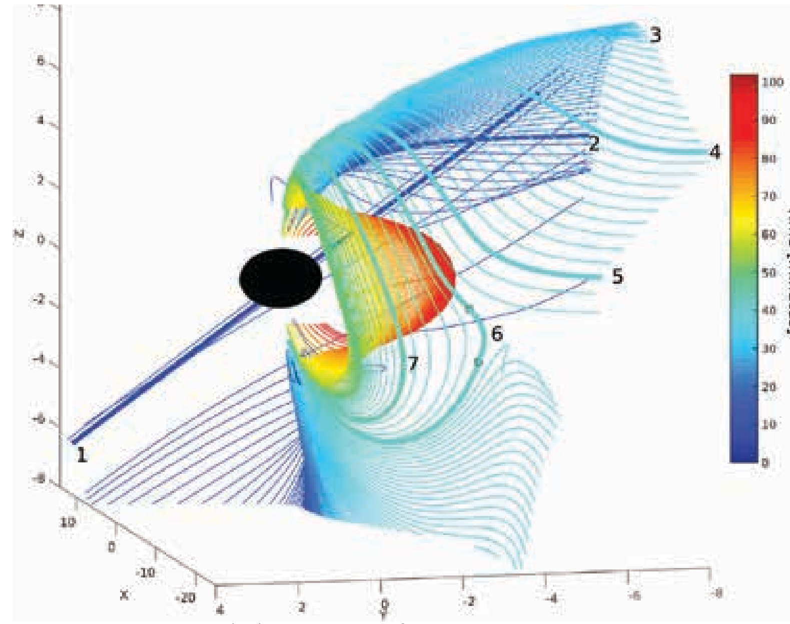
The highly variable orientation of the interplanetary magnetic field (IMF) strongly affects the geometry of the magnetosphere. A particularly well-known and much-studied phenomenon is the effect of a *y*-component in the IMF, a component in the direction perpendicular to the Sun-Earth line and the terrestrial magnetic field lines on low latitudes. A *y*-component in the IMF has been observed to induce a *y*-component in the magnetosphere, and it shifts the footpoints of magnetic field lines such that the aurora appears shifted. The *y*-component also leads to hemispheric asymmetries in plasma convection and currents in the ionosphere. This phenomenon has long been referred to as "$B_y$ penetration", a term which describes the observations, but is misleading in terms of the underlying mechanism. The actual mechanisms have not been well understood so far.

*Tenfjord et al.* (2015) address this phenomenon with theory, numerical simulations and observations, in order to provide new understanding of how the IMF $B_y$ induces a *y*-component on closed magnetospheric field lines (Figure 1). They find that the *y*-component leads to an asymmetry in the pressure distribution in the magnetosphere, and that this asymmetry produces the observed asymmetries in convection patterns and currents. This view contradicts previous theories claiming that magnetic reconnection in the tail is a key element in how $B_y$ appears on closed field lines.

The Q1 team has also published research which provides new understanding of the link between Birkeland currents and ground magnetic field measurements. Kristian Birkeland postulated the existence of magnetic field-aligned currents, a view that was highly controversial and not fully accepted before the currents were eventually discovered with satellite measurements. While Birkeland's suggestion turned out to be correct, his interpretation of magnetic field measurements was, strictly speaking, not: The Birkeland currents cannot be directly observed only with ground magnetometers. Nevertheless, *Laundal et al.* (2015) showed, using a combination of ground magnetometers and space-based measurements, that the Birkeland currents can have an indirect effect that can be measured on the ground at high latitudes (Figure 2). In particular, they found that, very close to the pole, Birkeland currents are "visible" in darkness, but not in sunlight. Considerable hemispheric differences must therefore be expected during solstices, since the magnetic field perturbations relate to different current systems.

The Q1 group has contributed at several meetings in 2015. At the AGU Fall Meeting in San Francisco, we again organized a session on inter-hemispheric asymmetries in high-latitude geospace. The session was well attended, and the Q1 team contributed five presentations. Steve Milan and Karl M. Laundal were invited to give presentations at an ISSI workshop, and have contributed three chapters to a book on the Earth's magnetic field. The team has given 35 presentations, at more than 12 different meetings. Eleven of these were invited talks. PhD student Jone Reistad spent six months on a Peder Saether scholarship at UC Berkeley, and PhD student Paul Tenfjord went to UCLA on a Fulbright scholarship in the fall of 2015, and will stay until the summer of 2016. Theresa Rexer and Anders Ohma received their master's degrees.

The group collaborates closely despite being based at different locations. The team communicates through weekly teleconferences using a web-based project management tool.




**Solar magnetic coordinates (SM):**
**(All values given as Earth radii,6371 km)**
**X-axis from the Earth to the Sun**
**Y-axis perpendicular to the Earth-Sun line towards dusk**
**Z-axis parallel to the north magnetic pole**

**Figure 1:** *Tenfjord et al.* (2015) ran global magnetohydrodynamic simulations to study in detail how a $B_y$ component in the interplanetary magnetic field induces a $B_y$ component in the magnetosphere. Such simulations make it possible to follow specific field lines in time, as shown in the figure. They used these simulations to develop a conceptual model to explain how asymmetric Birkeland currents can appear in the two hemispheres.

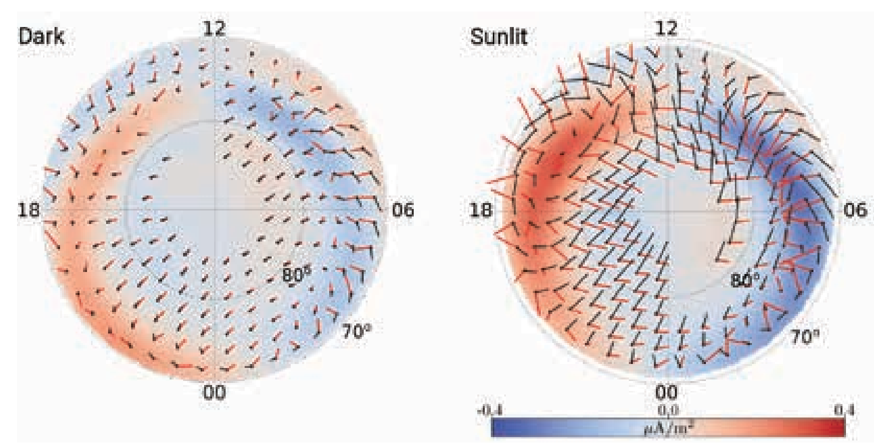



**Figure 2:** *Laundal et al.* (2015) showed that the Birkeland current system (colors in the background) relates differently to ground magnetic field perturbations in sunlight and darkness. In darkness, the current in the polar cap is likely to be very small, and the equivalent current, measured from ground (black vectors), is anti-parallel with the horizontal Birkeland closure currents (red vectors). In sunlight, Birkeland current signatures are largely invisible on the ground.

**Team**

**Jone Peter Reistad**
PhD candidate, UiB

**Kristian Snekvik**
Post-doc, UiB

**Paul Tenfjord**
PhD candidate, UiB

**Steve Milan**
Professor, UiB & Dept. of Physics & Astronomy, Univ. of Leicester, UK

**Stein Haaland**
Researcher, UiB & Max Planck Institute for Solar System Research, Göttingen

**Karl M. Laundal**
Co-leader, Researcher

# Q2 How do we get beyond the large-scale static picture of the ionosphere?

**The science targeted by Q2 is an acknowledgment that the magnetosphere-ionosphere system is highly dynamic including processes with scale sizes from hundreds of meters to thousands of kilometers (at ionospheric altitudes). Despite this well-known fact, most published models make the assumption that observed variations are solely due to spatial gradients or, in other words, that the system is static. This crippling assumption is largely due to the inherent observational shortcomings of single satellite missions, which cannot separate spatial and temporal variations of a measured electromagnetic parameter. However, progress has been made possible by the recent launch of multi-point satellite missions (e.g., ESA SWARM, THEMIS and Cluster). These missions, as well as some ground-based observations, finally provide us with the observational basis needed to advance our understanding of the coupling between the Earth and the near-Earth space.**

**Prof. Kjellmar Oksavik**
Team Leader

The Q2 group was extremely productive in 2015, breaking a new record with 19 published papers in one year in scientific peer-review journals. Below, we highlight two of these results:

The September 2015 cover page of the prestigious *Journal of Geophysical Research* (Figure 1) highlights a paper by our PhD student Xiangcai Chen and his collaborators *(Han et al., 2015)*. This paper made an extensive survey of the dayside diffuse aurora, which can be observed over Svalbard under very quiet geomagnetic conditions and equatorward of the traditional 630.0 nm cusp aurora. By analyzing seven years of all-sky camera data from the Chinese Yellow River Station in Ny-Ålesund, they found that bright features in the 557.7 nm dayside diffuse aurora alter their orientation with magnetic local time. At magnetic noon a new type of diffuse aurora was observed. This throat aurora is aligned with the plasma convection, and the authors speculate that it could be related to either ionospheric outflow or plasmaspheric drainage plumes.

The group has also begun to explore new and innovative data analysis techniques. Network analysis is a mathematical field that is used for brain research and studies of social networks – e.g., how do different parts of the human brain respond to inputs, how do people connect to each other in Facebook, and how does information propagate in social networks like Twitter? Jesper Gjerloev and collaborators (*Dods et al., 2015)* demonstrated how a similar technique can be applied to SuperMAG ground-based magnetometer data, in a first effort to quantify the rich and detailed evolution of auroral disturbances in time and space (Figure 2).

The group is pleased to report that our PhD student Christer van der Meeren received a prestigious Outstanding Student Paper award for his poster presentation at the European Geosciences Union General Assembly. Norah Kaggwa Kwagala completed her master's thesis in 2015, and the group had five invited talks at international meetings. On 20 March 2015, the group participated in a huge media event; a live broadcast of the total solar eclipse on Svalbard was aired to millions of TV viewers worldwide.

In June 2015, the group was very excited to learn that the Minister of Education and Research Torbjørn Røe Isaksen and the RCN made a decision to fund the first stage of EISCAT_3D. The University of Tromsø is the host institution of the application, on behalf of a national consortium where the BCSS Q2 team has made significant contributions. The NOK 288 million grant brings promise of a very exciting future for space science in Norway.

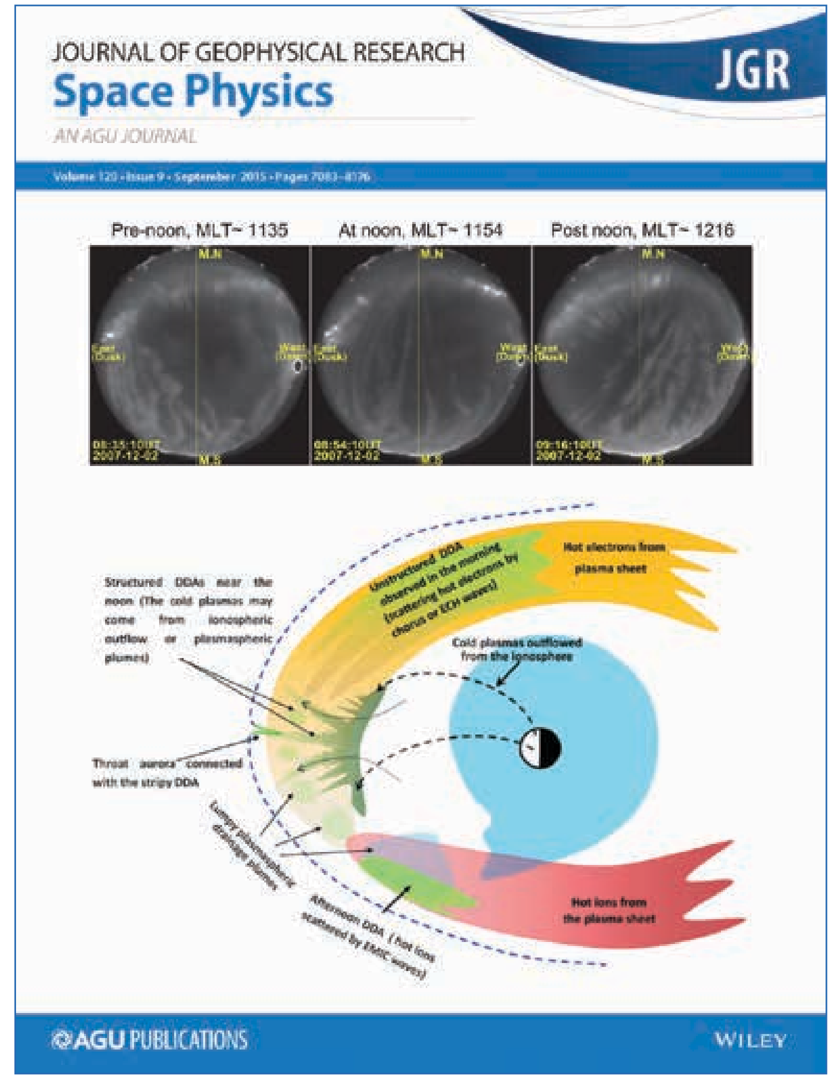



**Figure 1:** The research of PhD student Xiangcai Chen and his collaborators *(Han et al., 2015)* was featured on the cover of the September 2015 edition of the *Journal of Geophysical Research.*

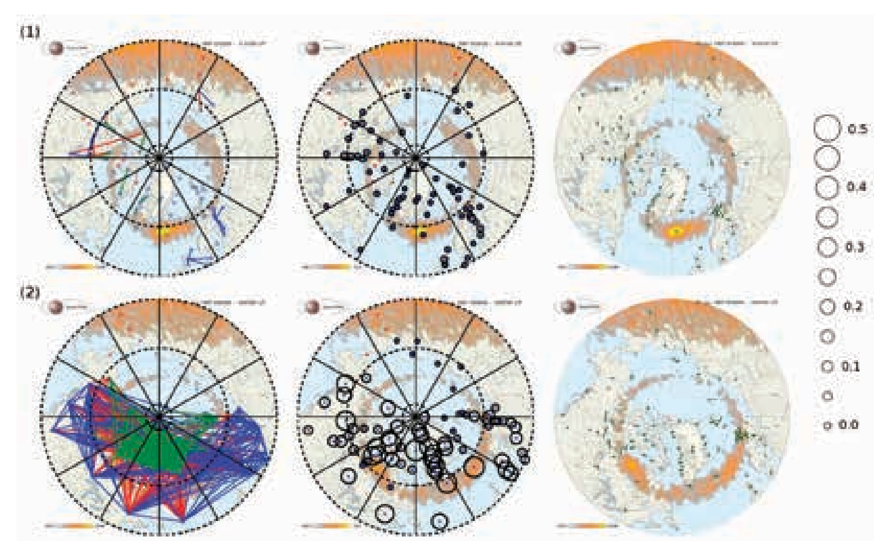


**Figure 2:** Jesper Gjerloev and collaborators *(Dods et al., 2015)* demonstrated how a network analysis technique can be applied to SuperMAG ground-based magnetometer data, in a first effort to quantify the rich and detailed evolution of auroral disturbances in time and space.

## Team

**Jesper Gjerloev**
Professor, Johns Hopkins Univ, USA
*(not photographed)*

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

**Lisa Baddeley**
Assoc. Professor, UNIS

**Finn Søraas**
Professor Emeritus, UiB

**Pål Ellingsen**
Post-doc, UNIS

**Beate Humberset**
PhD candidate, UiB

**Christer van der Meeren**
PhD candidate, UiB

**Norah Kwagala**
PhD candidate, UiB

**Xiangcai Chen**
PhD candidate, UNIS

# Q3 What are the effects of particle precipitation on the atmospheric system?

**Traditionally, atmospheric studies have been carried out within specific altitude regimes: thermosphere, mesosphere, stratosphere, and troposphere. However, the effects of energetic particle precipitation cross these traditional boundaries and a new cross-disciplinary approach is required to make further progress on the open questions. This is the cue for our latest research collaboration: Solar effects on natural climate variability in the North Atlantic and Arctic (SOLENA), with Yvan Orsolini as principal investigator, which has been accepted for funding by the RCN. Here we have joined forces with the Bjerknes Center for Climate Research, the Dept. of Geosciences, University of Oslo, and Geophysical Institute, University of Bergen.**

**Dr. Hilde Nesse Tyssøy, UiB**
Team Leader

SOLENA will address the solar forcing on climate arising from both radiance and particle flux variations. The effects of solar radiance and particle forcing will be examined, first separately and then jointly, using a common state-of-the-art modelling framework. SOLENA will rely on performing simulations with a chemistry-climate model that is coupled to the ocean and which has a high-top middle atmosphere component and interactive chemistry.

The mechanism through which particle forcing is predicted to interact with the middle atmospheric dynamics is the production of $HO_X$ and $NO_X$ gases and the subsequent reduction of ozone. Ozone is a radiatively active species which absorbs sunlight and emits infrared light, thus acting as both a heater and a cooler. The results by *Venkatesvara Rao et al.* (2015) shed light on its role as a heater, examining the influence of polar stratospheric ozone variability on the dynamics of the stratosphere and mesosphere. The stratospheric and mesospheric wind velocities are highly anti-correlated and the changes are driven by the total amount of ozone loss that occurs during the Antarctic spring ozone hole. When used as a proxy for the changes in the total ozone column imposed by strong particle events, these results imply that the changes in solar absorption due to Energetic Particle Precipitation (EPP) may play a minor role in affecting middle atmosphere dynamics.

Previous studies suggest that the role of ozone as a cooler will be of importance for the dynamics during the winter months. The bulk production of $NO_X$ by EPP occurs in the lower thermosphere. To efficiently affect ozone it needs to be transported down to the stratosphere. *Hendrickx et al.* (2015) applied epoch analyses to study the general descent of EPP-produced NO based on observations. They reveal that the direct production of NO by EPP occurs down to an altitude of 95-105 km. However, it also shows that the indirect effect of this EPP has a 27-day recurrence that extends down to about 50 km during the NH polar winter (Figure 1) and approximately 65 km during the SH polar winter.

A reliable quantification of the particle forcing to be used for both modeling, statistical and case studies continues to be an essential objective. *Hendrickx et al.* (2015) investigated the relationship between NO and different geomagnetic indices. General circulation models typically use the mid-latitude geomagnetic indices (Kp, Ap) as proxies for EPP and NO production. However, our study suggests that the auroral electrojet index is a better proxy for particle precipitation and the NO production above 100 km.

A more accurate estimate of the particle energy deposition is direct particle measurements. To improve the currently available measurements *Sandanger et al.* (2015) demonstrate a consistent and robust method to account for degradation in the MEPED proton detector. We find that the degradation has a clear solar cycle dependence combined with the particle fluxes it measures *(Ødegaard et al., submitted 2015)*. As a consequence we can prolong the validity for measurements performed by both old and new satellites. Ultimately it will extend our particle measurements to potentially cover more than three solar cycles enabling long-term studies.

The group has been very active at conferences in 2015, with presence at 11 conferences giving more than 20 presentations, three of which were invited talks. Yvan Orsolini has been elected as a member of the International Commission on the Middle Atmosphere (ICMA). We have also been recognized at a national level. Annet Eva Zawedde received the Martin Landrøs Prize for outstanding master's thesis (Figure 2) and held invited talks at both the Nordic Physics Days organized by National Physics Society and at the annual meeting at the Norwegian Geophysical Society. Hilde Nesse Tyssøy is a stand-in national delegate for the International Association of Geomagnetism and Aeronomy (IAGA).

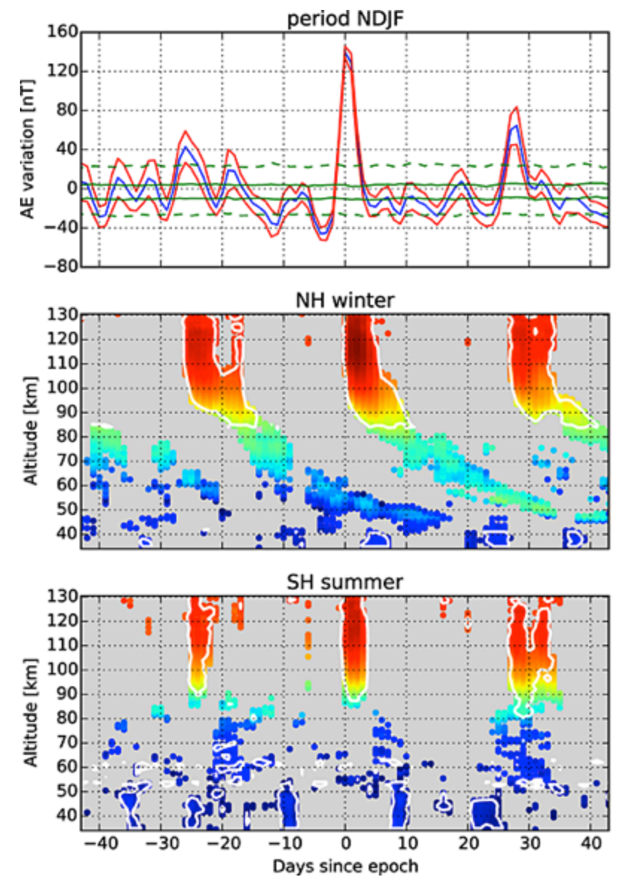



**Figure 1:** *Hendrickx et al.* (2015) performed a super epoch analysis in winter and summer in both hemispheres. Here, the upper panel shows the variation of AE index, and the lower panels the Northern Hemisphere and Southern Hemisphere NO enhancements during boreal winter. The result was featured in JGR space physics (adapted from *Hendrickx et al., JGR, 2015).*

**Figure 2:** Annet Eva Zawedde was awarded the Martin Landrøs prize for her physics thesis *Weak to Moderate Recurrent Storms and their Influence on the Middle Atmosphere Composition in 2008* (Thesis supervisor: Hilde Nesse Tyssøy).

## Team

**Annet Eva Zawedde**
PhD candidate, UiB
**Christoph Franzen**
PhD candidate, NTNU

**Silje Holmen**
PhD candidate, UNIS
**Linn-Kristine Ødegaard**
PhD candidate, UiB

**Sven Olav Kühl**
Post-doc, NTNU
**Kishore Grandhi**
Post-doc, UiB

**Noora Partamies**
Assoc. Professor, UNIS
**Nora Stray**
Assoc. Professor II, NTNU

**Marit Sandanger**
Post-doc, UiB
**Johan Stadsnes**
Professor Emeritus, UiB

**Yvan Orsolini**
Senior Scientist, NILU

**Patrick Espy**, Co-leader,
Professor, NTNU
**Robert Hibbins**
Professor, NTNU

# Q4 What is the role of energetic particles from thunderstorms in geospace?

**It is now 20 years since it was discovered that thunderclouds emit very energetic particles into the near space environment. The energetic gamma bursts are called Terrestrial Gamma-ray Flashes (TGFs) and they are the most energetic natural photon phenomenon in our atmosphere. Since then, it has also been found that energetic electrons and positrons are emitted from thunderstorms to space. To understand the mechanisms that produce this newly discovered phenomenon is the main science objective of our group. We are involved in both space missions, aircraft missions and laboratory experiments to support this research.**

**Prof. Nikolai Østgaard, UiB**
Team Leader and
Leader, Birkeland Centre for Space Science

One of the intriguing questions related to the terrestrial gamma-ray flashes is the following: Are they just a rare, exotic phenomenon or are they an intrinsic part of lightning discharges?

If the latter is the case, we have an energy deposition both locally and into the mesosphere and geospace that has not been accounted for. Two of our papers this year address this question. By optimizing the onboard software configuration, *Marisaldi et al.* (2015) reported that the Italian space mission AGILE was able to detect ten times more terrestrial gamma-ray flashes than it did earlier in the mission (Figure 1). In 2012, *Gjesteland et al.* (2012) optimized the search algorithm for terrestrial gamma-ray flashes in the RHESSI (NASA mission) dataset and found about three times more terrestrial gamma-ray flashes than had previously been reported. *Østgaard et al.* (2015) reported an even newer population in the same dataset (Figure 2), which cannot be identified with the current data search algorithm. They identified lightning discharges within a radius of 800 km from the satellite's footpoint and retrieved the RHESSI data centred at the time of the lightning discharges. Traveling time of photons was accounted for. By superposing 740 210 such data intervals, a significant signal appeared at the centre time, revealing about 100 new terrestrial gamma-ray flashes per year. Both studies support the suggestion that the global production rate of terrestrial gamma-ray flashes is larger than previously reported.

*Gjesteland et al.* (2015) reported three terrestrial gamma-ray flashes observed over the Mediterranean basin by RHESSI. These are some of the northernmost TGFs that have been observed, which means that, at middle latitudes, the tropopause is lower than at the equator. This also means that the TGFs are produced at lower altitudes. In order to produce a signal at the satellite altitude (550 km) after having been heavily absorbed on the way out of the atmosphere, they need to be more intense than TGFs produced a few km higher up. For one of these TGFs, they found that the fluence at source region had to be at least $10^{18}$ photons (or even $10^{19}$) which is 10 (100) times more than that usually assumed. The total energy in each TGF is another important parameter that needs to determine the importance of this phenomenon.

Our laboratory experiments from Eindhoven were the focus of *Carlson et al.* (2015). In these discharge experiments, we measure energetic X-rays in more than half of the sparks. As these experiments only involve 1 MeV compared to the 100 MeVs in a thundercloud, they are not one-to-one comparable to TGFs, but we can learn a lot about the micro processes involved in lightning. By performing a detailed statistical analysis of 900 laboratory sparks, they determined the average energy of the X-ray photons produced during these sparks to be 86 keV, which indicates that the energy of the electrons producing the X-rays is a few hundreds of keV. These results give us some clue about how relativistic electrons are produced in the TGFs as well.

This year we have published 7 papers and given 11 presentations at international meetings. We have organized our yearly sessions at both EGU and AGU. Three master's students (Vegard Aamodt, Stefan Coyle and Kjetil Albrechtsen) have finished and two new master's students have started. Pavlo Kochkin joined the group as a postdoc and Kjetil Albrechtsen started his PhD project.

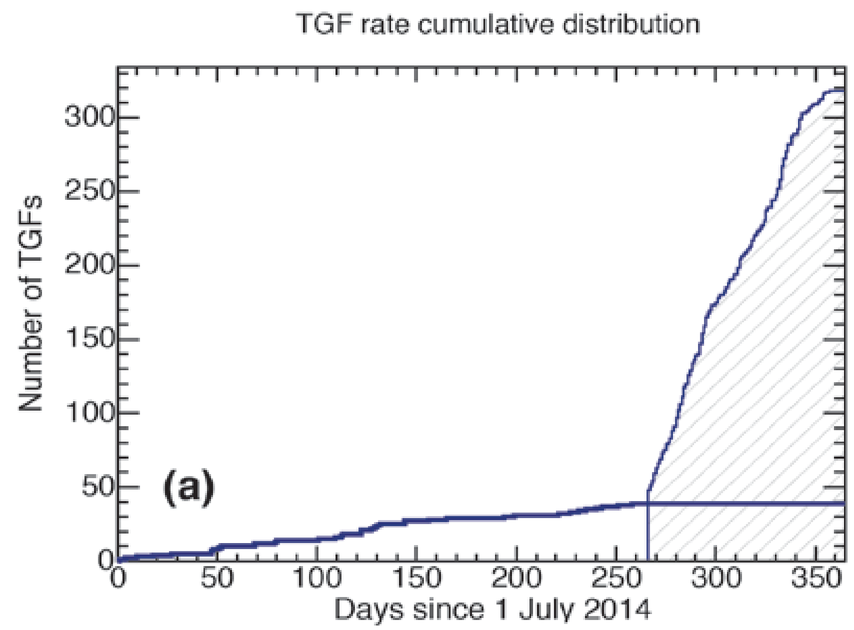



**Figure 1:** The increased rate (day 265) of TGF detection by AGILE after the software configuration was optimized *(Marisaldi et al., 2015)*.

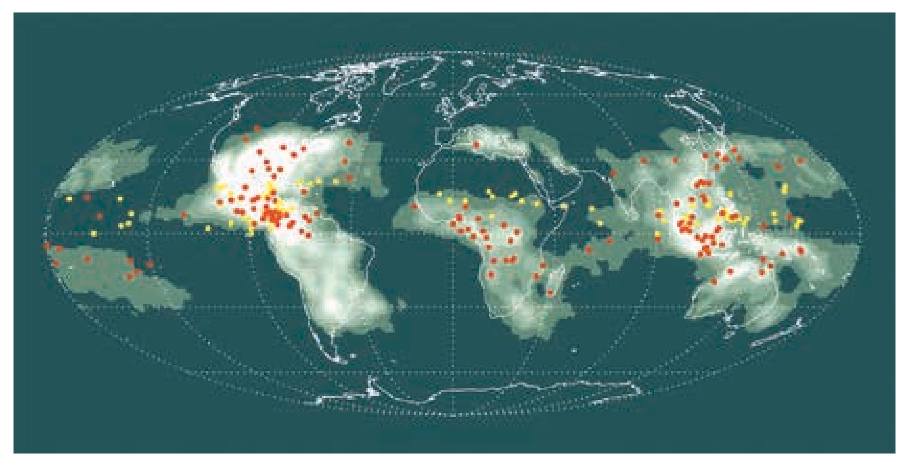


**Figure 2:** The already-known TGFs are shown in yellow. The new population is shown in red *(Østgaard et al., 2015)*.

Team

**Kjetil Albrechtsen**
PhD candidate, UiB

**Brant Carlson**
Researcher, UiB &
Carthage Coll., USA

**Andrey Mezentsev**
Post-doc, UiB

**Alexander Skeltved**
PhD candidate, UiB

**Pavlo Kochkin**
Post-doc, UiB

**Nikolai Lehtinen**
Researcher, UiB

**Martino Marisaldi**
Visiting Researcher, UiB
Researcher, INAF - IASF, Bologna

**Thomas Gjesteland**
Co-Leader,
Researcher, UiB

# Space Instrumentation Group

**2015 has been dominated by the MXGS (Modular X-ray and Gamma ray Sensor) of ASIM (Atmosphere-Space Interactions Monitor). Various environmental and functional tests on the instrument level, as well as the integration of the two detectors delivered by UiB, were performed.**

**In 2015, the mechanical design of the instrument that UiB delivers to fly together with the FEGS (Fly's Eye GLM Simulator) was developed. This instrument will fly on a NASA ER-2 aircraft at 22 000 m altitude. The mechanical PDR (Preliminary Design Review) took place in the last quarter of 2015. The design was accepted and a go-ahead for production was given. The planned delivery time is April 2016.**

**At the very end of 2015, BCSS was invited to participate in the SXI (Soft X-ray Imager) instrument on the SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) satellite. The mission is a joint venture between the European Space Agency (ESA) and the Chinese Academy of Science (CAS). The project just entered a two-year study phase, which will be followed by a four-year implementation phase, aiming at launch in 2021.**

**Maja Rostad, UiB**
Team Leader

**ASIM MXGS**
The MXGS consists of two X- and gamma ray detectors, one for detecting photons with high energy (HED) and one for lower energy quanta (LED). The LED is based on pixelated Cadmium Zink Telluride detectors, and has 16 384 pixels across an area of 1024 cm². The energy range of the LED is 15 keV-400 keV. The HED uses twelve Bismuth Germanate crystals and has an area of 900 cm². The energy range for the HED goes above 20 MeV.

The year 2015 has been marked by the damage of two of the HED detector units during the environmental tests at INTA in Spain. The failures were attributed to electrostatic discharges due to the very low humidity on site. This was a major setback and resulted in a complex and resource-consuming logistical operation (Figure 1). For the required repairs and extra penalty tests the units had to be transported several times back and forth all over Europe by air, land and sea.

Finally, both HED and LED were successfully delivered and integrated in the MXGS (Figure 2). The environmental tests so far have been successful too. The MXGS is expecting the arrival of its Power Supply Unit and the Data Processing Unit. There is one more functional test involving UiB personnel to be performed after the installation of the PSU. From that point on there should be no need for any involvement of our engineers in the hardware side of this project. The MXGS will undergo environmental testing at INTA, and then it will be shipped to Danish Technical University for calibration. After that it will go to Italy for the final integration into ASIM, before it takes the journey to Kennedy Space Center in Florida.

**FEGS**
FEGS (Fly's Eye GLM Simulator) is a project of the University of Alabama in Huntsville to calibrate the Global Lightning Monitor which will fly on a geostationary satellite. As a part of the collaboration with University of Alabama we are allowed access to NASA's ER-2 aircraft. This is a series of flights over thunderclouds at an altitude of 20-22 km. We are participating with an instrument for detecting high energy gamma rays. For the first flights we will use the spare HED detector unit from ASIM. These are three Bismuth Germanate crystals 150 x 50 x 30 mm. New electronics has to be built for the purpose, together with power and data processing unit. The embedded software running the instrument was finalized in 2015.

The mechanical design of the thermally controlled box was finalized in 2015 and the mechanical PDR took place (Figure 3). The hardware is presently in production. Delivery of the instrument is expected to take place by the end of April 2016. The first technical test flight is planned for 2016 and the first scientific flight in spring 2017.

For new aircraft campaigns with FEGS we will develop a new modular detector that will replace the ASIM crystals. This is a derivative design of the COBRAT detector. COBRAT, is a balloon campaign that has been postponed by the French Space Agency, CNES. The new detector for FEGS will be larger and more sensitive.

**SMILE**
At the end of 2015 BCSS was invited to participate in the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission. This is a joint mission between ESA and CAS and is led by UK. The responsibilities are as follows: CAS delivers the satellite bus and the propulsion system, ESA is responsible for the launch and the interface to the instruments onboard. The instruments are delivered by different groups in Europe and China. The main instrument onboard is the Soft X-ray Imager (SXI), which will be able to remotely detect the entry of plasma from the Sun into the Earth´s magnetosphere. We have been asked to deliver the door mechanism, which will protect the CCD camera of the SXI from the radiation it will otherwise be exposed to during perigee passage (Figure 4). The door will also be activated in case of severe solar storms.

**LINET**
We are now entering the fourth year of operation of the Bergen LINET station. This is a VLF/LF radio receiver maintained by the BCSS. It is a part of the lightning detection network LINET, which is run by the University of Munich.


**Figure 1:** (Above) How MXGS was transported several times back and forth all over Europe by air, land and sea.

Photo: INTA

**Figure 2:** (Above) The HED is integrated into MXGS at INTA.

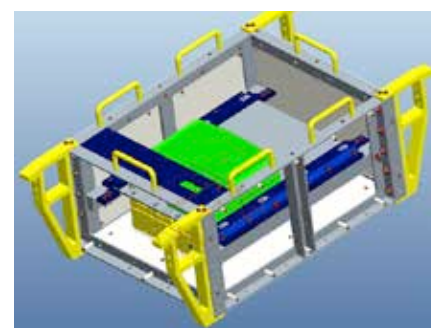


**Figure 3:** (Above) The box containing our instrument for FEGS.

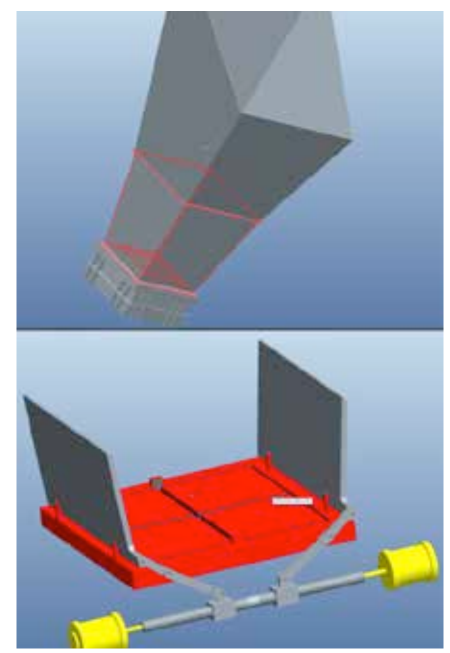


**Figure 4:** (Right) Upper panel: The SXI on SMILE. Lower panel: The door mechanism to protect the CCD in the camera when passing through the radiation belt of the Earth.

## Team

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# Ground-based Instrumentation Group

**The ground-based instrumentation group is running and maintaining the research infrastructure (KHO and the new SuperDARN radar). This considerable effort includes a long-duration campaign of five months every year. This section reports on the main activity in 2015 at the Kjell Henriksen Observatory (KHO), the new node to the Super Dual Auroral Radar Network (SuperDARN), the BCSS Scintillation and Total Electron Content (TEC) network, instruments at NTNU's Dragvoll campus in Trondheim and SuperMAG.**

**Prof. Fred Sigernes, UNIS**
Team Leader

**The Svalbard SuperDARN (Super Dual Auroral Radar Network)**
Radar Planning permission for the facility was awarded in May 2014 and construction on the site began in October 2014. The antenna masts were mounted in August 2015 (Figure 1). Main power and optical fiber connections were also installed in 2015. Radar functionality tests were first carried out in November 2015 and routine operations are expected to begin in early 2016.

In addition, a new HF transmitter is deployed to Hornsund to study small-scale ionospheric and gravity waves. The receiver is installed at KHO.

**Royal visit**
Her Royal Majesty Queen Sonja of Norway visited KHO for the second time, in 2015. Together with friends, she inspected key instruments and was given an update on our research on aurora and airglow. Also discussed were the global weather machine and the impact of the sun on climate changes.

**The total solar eclipse campaign on Svalbard**
The total solar eclipse on Friday 20th March 2015 started in the western Atlantic, 650 km west of Canada's Labrador coast and 450 km south of the southern tip of Greenland. It then raced across the Atlantic ocean touching land at only two places: the Faroe Islands between Scotland and Iceland, and the Svalbard Archipelago (particularly, Spitsbergen Island) (Figure 2).

The UNIS course AGF-216: The Stormy Sun and Northern Lights, was offered to students and local people from Longyearbyen. High resolution ground-based spectral measurements were carried out by a team from the Institute for Astronomy at the University of Hawaii. They used the old station in Adventdalen. Coronal dynamics was studied by a group from Williams College, Massachusetts.

KHO was operative to see if we were lucky to detect aurora. In addition, an airborne experiment was conducted to image the event with a new hyperspectral camera.

**The Rocket Experiment for Neutral Upwelling 2 (RENU2)**
KHO has successfully supported the Rocket Experiment for Neutral Upwelling 2 (RENU 2) campaign. Our instruments, together with the Eiscat radar, identified and tracked the target–the dayside aurora–and the rocket was launched on the 13th of December 2015 at 07:34 UT from Andøya Space Centre. The Principal Investigator (PI), Dr. Marc Lessard from the University of New Hampshire, headed the campaign using KHO as his headquarters.

The rocket (Black Brant XII) flew through the magnetospheric cusp during a neutral upwelling. The mission successfully acquired new *in situ* data that will provide us with a fresh perspective on understanding the effect of upwelling.

**The NTNU ground-based instruments**
At NTNU, the momentum flux meteor radar continues to operate without interruption. Data from this instrument and that from a co-located near-IR spectrometer have been used in several master's and technical physics specialization projects at NTNU this year. In addition, the data have also been used by three students who have been working on atmospheric wave variability using meteor wind data from the mid- to high-latitude chain of northern hemisphere SuperDARN radars. PhD student Christoph Franzen has initiated a new collaboration with the Nordic Optical Telescope on La Palma, developing a new technique to measure the variability of the low-latitude mesopause region from archived astronomical data. These low-latitude data will be used in conjunction with data from the Trondheim spectrometer to deduce the relative influence of solar UV and solar particle precipitation on the chemistry and dynamics of the mesosphere and lower thermosphere.

**GNSS receiver network**
BCSS operates scintillation and total electron content receivers at four sites in Svalbard: Ny-Ålesund, Longyearbyen, Hopen and Bjørnøya. Each receiver records detailed information about the amplitude and phase of navigation signals from GPS, GLONASS and GALILEO. The data are used to understand how navigation signals are affected by plasma irregularities on their way through the ionosphere. The network operated nominally in 2015.

**SuperMAG**
The worldwide ground based magnetometer collaboration, SuperMAG, had a very successful year in 2015. Registered users (~900 as of February 2016) downloaded >50.000 data products and produced ~40 peer reviewed papers. Many new tools were released, data holdings were expanded and, through funding provided by ESA and NASA, we added footprints of ESA SWARM and NASA RBSP satellites. Further, we expanded the global ULF tools to cover the entire period from 1980 to 2015. Figure 3 shows examples of these new capabilities.

The SuperMAG organization consists of a steering committee, a collaborator committee and a science team. Of particular relevance to BCSS, the SuperMAG lead programmer and PI are, respectively, Mr. Brage Førland and Dr. Jesper W. Gjerloev.

Photo: Mikko Syrjäsuo/UNIS

**Figure 1:** The SuperDARN radar under construction.

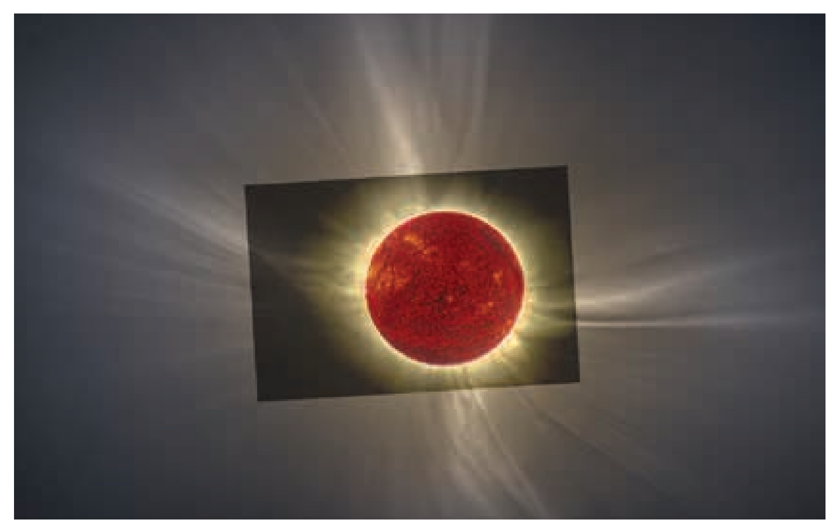

**Figure 2:** The total eclipse on the 20th of March 2015 as seen from Longyearbyen. A High Dynamic Range (HDR) image is fused with the highpass cascade video sequence from NRK and the Solar Dynamics Observatory (SDO) image at 304 nm.

**Team**

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**Brage Førland** Chief Engineer, UiB
**Robert Hibbins** Professor, NTNU
**Dag Lorentzen** Professor, UNIS

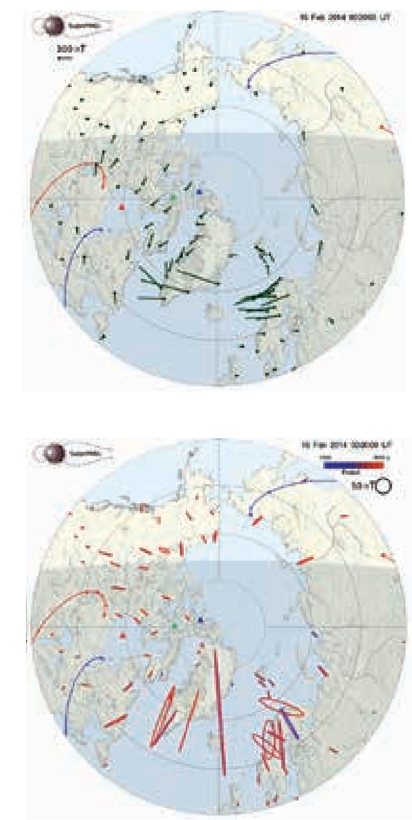

**Figure 3:** Polar plots of ground level equivalent current vectors (top) and ULF activity. Note the NASA RBSP footprints (red and blue lines) and the ESA SWARM footprints (red, green, blue triangles). Plots downloaded from SuperMAG.

# Education and Public Outreach

**The Education and Public Outreach Group (EPO) is responsible for making BCSS research results accessible to interested public. In 2015, we have written ten news articles that have been published on the BCSS webpage. In addition to these BCSS news items, 20 media articles involving our researchers were produced in 2015.**

**Dr. Arve Aksnes, UiB**
Team Leader

### Newsletter Aurora

In 2015, the EPO group published the two first editions of an e-newsletter entitled *Aurora*. The newsletter contains reports on recent activities and upcoming events at the Centre. Journalists, politicians and business people are on the mailing list.

### Recruitment event

In order to attract bachelor students to our space science master's program, we arranged a recruitment event in the spring of 2015. Students were invited to learn more about space science and to interact with our staff and students (Figure 1). Over twenty students came and Centre leader Nikolai Østgaard kicked off the occasion with a short presentation on the Centre and its research. After the talk, the visitors had the opportunity to discuss space research face-to-face with Centre staff and students.

### Design of the vestibule

During the summer of 2015, we installed three TV-screens providing real-time space weather data and showing various informative films on space science.

### EPO goals fot the years to come

During the first two years of the Centre's life, the EPO group's primary focus had been to get the nuts and bolts of operation up and running. We worked on developing the visual profile, the website—with its up-to-date listing of the group's publications and presentations and newsworthy happenings, the physical space—with adequate exhibition space for posters and other materials, and a template for annual reporting. In 2015, we turned our focus towards establishing goals for our group.

In order to be inspired and informed, two members of the EPO group went abroad at the end of April 2015 to visit two established EPO groups in the US, namely the Solar Center at Stanford University and the Space Science Laboratories at University of California, Berkeley. Both these groups have a long track record in being a resource for students and educators and in raising awareness among the general public. Our mission was to learn from the experiences of these groups.

At Stanford University, Deborah Scherrer conducted a two-day EPO workshop for us. We were presented with a variety of ways to promote science to the public, in particular to school-aged children.

At the Space Science Laboratories, we met with Dr. Laura Peticolas, who is herself a space scientist. Laura leads a team of twelve with diverse backgrounds within space/solar physics and education and outreach. Through the program they call Multiverse, the group seeks to bring earth and space science educational opportunities and resources to a variety of audiences, especially those who are underrepresented in the sciences. The program's vision is of a more science literate world.

Meeting with the two groups gave us valuable insight into what was, and wasn't, relevant for our own group. After careful consideration, we have identified the following goals, in order of priority:

1. To present BCSS research results to the international and national public

2. To promote the Centre's major achievements (funding, large hardware, stipends etc.) to the international and national public

3. To create a feeling of pride, ownership, and a sense of belonging within the Birkeland Centre of Space Science in order to create a more cohesive community

4. To recruit bachelor's students to our master's program and to recruit high school students to higher education (university level) in physics

### Solar eclipse events

During the solar eclipse event on March 20, 2015, the EPO group organized a well-attended event in Bergen (in collaboration with the Bergen science center VilVite). About a hundred high school students participated in both hands-on activities and lectures presented by BCSS staff – including associate professor Kjartan Olafsson, guest lecturer Thomas Gjesteland and master's student Stefan Coyle. Conditions for viewing the eclipse were not so favorable in Bergen. However, on Svalbard weather conditions were excellent for enjoying a total solar eclipse, and several BCSS members from Q2 participated in the TV broadcast that was aired both nationally and internationally (Figure 2).

### Bringing space science directly to the public

During the Research Days, the annual science fair that takes place in the centre of Bergen, the BCSS participated in two of the events, and, as part of the preparations, the EPO group developed exhibition materials including a design for the kiosk and t-shirts for the student participants. The theme of the kiosk was "Bergen calling space".

During the first event, in mid-September, we had a stand aimed at people of all age groups, and as seen in Figures 3 and 4, there was lively public engagement in the activities presented by the BCSS group.

We also had another successful stand during an event one week later known as "Forskningsdagene UNG", aimed solely at high school students. Some of the Centre's master's and PhD students participated in showing the young audience how exciting and interesting science can be.

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Photo: Arve Aksnes

**Figure 1:** (Left)
Bachelor's recruitment event at Birkeland Centre.

Photo: forskning.no

**Figure 2:** (Left)
Prof. Kjellmar Oksavik on Svalbard during the solar eclipse.

**Figures 3 & 4:** (Left and below)
The Research Days 2015, Festplassen, Bergen.

Research Days photos: Kjartan Olafsson

# Projects BCSS 2015

**Birkeland Centre for Space Science (2013-2022): Funding 160 MNOK; Additional funding from UiB: 20 MNOK**

| Programme / Contract | Period | Project | P.I. | Funding |
|---|---|---|---|---|
| European Research Council Advanced Grant \| 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 will be performed from space, balloons, aircraft and in the laboratory. | P.I. Nikolai Østgaard | 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 TER-SPACE-CON-DTU_SPACE-002_rev2 | 2010-2017 | **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 2017. | P.I. Nikolai Østgaard | 2.85 MEUR |
| Strategic Core Activities for the Space Physics group at the University of Bergen (SCASP-UIB) \| Project: 216872/F50–NFR/Prog. for Space Research | 2012-2015 | A project to support TGF research and Cluster studies – one PhD student | P.I. Nikolai Østgaard | 3 MNOK |
| Norwegian Research Council Program for Space Research \| Project: 208028/F50 | 2010-2016 | **Terrestrial Gamma Flashes—the Most Energetic Photon Phenomenon in our Atmosphere** Project to support TGF research, PhD student, engineer and balloon instruments/campaigns | P.I. Nikolai Østgaard | 4.86 MNOK |
| Norwegian Research Council Program for Space Research \| Project: 230956/F50 | 2014-2016 | **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: 195385/F50 \| NFR/Infrastruktur | 2010-2017 | **Infrastructure for space physics related research on Svalbard** A project to develop new space-related infrastructure on Svalbard | P.I. Dag Lorentzen | 8.2 MNOK |
| UK Natural Environment Research Council standard grant \| NE/I010173/1 | April 2011-Mar. 2015 | **Solar wind connection to regional climate** British Antarctic Survey | Co-I. Robert Hibbins | Full economic cost £457K |
| Tech. Support for ESA SWARM SuperMAG Activity \| ESA PRODEX funding \| Contract: 4000114432/15/NL/FF/ah | 2015-2016 | **SuperMAG –** is a worldwide collaboration of organizations and national agencies that currently operate more than 300 ground-based magnetometers. | P.I.s Jesper Gjerloev, Nikolai Østgaard | 120 KEUR |

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# **Personnel** 2015

### Summary

| | TOTAL | UiB | NTNU | UNIS | MEN | WOMEN |
|---|---|---|---|---|---|---|
| **Professors** | 11 | 6 | 2 | 3 | 9 | 2 |
| **Professors Emeriti** | 2 | 2 | - | - | 2 | - |
| **Scientists / Postdocs** | 16 | 13 | 2 | 1 | 13 | 3 |
| **PhD Candidates** | 13 | 10 | 1 | 2 | 8 | 5 |
| **Technicians** | 10 | 8 | - | 2 | 9 | 1 |
| **Master's Students** | 21 | 12 | 9 | - | 15 | 6 |
| **Administration** | 3 | 3 | - | - | 1 | 2 |

### BCSS Team

| | | |
|---|---|---|
| **Centre Leader** | Nikolai Østgaard | UiB |
| **Adm. Coordinator** | Katarzyna Kosela-Dordevic | UiB |
| **Centre Board** | Jarl Giske, *Vice-Dean, Faculty of Math. & Natural Sciences* | UiB |
| | Bjørn Åge Tømmerås followed by Elisabeth Müller Lysebo *Director, Faculty of Math. & Natural Sci.* | UiB |
| | Øyvind Frette *Head, Dept. of Physics and Technology* | UiB |
| | Mikael Lindgren followed by Erik Wahlström, *Head, Dept. of Physics* | NTNU |
| | Ole Arve Misund, *Managing Director* | UNIS |
| | Nikolai Østgaard, *Leader, BCSS* | UiB |
| | Katarzyna Kosela-Dordevic, *Administrative Coordinator, BCSS* | UiB |

### Engineering Team

| | |
|---|---|
| Lisa Baddeley | UNIS |
| Thomas Riis Bjørnsen | UiB |
| Georgi Genov | UiB |
| Robert Hibbins | NTNU |
| Dag Lorentzen | UNIS |
| Kåre Njøten | UiB |
| Thomas Poulianitis | UiB |
| Bilal Qureshi | UiB |
| Maja Rostad | UiB |
| Fred Sigernes | UNIS |
| Mikko Syrjäsuo | UNIS |
| Kjetil Ullaland | UiB |
| Shiming Yang | UiB |

### Education and Public Outreach Team

| | |
|---|---|
| Arve Aksnes, PhD, *Team Lead* | UiB |
| Brage Førland, PhD, *Chief Engineer* | UiB |
| Kjartan Olafsson, PhD, *Associate Prof.* | UiB |
| Kavitha Østgaard, *Senior Consultant* | UiB |

### Science Advisory Board (SAB)

| | |
|---|---|
| Margaret Chen, *Aerospace Cooperation, Los Angeles* | USA |
| Alan Rodger, *Former Director of British Antarctic Survey* | UK |
| Asgeir Brekke, *Professor Emeritus, University of Tromsø* | NOR |

### Scientific Team

| | | |
|---|---|---|
| Lisa Baddeley | Associate Professor | UNIS |
| Patrick Espy | Professor | NTNU |
| Jesper Gjerloev | Professor, *20% UiB*/JHAPL | UiB |
| Robert Hibbins | Professor | NTNU |
| Dag Lorentzen | Professor | UNIS |
| Steve Milan | Professor, *20% UiB*/Univ. of Leicester | UiB |
| Kjellmar Oksavik | Professor | UiB |
| Noora Partamies | Associate Professor | UNIS |
| Johan Stadsnes | Professor *Emeritus* | UiB |
| Nora Stray | Associate Professor II, *20% UiB*/NTNU | NTNU |
| Finn Søraas | Professor *Emeritus* | UiB |
| Kjetil Ullaland | Professor | UiB |
| Nikolai Østgaard | Professor | UiB |
| Brant Carlson | Researcher *20% UiB*/Carthage Coll. | UiB |
| Pål Ellingsen | Post-doc | UNIS |
| Thomas Gjesteland | Researcher | UiB |
| Kishore Kumar Grandhi | Post-doc | UiB |
| Stein Haaland | Researcher *20% UiB*/ISSI | UiB |
| Pavlo Kochkin | Post-doc | UiB |
| Sven Olav Kühl | Post-doc | NTNU |
| Karl Laundal | Researcher | UiB |
| Nikolai Lehtinen | Researcher | UiB |
| Martino Marisaldi | Visiting scientist, Univ. of Bologna | UiB |
| Andrey Mezentsev | Post-doc | UiB |
| Yvan Orsolini | Researcher, *20% UiB*/NILU | UiB |
| Marit Sandanger | Post-doc | UiB |
| Kristian Snekvik | Post-doc | UiB |
| Hilde Nesse Tyssøy | Researcher | UiB |
| Kjetil Albrechtsen | PhD candidate | UiB |
| Xiangcai Chen | PhD candidate | UNIS |
| Christoph Franzen | PhD candidate | NTNU |
| Silje Eriksen Holmen | PhD candidate | UNIS |
| Beate Humberset | PhD candidate | UiB |
| Norah Kwagala | PhD candidate | UiB |
| Jone Reistad | PhD candidate | UiB |
| Theresa Rexer | PhD candidate | UiB |
| Alexander Skeltved | PhD candidate | UiB |
| Paul Tenfjord | PhD candidate | UiB |
| Christer van der Meeren | PhD candidate | UiB |
| Annet Eva Zawedde | PhD candidate | UiB |
| Linn Kristine Ødegaard | PhD candidate | UiB |

# **Major Achievements** 2015

| | |
|---|---|
| **November 2015** | Dr. Jesper Gjerloev has been a co-author on a paper by *Dods et al.* (2015) which reports on how SuperMag magnetometers behave like a social network by “talking” to each other through vectors. The paper is highlighted in *Science Newsline*. |
| **October 2015** | The SuperDARN radar on Svalbard is finalized. |
| **September 2015** | PhD candidate Xiangchai Chen has been a co-author on a paper by *Han et al.* (2015). One of the figures from this paper is featured on the cover of the *Journal of Geophysical Research.*<br><br>Dr. Hilde Nesse Tyssøy is one of the authors of the Norwegian science anthology book *Stjerneklart*. |
| **August 2015** | A SWARM-SuperMAG project with Dr. Jesper Gjerloev as Principal Investigator receives funding from ESA.<br><br>Assoc. Prof. Kjartan Olafsson and Dr. Arve Aksnes are invited to be editors of the Space Physics Section of the Norwegian online encyclopedia entitled *Store Norske Leksikon*. Prof. emeritus Jan Holtet at the University of Oslo has played a major role in building up the Space Physics Section, and he will now be succeeded by Drs. Olafsson and Aksnes. |
| **June 2015** | UiT/The Arctic University of Norway is awarded NOK 288 million for EISCAT_3D, with Prof. Kjellmar Oksavik as co-investigator. The award from the Research Council of Norway (RCN) will be used to build the first stage of the most advanced 3D imaging radar system in the world.<br><br>Annet Eva Zawedde is awarded the Martin Landrøs Prize for outstanding master’s thesis. Title: “Weak to Moderate Recurrent Storms and their Influence on the Middle Atmosphere Composition in 2008”. Supervisor: Hilde Nesse Tyssøy. |
| **May 2015** | The Solar-Terrestrial Sciences (ST) Division of the European Geosciences Union (EGU) awards PhD candidate Christer van der Meeren the EGU Outstanding Student Poster (OSP) award for his poster entitled “Observations of simultaneous multi-constellation GNSS scintillation in nightside aurora over Svalbard”. |
| **April 2015** | A January 2015 article in *Geophysical Research Letters* by *Lühr et al.*—with BCSS’ Dr. Jesper Gjerloev as co-author—is selected as a “Research Spotlight” by the journal’s editors.<br><br>Dr. Martino Marisaldi of BCSS and INAF - IASF Bologna wins the Fulbright Research Scholar Grant to spend a six month research period starting in October 2015 at the Dept. of Electrical and Computing Engineering at Duke University, NC, USA. |
| **March 2015** | Prof. Kjellmar Oksavik and the UNIS team contribute with instruments and expertise during the total solar eclipse on Svalbard on the 20th of March, an event that was broadcast live all over the world. |

Cover: Inspired by Østgaard et al., Figure 2, page 11.

Photos: Unless otherwise mentioned, all photographs by C. van der Meeren.