Rosseland Centre for Solar Physics

Annual report 2018

UiO : University of Oslo

Norwegian Centre of Excellence
The Research Council of Norway

Contents

Annual report 2018

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Rosseland Centre for Solar Physics (RoCS)

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Our vision is understanding the workings of the energetic Sun.

1. To understand the origin and evolution of the solar magnetic field on spatial scales ranging from the smallest observable (<100 km) to the size of active regions (100,000 km).

2. To understand the dynamic structuring and mass and energy transfer in the solar atmosphere from the relatively cool (6,000 K) surface to the multi-million degree corona.

3. To understand which configurations of the magnetic field, ambient and emerging, lead to the development of dynamic phenomena such as surges, jets and flares of all sizes that permeate the active solar atmosphere.

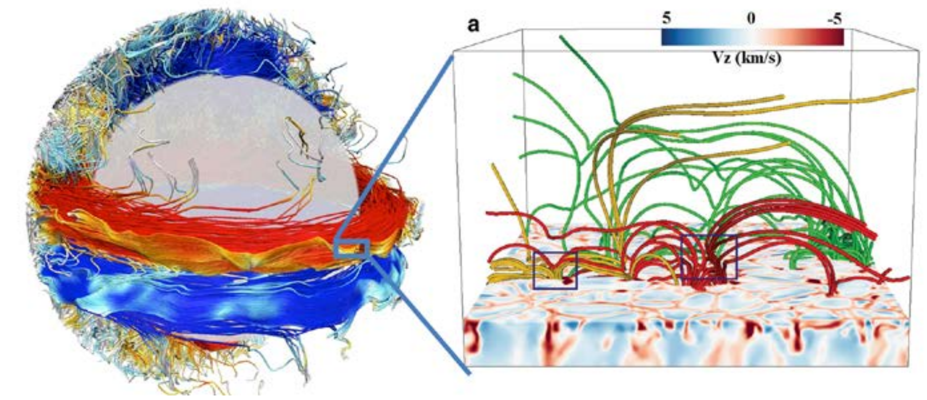
4. To go beyond the single-fluid magnetohydrodynamic (MHD) paradigm, which breaks down in the nearly neutral chromosphere and the almost collisionless coronal plasma. We will do this by applying multi-fluid and particle-in-cell techniques, providing new understanding of heating and particle acceleration in both quiet and active solar environments.

From the opening of RoCS November 1 2017. From left: Boris Gudiksen (PI), Sven Wedemeyer (PI), Mats Carlsson (director), Viggo Hansteen (PI), Luc Rouppe van der Voort (PI)

From the Director

This is the first annual report of the Rosseland Centre for Solar Physics (RoCS). The centre is one of the 10 centres of excellence selected by the Research Council of Norway in the fourth round of the centres of excellence scheme. As this is the first report, we have taken the opportunity to have a presentation of the vision and scientific programme of the centre and also of all the people working at RoCS. I would also like to give some background from how the centre came into realisation.

The process towards establishing a Centre of Excellence is long and full of hard work. The deadline for phase I of the proposal (a project description limited to five pages) was November 25th 2015 and the PI team and Bart De Pontieu worked most of October and November that year on the proposal. The verdict from the evaluation was expected on March 17th (my birthday) but we got the positive message two days before and we then had two months of intensive work to finish the full proposal before the deadline May 25th 2016. We got the report from the expert referees in October (with an overall rating of seven, exceptional) but since the report invited comments on some unclear parts, we used the opportunity to send in one page with comments on the report. The proposed directors of all 34 finalists were asked to give a five-minute presentation in front of the expert panel followed by a twenty-minute interview. This happened on January 24 2017. The final, official decision from the Research Council was taken by the board on March 14 but with an embargo until 02:00 at night on March 15. The centre leaders got the information just after the board meeting. I was in Boulder, Colorado, at the time and because of the time-zone difference I got the excellent news in the morning and was dying to send around the message to the whole team and the supporting people at the University of Oslo. I almost sent off the email one hour too early because the time-zone difference was one hour less than normal (daylight savings time in the USA but not in Europe) but realised just in time. The message was sent off on the minute 02:00 and all PIs responded within minutes so all were waiting for the news. Lots of champagne followed.



Simulation of the solar dynamo that generates the magnetic field (left, simulation by the group in Paris) and a simulation of the outer solar atmosphere (right, simulation by RoCS) where the emerging field interacts with pre-existing field creating explosions and jets.

But the reward of hard work is more hard work – much remained before the official start of the centre on November 1st 2017: final adjustments for the contract, making plans for the renovation of the Svein Rosseland building that houses the Institute of Theoretical Astrophysics to make room for the expansions, announcements of positions and selections of candidates, etc, etc. Throughout the application process and up to the starting date and this first year of ramping up, lots of persons have been involved – the current RoCS team, the leadership, administrative staff and technical staff of the Institute of Theoretical Astrophysics, support personnel at the Faculty of Mathematics and Natural Sciences and the University of Oslo. They are all thanked.

Project start was November 1st 2017 and that day we had an opening seminar with presentations of the research plan of the centre. The Scientific Advisory Committee attended and the four members gave their view on the way forward for RoCS. The starting two months were also used to select the first employees of the centre and for preparing for the adaption of new rooms in the Svein Rosseland building.

In 2018 the ramp-up of activities continued. Two faculty positions were filled with partial funding from RoCS: Sven Wedemeyer and Tiago Pereira. Three postdoctoral researchers and four PhD students started in 2018. We also completed a contract with the University of Glasgow enabling professor Lyndsay Fletcher to work 20% for RoCS from December 1st 2018. The possibility through a centre to attract leading scientists to come for shorter or longer visits have often been highlighted as one of the most important aspects by other centres of excellence. We are ramping up this activity and are in the final stages of signing several 20% contracts with leading experts, thus expanding the knowledge base of the centre. Another important activity here is our International Rosseland Visitor Programme, which is described in more detail in Section 4.

During 2018 we have also worked to strengthen internal collaboration within the centre. Our first retreat was in March 2018 and the emphasis was on synergy between existing activities when planning for the future. We also took an active part in a pilot project on career development for temporary researchers. This is in collaboration with other centres of excellence in Oslo, after the initiative from the Hylleraas Centre for Molecular Quantum Chemistry.

A new international project got selected for funding in 2018: a very prestigious synergy grant from the European Research Council (ERC). In this project, called WHOLE SUN, we work with groups in Paris, Göttingen, St. Andrews and Tenerife. The WHOLE SUN project attempts to link the eruptive phenomena observed in the solar atmosphere to the motions of plasma deep in the interior of the Sun, where its magnetic field is generated. One of the goals is to develop a new code that can treat this whole region as one system. Computationally, this is very challenging and in need of exascale class capacity (about 100 times more powerful computers than the top computers today).

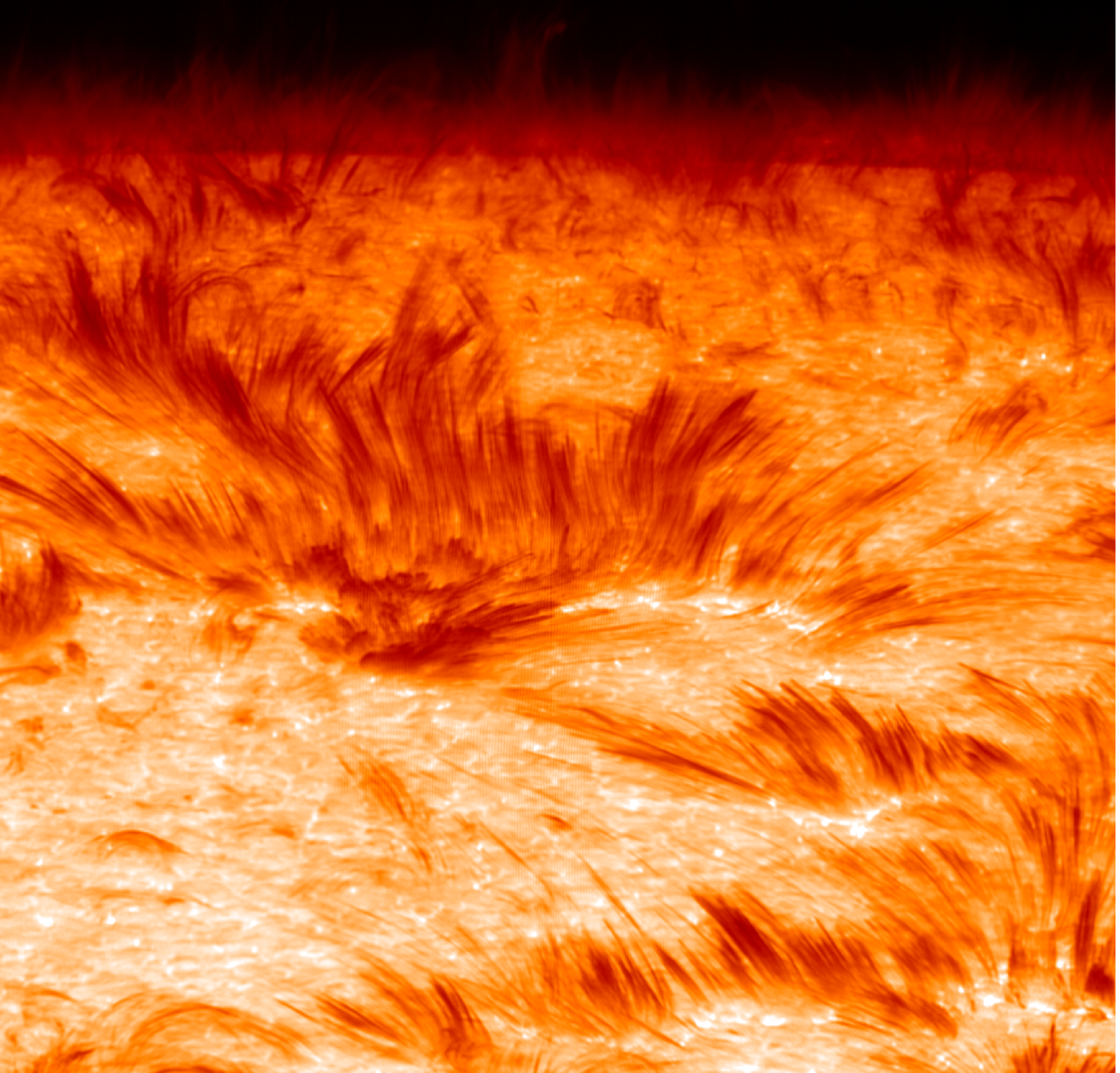
A number of exciting results have been obtained in 2018. A selection of these are reported on in this annual report in Section 3 with a full list of papers published in refereed journals in Appendix 2.

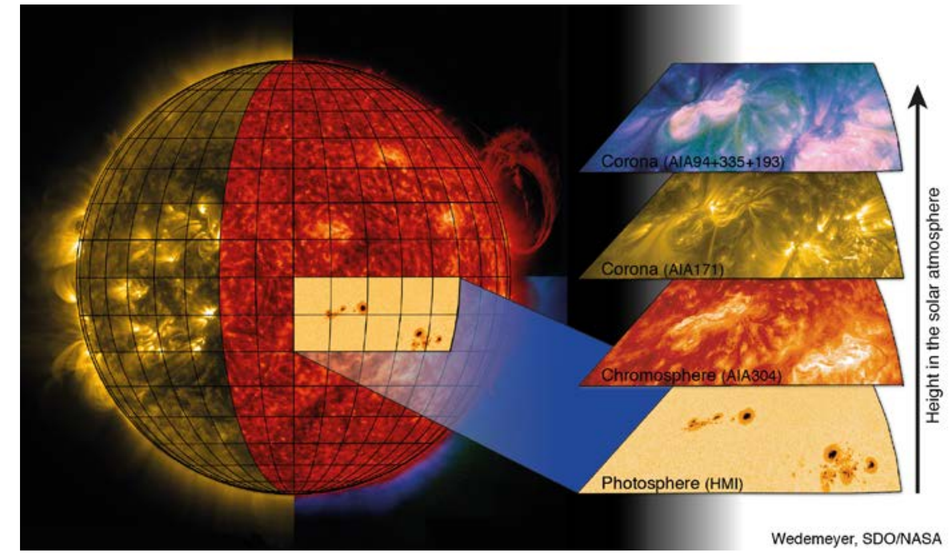
A large number of exciting projects are well under way. The ramping up of activities continues with more people coming on board all the time. Together we are making a difference!

March 2019

Mats Carlsson,
Director of RoCS

What is the Sun?





The different atmospheric layers of the Sun and the height ranges sampled by the instruments to be used by RoCS.

Sufficiently stable to nurture life during the last 4 billion years, and modern humans the last 100,000 years, the Sun is neverthe-less a variable star. While the total solar irradiance only varies about 0.1% during the 11-year solar cycle, the high-energy portion of the solar output can vary by several orders of magnitude on timescales of minutes.

Solar activity - sunspots and active regions, UV and X-ray emission, the million degree corona, flares, coronal mass ejections, the acceleration of energetic particles - is increasingly interfering with human activity as our society's dependence on sensitive electronic equipment grows and as we venture beyond the Earth's magnetosphere and into the solar system proper. There is a pressing need to understand the workings of the energetic Sun; such understanding is now within reach, and is the goal of RoCS.

The Sun is a glowing ball of gas with a surface temperature of 6000 K. Its structure is determined by the forces of gravitational contraction and pressure-driven expansion. These forces are in an exquisite balance that requires the solar centre to be extremely hot, hot enough for fusion of hydrogen atoms to occur in the core, releasing prodigious amounts of energy. This energy is steadily diluted as it diffuses away, and the temperature of the solar envelope decreases with increasing distance from the site of nuclear burning. Two thirds of the way out from the core, convection becomes more efficient than radiative diffusion so that in the top layer of the solar interior mass motions carry energy towards the solar surface. It is these convective motions, combined with the Sun's enigmatic differential rotation, that generate the magnetic field and drive the large range of phenomena we call solar activity.

At the top of the convection zone lies the solar surface, the photosphere, comprised of convection cells and threaded with magnetic fields. Above the photosphere we find the outer solar atmosphere where, astonishingly, the temperature starts to rise; the chromosphere with temperatures around 10,000 K, the transition region, the hot (> 1 MK) corona, the solar wind, and the outer heliosphere, extending out to more than twice the distance of Pluto. Understanding the non-intuitive rise in temperature and the processes driving the supersonic solar wind outflow that inflates the solar heliosphere has been a central goal of solar physics since the discovery that the corona is hot in the late 1930's.

The solar magnetic field, generated in the convection zone and photosphere, is at the heart of these thorny problems. In the solar photosphere the plasma dominates the magnetic field, forcing the field to continual motion. The emergence and displacement of magnetic flux at photospheric heights as the plasma does work on the field imply an upwardly propagating energy flux. The magnetic field is also the primary agent for transporting this "mechanical" energy from the convection zone into the outer solar atmosphere, where it is dissipated. A wide variety of physical mechanisms have been proposed, but the complexity of the atmosphere has precluded consensus on which of these mechanisms dominate the heating of the solar atmosphere and drive violent eruptions.

Towards understanding: RoCS goals

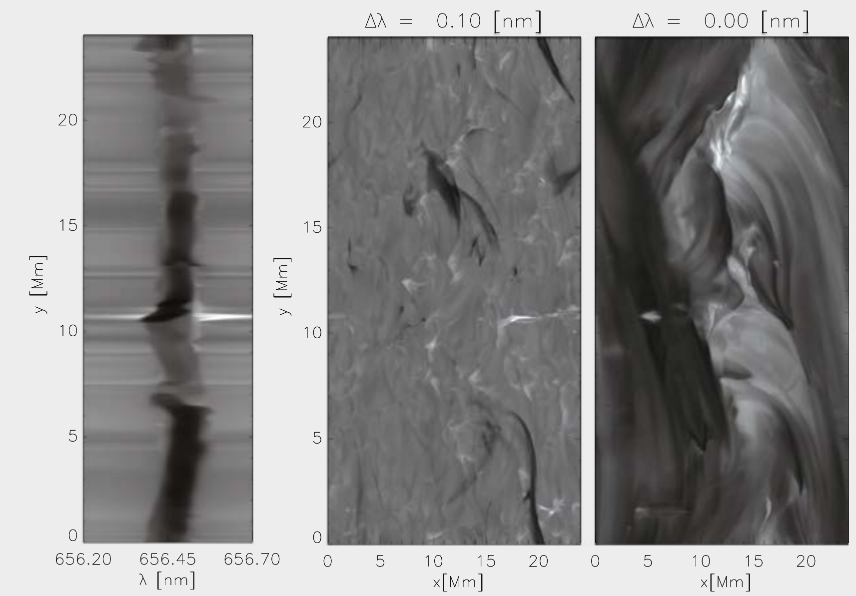
New hardware and novel techniques, both computational and observational, promise to revolutionise our understanding of the workings of the entire coupled solar atmosphere. The solar physics group of the Institute of Theoretical Astrophysics at the University of Oslo has played a central role in these developments and has also exploited them to make significant contributions at the forefront of solar physics.

The Rosseland Centre for Solar Physics (RoCS), named after the founder of the Institute of Theoretical Astrophysics (ITA) who initiated solar physics research in Norway, dramatically expands these efforts to build a comprehensive understanding of chromospheric and coronal heating and violent solar activity.

Several recent developments have made the complex physics of the outer solar atmosphere tractable to quantitative analysis. In particular, the development of high performance computers has allowed us to build 3D radiative MHD codes designed to treat the physics of the chromosphere and corona as well as software capable of converting simulation output into synthetic observables. Similarly, the last few years have seen major progress in extremely high resolution imaging spectroscopy, enabled by adaptive optics and image reconstruction techniques, as well as novel diagnostics from space-based observatories.

RoCS is in a unique position to capitalise on these exciting developments and drive major breakthroughs in understanding the interplay between the magnetic field and the plasma in the outer solar atmosphere, and the deeply rooted connections between convective motions in the Sun's interior and the structuring and activity of the corona. The investigations are two-pronged: advanced 3D numerical simulations, which can be directly compared to high-resolution observations from the ground and from space. Synthetic diagnostics are computed from the models and compared with high-resolution observations. The similarities and discrepancies are used to investigate the role of various physical mechanisms that have been proposed as drivers of the energetics and dynamics of the active solar atmosphere, such as shocks, magneto-acoustic waves, magnetic reconnection and various plasma instabilities.

Our primary objective is understanding the workings of the energetic Sun.



From the simulation output we calculate synthetic observables. For optically thick lines formed in the chromosphere, this is a complicated task since the Local Thermodynamic Equilibrium (LTE) approximation breaks down and strong lines are also affected by 3D effects and by partial frequency redistribution of photons (PRD). The figure shows synthetic intensities in the H-alpha line from neutral hydrogen calculated from a simulation of an explosion in the upper photosphere.

Advanced numerical simulations

In order to unravel the workings of the outer solar atmosphere, it is necessary to take into account many different physical processes. Because of the inherent complexity of the Sun's atmosphere, the only way forward is through numerical simulations that are compared with observations. The "Bifrost" code developed at ITA is designed to treat the physics of the photosphere, chromosphere and corona in a realistic manner, and is currently state of the art. Bifrost allows one to construct "box in a star" models, in which a certain portion of the Sun, from convection zone to corona, spanning horizontal scales commensurate with solar magnetic scales is evolved forward in time. Constructing such models is time consuming; generating a typical model consumes several months computing time on massively parallel computers, and the production of synthetic diagnostics will take at least an equal amount of time. In RoCS we plan to construct a variety of such models spanning a large parameter space of spatial size, horizontal extent and magnetic field configurations. Both the construction and the subsequent analysis of a model run require several years of continuous effort from highly skilled researchers. This approach, guided by observational input, will yield considerable insight.

As one proceeds towards the outer layers of the solar atmosphere the assumptions underlying the MHD description become invalid under certain conditions. The density drops very rapidly with height above the photosphere and collisions become so infrequent that the plasma is no longer in statistical equilibrium. Some of these effects, such as the non-equilibrium ionization of hydrogen and helium, are already included in the current Bifrost implementation. As collision rates drop even further when approaching smaller physical scales or proceeding further up into the upper chromosphere, transition region and corona, the approximation of MHD is no longer valid and a different approach is needed. We have completed an implementation of generalised Ohm's law in Bifrost with promising first results. To go beyond MHD, a multi-fluid or particle-based treatment is necessary to model the plasma. This is especially the case for violent episodic phenomena such as flares and micro-flares, which produce non-Maxwellian particle distributions and copious amounts of highly energetic particles.

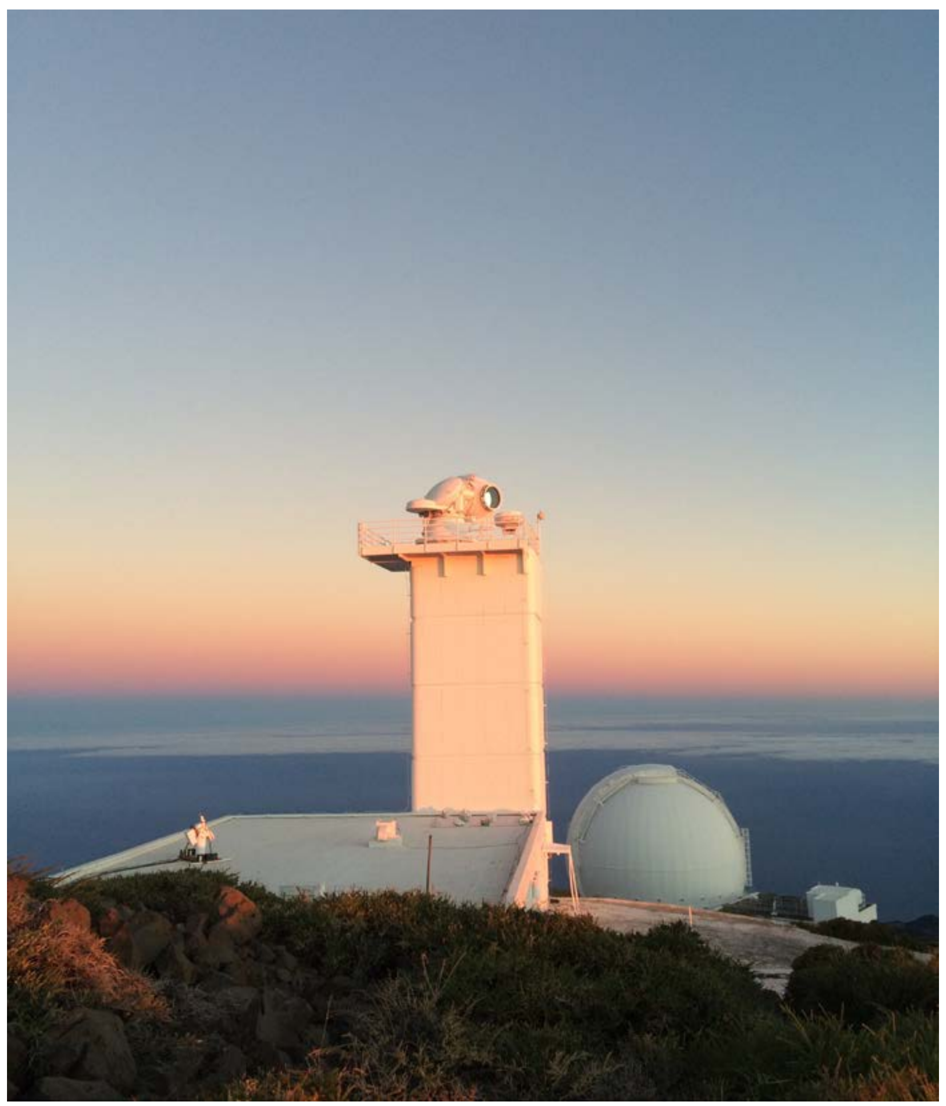
In RoCS we address this issue by expanding our computational capabilities beyond the state of the art:

Multi-fluid methods. We are developing a multi-fluid extension of Bifrost, designed to study partial ionization in the upper chromosphere where collisional processes are slow enough to invalidate even the generalised Ohm's law. This code development builds on our previous experience with multi-fluid solar wind models and will also be of great interest for coronal studies, including the long-standing problem of species fractionation (so called FIP-effect), which has wide-ranging astrophysical implications.

Hybrid methods. Great progress has recently been made in understanding the microphysics of particle acceleration and magnetic reconnection using particle and/or hybrid codes but with simplifying assumptions and limited spatial extent. We are implementing a particle-based model that can be run in conjunction with or "inside" a Bifrost simulation. Of special interest in this context is to consider the structure of current sheets, reconnection, and the acceleration of particles in the complex chromospheric and coronal environment that Bifrost uniquely models.

High quality observations

It is first when coupled and confronted with the observational ground truth that models come alive. Coverage of the entire solar atmosphere, from photosphere to corona, requires both ground-based and space-borne instruments. The team is closely involved as core members of instrument teams and scientific working groups in several world class observatories that, when combined, will provide an unprecedented view of the entire solar atmosphere:



The Swedish 1-m Solar Telescope (SST)

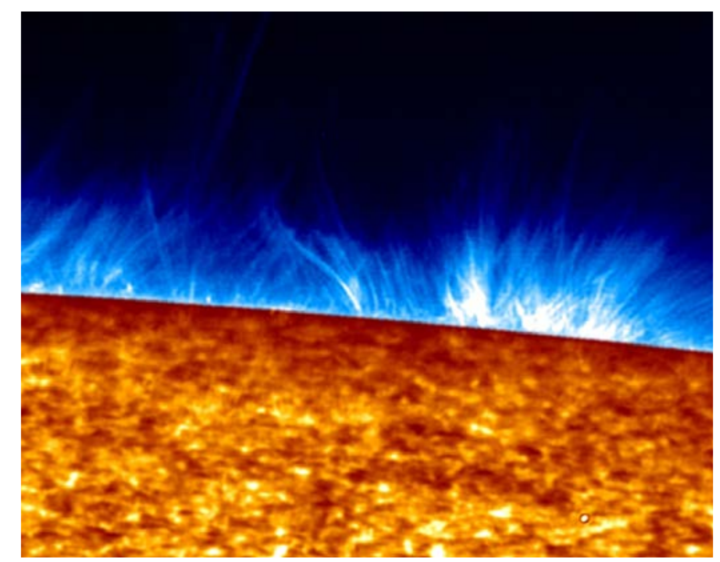
The Swedish 1-m Solar Telescope (SST) on La Palma is a world-leading facility for high-resolution observations of the Sun. It continues to rival contemporary larger aperture telescopes because of its unique combination of extraordinary site characteristics, optical design, adaptive optics and advanced image restoration techniques. Furthermore, it utilises pioneering instrumentation such as the CRISP imaging spectro-polarimeter, a versatile tunable filtergraph that allows fast spectral imaging in the red part of the electromagnetic spectrum.

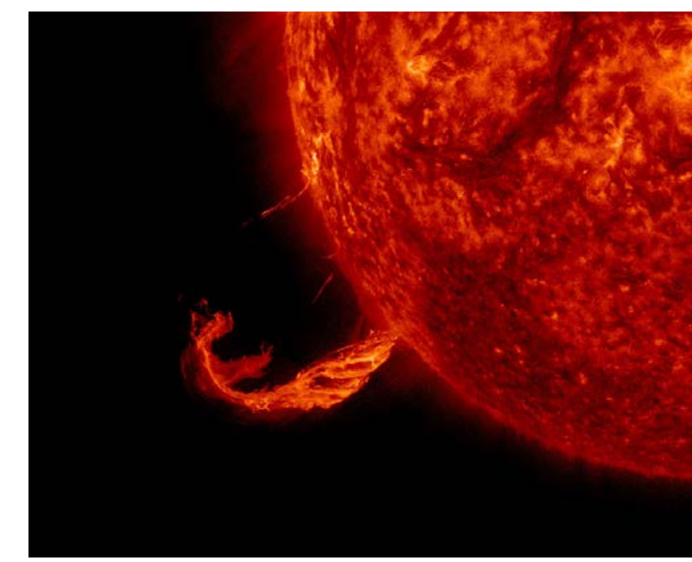
The new CHROMIS instrument, the short-wavelength companion of CRISP, became available for use in 2017. CHROMIS provides diffraction-limited spectral imaging in the blue/violet including the potent Ca H and K lines. This means resolving spatial scales below 100 km and thereby providing an unprecedented window on chromospheric heating at the smallest resolvable scales.

Jim Dowdall/Lockheed Martin

NASA's Interface Region Imaging Spectrograph (IRIS)

Since its launch in June 2013, NASA's Interface Region Imaging Spectrograph (IRIS) satellite is obtaining unique views of the solar atmosphere from high resolution ultraviolet images and spectra at high cadence (down to 0.5s). The UV provides diagnostics on the upper chromosphere and transition region that were never before observed at this high spatial and temporal resolution. The combination of SST and IRIS now covers, at high resolution, the full pathway from the photosphere through the chromosphere and transition region into the corona. The RoCS team includes the principal investigator of IRIS, professor Bart De Pontieu.





NASA

Hinode

Hinode is a Japanese solar satellite that carries three telescopes; a 50 cm Solar Optical Telescope (SOT), where the spectropolarimeter currently sets the standard for high-sensitivity measurements of the photospheric magnetic field, an Extreme ultraviolet Imaging Spectrograph (EIS) and an X-ray telescope. The Institute of Theoretical Astrophysics, UiO, operates the Science Data Centre Europe with a complete set of all the data from Hinode.

The Solar Dynamics Observatory (SDO)

The Solar Dynamics Observatory (SDO) is a NASA solar satellite launched in 2010 that observes the whole Sun continuously. The Atmospheric Imaging Assembly (AIA) provides whole-disk imaging with 12s cadence in an extended range of filters that cover the chromosphere to the corona. Its continuous operation provides valuable context information on the history and large-scale connectivity of the plasma in the high-resolution SST/IRIS fields of view. Furthermore, it serves as an excellent reference for co-alignment between different instruments. The Helioseismic and Magnetic Imager (HMI) provides full-disk magnetic field measurements.

> "If the Sun did not have a magnetic field, it would be as boring a star as most astronomers believe it to be"
>
> Attributed to R.B.Leighton

Clem & Adri Bacri-Normier (wingsforscience.com)/ESO).

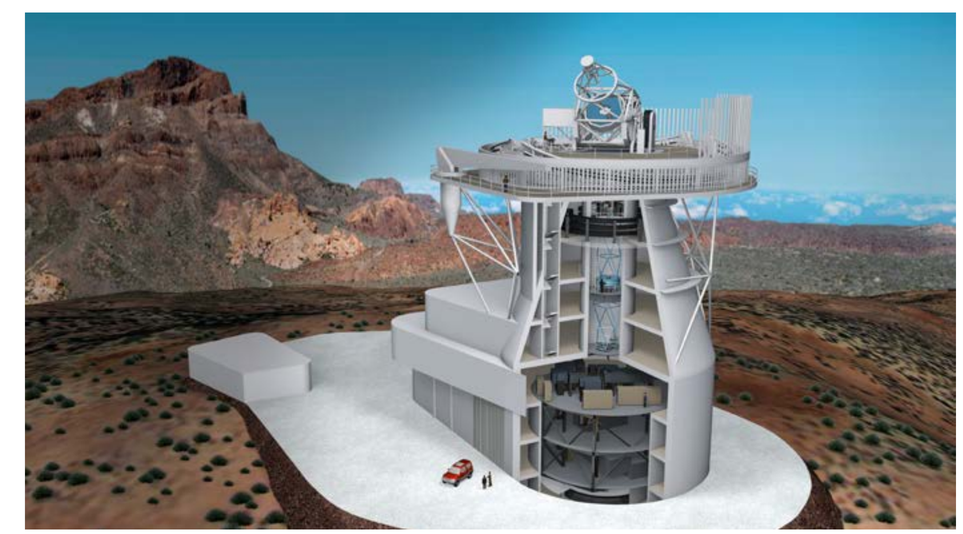
The Atacama Large Millimetre/sub-millimetre Array (ALMA)

The Atacama Large Millimetre/sub-millimetre Array (ALMA) in the Chilean Andes is currently the world's largest astronomical facility. It consists of 66 telescopes, most of them with a diameter of 12m, which are distributed across the Chajnantor plateau in the Atacama Desert at an altitude of 5000m. ALMA observes at wavelengths between 0.3mm and 3.6mm (to be extended to 8.6mm). Since 2016, ALMA offers regular observations of our Sun, opening up new complementary ways to look at the solar chromosphere at high spatial, temporal and spectral resolution. Most importantly, ALMA can provide temperature maps of the observed chromospheric gas. This new scientific opportunity laid the foundation for related research activities at RoCS. See https://www.almaobservatory.org for more information about ALMA.

NSO/AURA/NSF

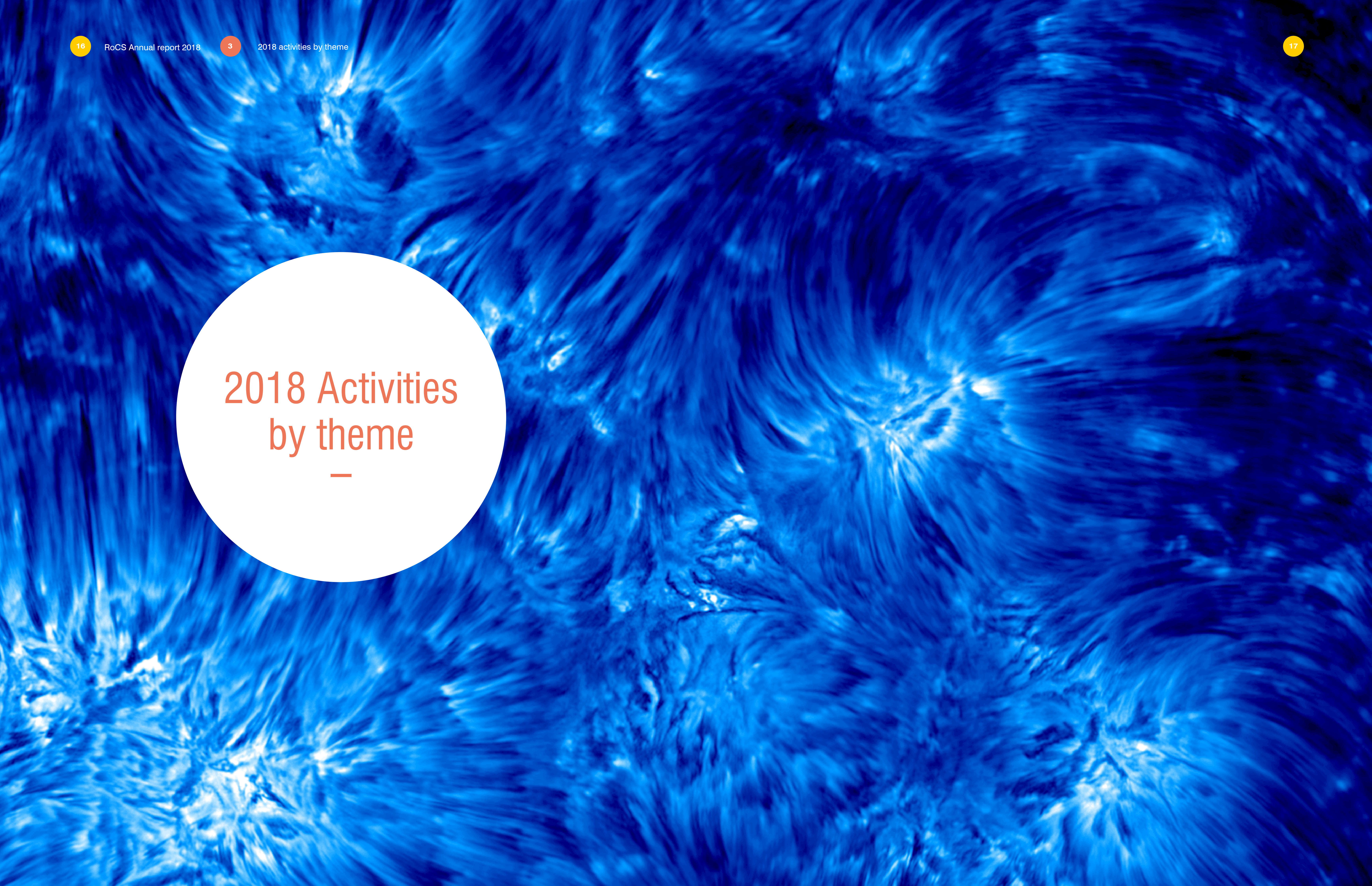
The Daniel K Inoue Solar Telescope (DKIST)

The Daniel K Inoue Solar Telescope (DKIST) currently under construction in the USA is the first in the next generation of 4-m class aperture solar telescopes, representing an enormous leap in capabilities compared with the largest current solar telescopes (1.6 m aperture). The RoCS team has been involved in DKIST at several levels from the design phase into construction and we expect to benefit from access to very high quality observations from DKIST from first light (end of 2019) and onwards.



The European Solar Telescope (EST)

The European Solar Telescope (EST) is the next generation 4-m solar telescope in Europe. EST is the top-ranked mid-size project in the ASTRONET roadmap for infrastructures in Astronomy 2010-2030 and has recently been included in the European Strategic Forum on Research Infrastructures (ESFRI) Roadmap 2016. An infrastructure application has been submitted to the Research Council of Norway to enable a strong Norwegian contribution to EST. The European Solar Telescope has a symmetric design with a minimum of instrumental polarisation making it complementary to the off-axis DKIST telescope and ideal for measuring chromospheric magnetic fields. First light for EST is expected in 2027.



2018 Activities by theme

Simulations

The Bifrost code is designed to model the outer layers of the solar (or stellar) atmosphere and aims to include all the relevant physics needed to interpret and understand the observations.

Modelling the energetic Sun

The input parameters to simulations are, roughly speaking, the entropy flux needed in the convection zone to maintain a given effective temperature, and the initial magnetic field configuration and/or the magnetic field to be injected at the bottom boundary. Simulations are run over one to several hours solar time, typically producing a snapshot of containing all the magnetohydrodynamic variables every 10 seconds.

These snapshots are the basis for computing detailed synthetic diagnostics of spectral lines that can, at least statistically, be compared with actual observations from the solar atmosphere.

Hitherto these simulations have been concentrated on sections of the solar atmosphere best characterised as "quiet Sun" with relatively weak magnetic fields compared to sites of emerging flux or fully developed active regions. However, the premise of RoCS is to study "the active Sun" and the simulations carried out in 2018 have focused on the dynamics and energetics that ensue when the magnetic field becomes stronger and approaches values similar to those encountered in sunspots. Additionally, the year has been spent exploring the importance of spatial resolution in determining the dynamics of the chromosphere and corona; previous simulations have shown that the solar atmosphere may be more dynamic and more magnetically dominated, even in the quiet or semi-quiet Sun, than thought earlier.

Importance of resolution

There are indications that increased numerical resolution would increase the dynamics found in the chromosphere in the simulation. Since one of the major shortcomings of the current generation of simulations is too narrow spectral lines compared with the observations, increased numerical resolution could be important for the creation of more realistic simulations. To investigate this further, a number of simulations have been started – a series of simulations with hydrogen ionisation in equilibrium, a restricted height range and a small box (to have short wall clock times for the runs): 6 Mm x 6 Mm horizontal box and [-2.5,7.5] Mm vertically with horizontal resolutions of 40, 20, 10, and 5 km. The results are under investigation. A large simulation corresponding to the published hydrogen non-equilibrium simulation (Carlsson et al 2016) but with double the resolution (24 km horizontally) has also been started.

In the same vein, but also to better understand the corrugation of the transition region, 2D numerical experiments have been computed of a coronal-hole-like atmosphere in a box with 16 Mm in the horizontal direction and [-2.6, 14] Mm vertically. There are four experiments of this kind with increasing numerical resolution; from horizontal resolution of 31 km to 4 km and vertical resolutions from 20 km to 2.5 km. The results are not yet fully analysed, but a first look at the experiments shows potentially interesting features in terms of the generation of spicules. These snapshots have a cadence of 2 seconds, which increases the possibilities of analysing the more dynamical structures and to carry out Lagrangian tracing to study them in detail.

Flux emergence

The interaction of magnetic flux recently emerged from the solar interior with the pre-existing coronal magnetic field is of special interest: many prominent features in the solar atmosphere are related to this fundamental process. A number of simulations have been run both in 3D and in 2D in which fields are injected at the lower boundary and are allowed to propagate up through the convection zone. The field breaks through the photosphere and emerges into the outer atmosphere interacting with the pre-existing ambient field as large-scale magnetic structures are built up in the chromosphere and corona.

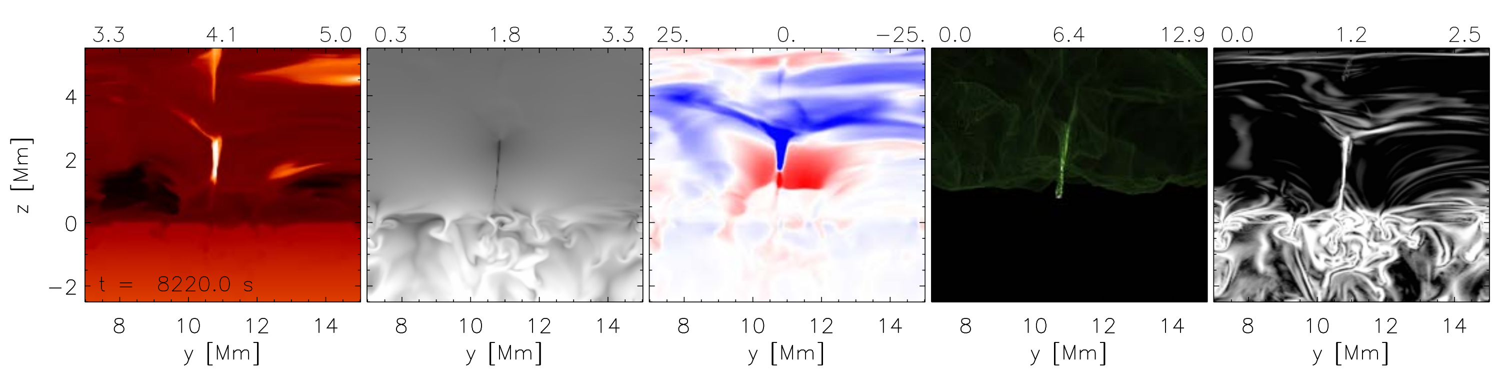
A number of studies with horizontal resolution of 31 km and vertical resolution of 12 km have been run. These simulations have several goals: To see whether the quiet Sun magnetic field is maintained by a local shallow dynamo or requires the injection of field from the deeper convection zone. To understand the formation of strong chromospheric fields in a nascent active region. To study the observational consequences of the interaction of emerging fields as they form the active chromosphere and corona. These simulations show synthetic diagnostics that are remarkably similar to what is observed. Amongst other results we find that Ellerman bombs and UV-bursts are formed naturally and sometimes co-located and co-temporally as a result of large angle reconnection in emerging flux regions.

Nevertheless, there are still open questions concerning the flux emergence process itself, also because of the challenge posed by out-of-equilibrium ionisation throughout the outer atmosphere. Therefore, 2D flux emergence experiments that combine the non-equilibrium ionisation of hydrogen and including the effects of ambipolar diffusion have been run.

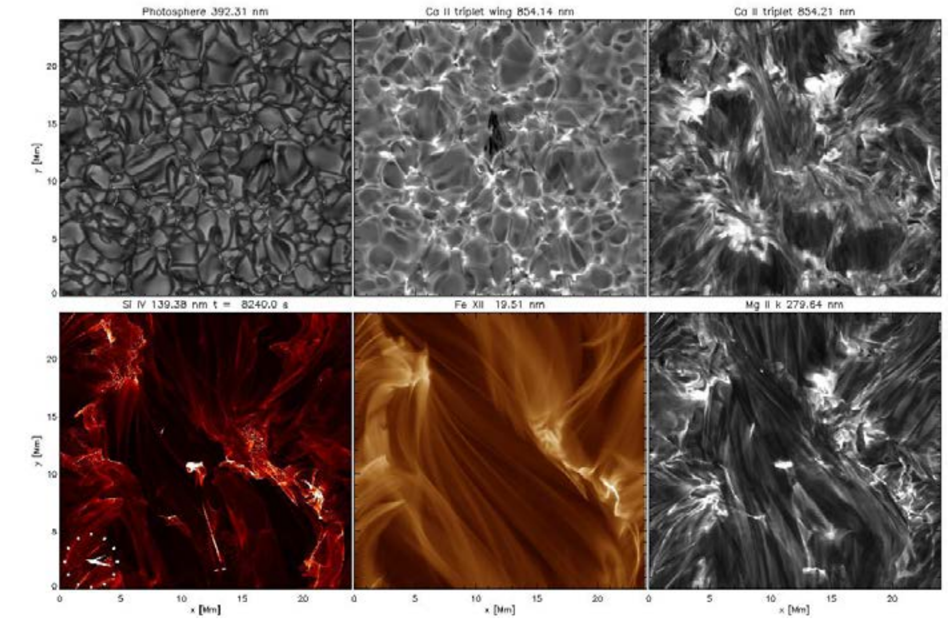
Several of the results of the simulations described above are under investigation and will be presented at the Flux Emergence Workshop in Tokyo in mid-March of 2019.

Deep models, large models

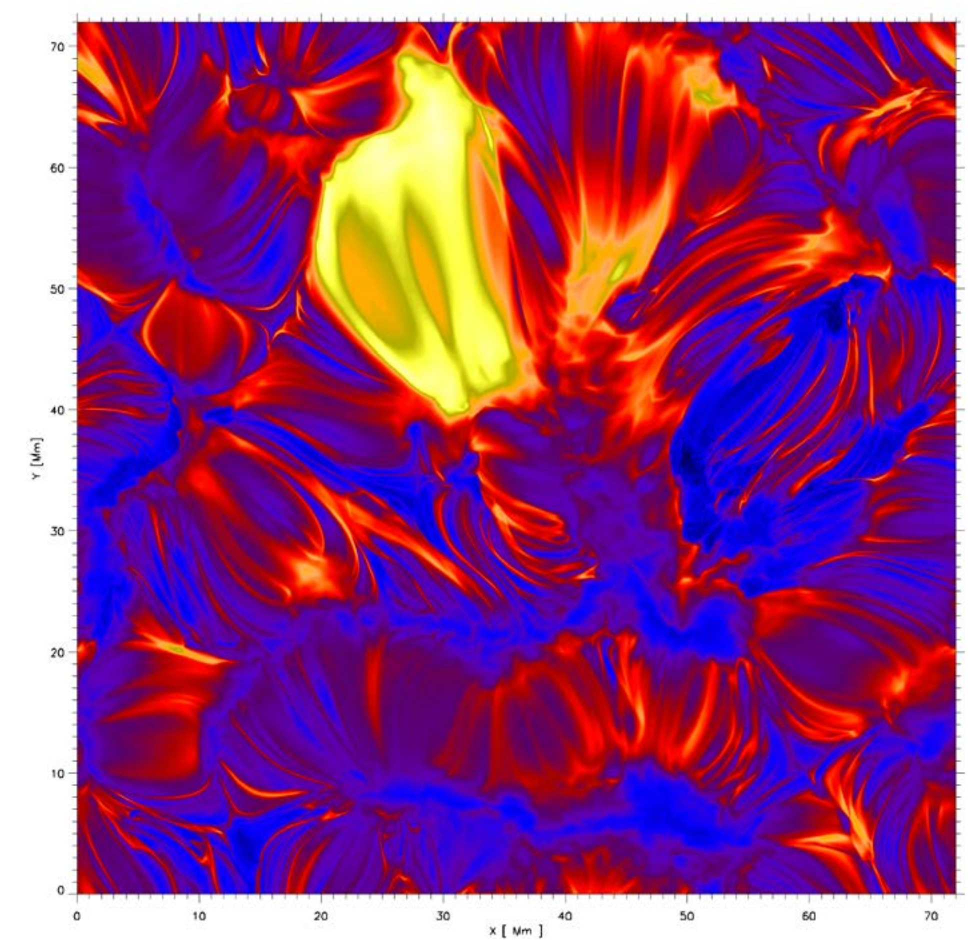
Finally, a number of "deep" models, extending to 8 Mm or more below and up to 50 Mm above the photosphere and 72 Mm wide horizontally are being run. These models should allow the study of the formation and evolution of the chromospheric network and most ambitiously the formation of strong photospheric fields such as sunspots and the study of the chromosphere and corona above these. These models have so far been run with a relatively coarse horizontal resolution of 100 km, but it is planned to refine this to 50 km now as the models have achieved close to steady-state conditions where the dynamics of the deep convection zone are mirrored in the topology of the chromosphere and corona.



Current sheet in the photosphere through the chromosphere that generates both Ellerman bombs and UV bursts. These snapshots show how emerging flux leads to violent reconnection in the outer solar atmosphere.



Synthetic observables from an Ellerman bomb/UV-burst simulation. Note the disturbed granulation pattern in the photosphere, the cool surge in the line wing of Ca II 854.2 nm, the strong emission in the Si IV 139.4 nm line, and the lack of emission in the hot Fe XII 19.51 nm line.



Synthetic image of a proxy for the 19.5 nm Fe XII line from a deep, large simulation. This line is formed at temperatures > 1 million K. Note the plethora of long loop like structures.

Observations with SST and IRIS

The RoCS group is the largest external user of the Swedish 1-m Solar Telescope (SST) at La Palma in the Canary Islands. All observations are coordinated with the IRIS satellite so that we have dense coverage of the solar atmosphere from the photosphere up through the chromosphere and transition region into the corona.

The observing time at SST is usually spread over three 2-week campaigns. In 2018, these campaigns were in May, September and October. These campaigns are very much a team effort and this year 8 RoCS members participated in the observations. The observations involved daily interaction with the IRIS planners to decide what target to observe and which observing program to run. The Sun is currently in the quiet phase of its 11-year magnetic activity cycle, and most of the observed targets were in quiet regions.

Special focus of this year was to do experiments to improve the data quality of observations at the solar limb. Observations at the limb are challenging since both the adaptive optics system and image restoration have difficulties with the sharp drop in light level at the edge of the solar disk. A strong motivation to try limb observations this year is the use of the new CHROMIS instrument and the potential to get unique high-spatial-resolution observations of jets and spicules in the calcium K spectral line. While the weather conditions were not of the desired quality and stability, we managed to get very good results. We are planning to pursue these new directions and discuss with the institute in Stockholm to make a more permanent solution for limb observations.

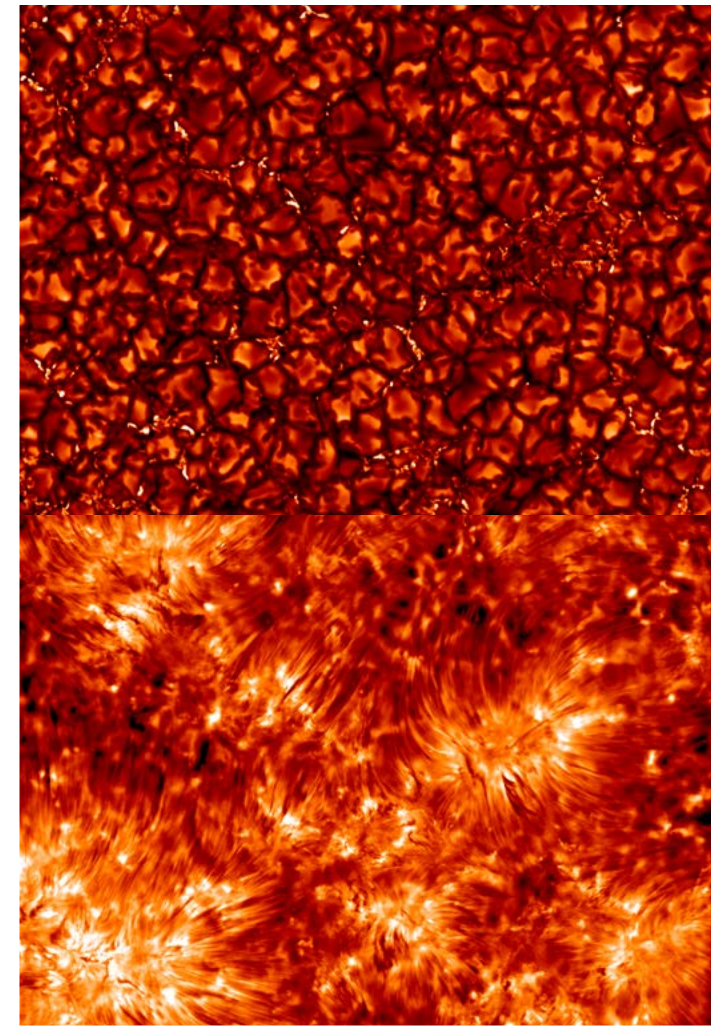
We have close collaboration with the group at the Lockheed Martin Solar and Astrophysics Laboratory (LMSAL) in Palo Alto (USA). The LMSAL group has one 2-week observing campaign at the SST and we are involved in the planning, IRIS coordination and data reduction. For most of their campaign, they supported a multi-day IRIS program to track one of the rare magnetically active regions during its passage over the disk. This program resulted in a few interesting data sets of the active region filament above the polarity inversion line in the centre of the active region. They further managed to acquire a high quality coronal hole time series during one of the best seeing periods of 2018.

Data reduction

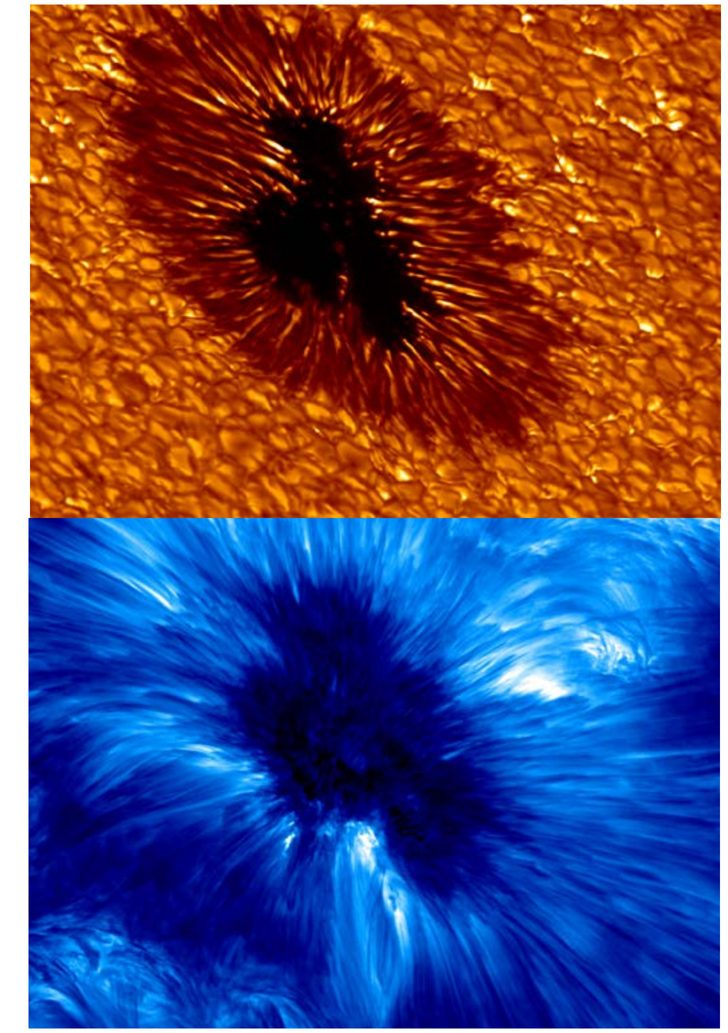
Besides planning and acquiring new observations, the reduction and data processing of current and earlier observations is one of the other main activities of the observations group. We employ image restoration techniques to mitigate the effect of atmospheric turbulence (so-called “seeing”) on the data quality. Like all modern telescopes, the SST employs an adaptive optics system to correct for seeing in real time during the observations. Adaptive optics provides a significant improvement of the data quality but post-facto image restoration is mandatory to attenuate residual seeing deformations.

With image restoration, high data quality can be achieved over a larger field of view and over longer periods of time. Besides considerable computing power and data storage capacity, data reduction requires a fair amount of manpower and is handled as a team effort. We collaborate with the SST staff in Stockholm and La Palma to improve, optimise and further develop the data processing pipelines for the CRISP and CHROMIS instruments.

One of the highlights of the reduction efforts in 2018 is an enhanced network data set acquired in May 2017. This is a time series of more than 2 hours duration and covers a region close to disk centre with extended patches with mixed magnetic field polarities. The seeing was excellent and stable for long duration. Instrumentation at the SST worked flawlessly and the coordination and co-pointing with IRIS was optimal. After all processing and co-alignment we have now a unique dataset with chromospheric spectral imaging in calcium K (from CHROMIS) and hydrogen alpha (CRISP) and photospheric magnetometry from Fe 6302 spectropolarimetry (CRISP). IRIS provides upper chromospheric and transition region diagnostics from a high-cadence spatial raster that runs right through the center of the SST field-of-view. Upper transition region and coronal images are added through alignment with data from NASA’s Solar Dynamics Observatory (SDO). Several science projects are planned for this dataset, for example related to the generation and evolution of spicules.



Region with enhanced magnetic field observed with CHROMIS (25-May-2017). The top panel shows the photosphere as imaged with the CHROMIS wideband channel (wavelength 395 nm), the bottom panel is recorded with CHROMIS in the blue wing of the Calcium K line at a Doppler offset of 20 km/s.



Sunspot observed with CHROMIS (22-Sep-2017). The top panel shows the photosphere as imaged with the CHROMIS wideband channel (wavelength 395 nm), the bottom panel shows the chromosphere as imaged with CHROMIS in the Calcium K line (wavelength 393.3 nm).

Ellerman Bombs and UV bursts

Magnetic reconnection in the solar atmosphere is one of the main topics of research of RoCS. Observationally, magnetic reconnection is manifested in so-called Ellerman Bombs in the lower solar atmosphere and UV bursts in the upper chromosphere and transition region. Several aspects in the relation between Ellerman Bombs and UV bursts have been addressed with coordinated SST and IRIS observations and are still being investigated. We have been involved in a comprehensive review paper with Dr. Young from George Mason University and NASA as lead author. The review provides a full observational characterisation of UV bursts and addresses their relation to so-called explosive events, known from low spatial resolution UV spectroscopy from earlier space missions before IRIS.

Our extensive database with SST active region observations has been exploited for a paper by Dr. Vissers from Stockholm University as the lead author. This study presents a recipe for detecting Ellerman Bombs in the AIA 1700Å channel of SDO. Ellerman Bombs are normally detected in ground-based hydrogen alpha spectral imaging. With this recipe, Ellerman Bombs, and with them sites of significant photospheric reconnection, can be detected in the full-disk and continuous database of SDO, bypassing the inherent intemittency of ground-based observations. To devise this recipe, active regions from 10 different SST data sets, acquired between 2010 and 2015, were aligned to SDO imaging and analysed.

Observations with ALMA

The capability of measuring the temperatures of the gas in the Sun's chromosphere with the Atacama Large Millimetre/sub-millimetre Array (ALMA) opened new scientific avenues that laid the foundation for a new branch of research activities at RoCS.

ALMA-related science at RoCS

The backbone of all ALMA-related activities at RoCS is the Solar ALMA project*, which is funded by a Consolidator Grant from the European Research Council. The project started in 2016. After a second PhD research fellow joined in 2018, the project currently employs two researchers and 2 PhD research fellows in addition to the PI Sven Wedemeyer. The scientific goal is to constrain heating processes in the solar atmosphere with ALMA observations of the Sun, whereas the broader technical goal is to develop the necessary observational and simulation tools for fully exploiting ALMA's diagnostic potential.

Observations in 2018

Applying for observation time with ALMA is a competitive process. In 2018, several proposals for ALMA observations of the Sun and other stars have been submitted by RoCS staff of which one has been approved with a PI from RoCS. The proposed observations of the Sun in ALMA Band 3 and Band 6 have been carried out successfully in December 2018.

From measurement to science-ready data

The observational data delivered by ALMA needs to be processed before the resulting time series of images of the solar chromosphere are ready for scientific analysis. The complexity and novelty of these observations makes the processing a very challenging task. The main focus of the ALMA team at RoCS in 2018 has therefore been the development and optimisation of calibration and processing software for ALMA data, resulting in a first version of the Solar ALMA Pipeline (SoAP). The processing also includes the co-alignment of ALMA observations with space-borne co-observations with the IRIS and SDO satellites. Many challenges of interferometric imaging of our Sun have been overcome so that the quality of the resulting image series was improved significantly in 2018. Regular data processing with SoAP started with the first observational data sets from earlier test observations and regular observations from 2016/17 so that an increasing number of data sets now becomes ready for scientific analysis. The long-term aim of RoCS' ALMA efforts is to provide such processed data sets to the wider solar community.

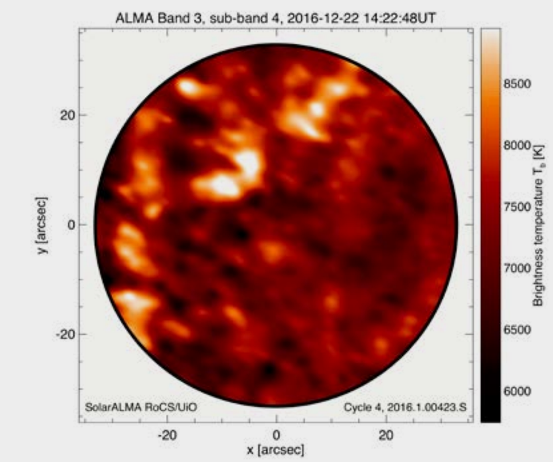
First scientific results

Among the first applications of SoAP-processed data was the detailed comparison of sunspot observations with ultraviolet observations from IRIS. For that purpose, the ALMA data was split into frequency sub-bands that are formed at slightly different heights and thus give a first impression of how the observed structure of the sunspot and its surrounding change with height. The analysis of early data from ALMA Band 3 and Band 6, which cover different wavelength ranges and thus map different heights, has begun with the aim to study the small-scale structure and dynamics of the solar chromosphere by making use of the remarkably high cadence of 2s.

Developing new scientific tools

The ALMA team at RoCS continues to contribute to the further development of the solar observing modes as part of the international ALMA solar development group, gradually expanding the scientific possibilities. The year 2018 also marks the official start of an ESO-funded ALMA development study in co-operation with the Nordic ALMA Regional Center node at the Onsala Space Observatory and Stockholm University, Sweden. In the course of three years, simulation tools will be developed that will allow to quantitatively test, optimise and further develop the data processing pipeline (SoAP) and thus increase the quality and scientific impact of ALMA observations of the Sun. Initial tests have been carried out in 2018. An important requisite for the study was the development of the Advanced Radiative Transfer code (ART), based on an initial version by Jaime de la Cruz Rodriguez (Stockholm University). In the framework of a PRACE Preparatory Access project (2017-18), the performance of ART was increased substantially, making it the future workhorse for producing synthetic observations that are a crucial component of the envisaged processing tests and for comparisons between observations and simulations.

*The SolarALMA project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 682462).



One of the first ALMA Band 3 images produced with the data processing pipeline SoAP. The circular map has a diameter 66 arcseconds, which corresponds to 48000 km on the Sun and thus covers only a small region of it. The brightness temperature (colour-coded, see legend to the right) range from 5700 K to about 9000 K. The image illustrates the complicated structure of the solar chromosphere on a large range of spatial scales. A typical data set contains time series of such images for up to an hour and for different frequencies.

Reaching for the stars

In the future, the ALMA-related activities at RoCS will be extended to the study of other stars, providing wider parameter ranges to which the Sun as a reference star can be compared to. In 2018, the international team "A New View of the Solar-stellar Connection with ALMA", led by S. Wedemeyer (RoCS), T. Bastian and H. Hudson and funded by the International Space Science Institute (ISSI), Bern, Switzerland, had its second meeting and created a plan for how to review the phenomenon of solar and stellar activity with the new observational possibilities provided by ALMA. In December 2018, a FRINATEK project was granted by the Research Council of Norway, named EMISSA (Exploring Millimeter Indicators of Solar-Stellar Activity). The EMISSA project will start at RoCS in 2019 and will complement ongoing research.

Networking

The Norwegian ALMA Day 2018 was held on March 21, 2018, in cooperation with the Nordic ALMA Regional Center node, Onsala Space Observatory, Sweden. As in the year before, the aim was to attract new potential ALMA users from Norway and to inform about new possibilities in the then announced observing cycle 6. The Solar Simulations for the Atacama Large Millimeter Observatory Network (SSALMON) continued its work and launched a new expert team tasked to find a common standard for data processing of solar ALMA data.

Public outreach and networking

The SolarALMA project was presented at public outreach events at the University of Oslo for teachers ("Faglig pedagogisk dag) and for school classes ("Ungforsk"). The project was also featured in the article "Sun like it hot" in EU's research and innovation magazine Horizon.

A. Marinkovic/X-Cam/ALMA (ESO/NAOJ/NRAO)

The ALMA 12m antennas can be relocated in different array configurations with different sizes and resulting angular resolution. On this picture, a 12m antenna is transported to its new location.

ALMA (ESO/NAOJ/NRAO)

ALMA combines different types of antennas, which have been developed and produced by Europe, North America, and Japan. For observations of the Sun, more than 50 antennas are connected in order to mimic a telescope with a diameter of up to 500m. The number of the involved antennas and the resulting size of this array will be increased in the future.

Four antennas of the Atacama Large Millimeter/ submillimeter Array (ALMA) at the Operations Support Facility (OSF), 2900 m above sea level. The three larger antennas have a diameter of 12m whereas the smaller one measures 7m. The different sizes and flexible locations within the array enable unprecedented observations of a multitude of different objects on the sky, including our Sun. The ALMA project is an international collaboration between Europe, East Asia and North America in cooperation with the Republic of Chile.

A. Marinkovic/X-Cam/ALMA (ESO/NAOJ/NRAO)

New code developments

To reach the ambitious goal of modelling the active sun, we need new codes that are radically different from the codes that have so far been used in the investigation of the solar atmosphere.

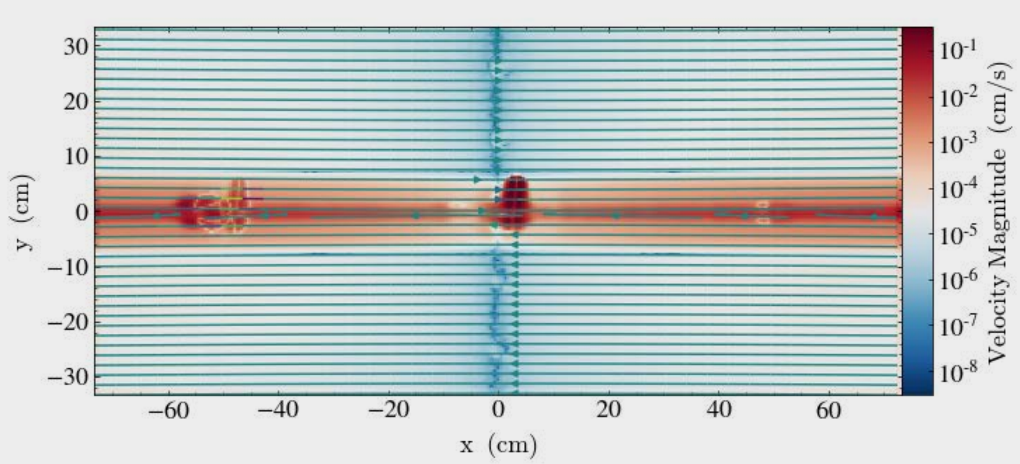
The end goal is to produce a code that is able to handle the different physical regimes and the different resolution requirements needed in different regions of the active sun. Examples of very different physical regimes could be the deep convection zone where the typical time scale and length scale are hours and several Mm respectively and the relevant physics can be handled (almost) as simple hydrodynamics. Conversely, the inner parts of a solar flare involve magnetic instabilities than cannot be well simulated by MagnetoHydroDynamics(MHD) because the diffusion length is on the order of the mean free path of the ions and electrons in the solar corona. Consequently, we now need to employ a Particle In Cell (PIC) code to treat the electromagnetic environment of the constituent particles in the coronal plasma to provide the correct answers to how solar flares are produced and in which way they release the large amount of energy we observe from our solar observatories.

Three development paths

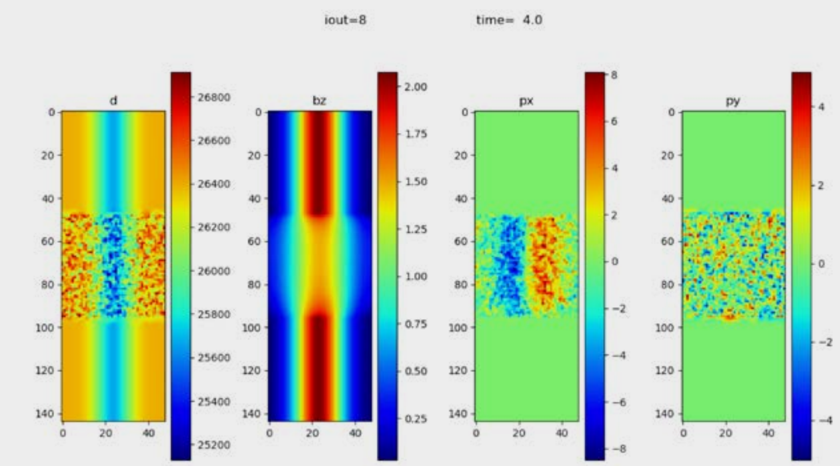
The numerical tools being developed under RoCS have in 2018 been focused on three aspects: The integration of Bifrost into the DISPATCH framework, the ability of DISPATCH to seamlessly switch between different types of physics and finally running simulations spanning, large physical volumes and including large amounts of magnetic flux.

Bifrost & DISPATCH

Bifrost is at the moment one of the leading numerical codes for simulating the solar atmosphere from the upper convection zone to the lower corona. Due to the inherently modular structure of Bifrost, the integration of Bifrost into DISPATCH can be done in steps. After the initial step of settling on a plan for the integration, we have also been working on a self-contained testing strategy which make it possible to stop bugs from infecting the production version of the code and should make it possible for us to evaluate implementation strategies much faster. This automatic testing regime was only partially implemented in Bifrost and existing in DISPATCH, so the two versions of such a system needed integration. The main MHD solver of Bifrost has now been implemented in the DISPATCH framework, and initial testing results are being produced, with the goal of running further more complex setups during 2019.



Magnetic reconnection test experiment with the main Bifrost MHD solver implemented in the DISPATCH framework.



Test of the PIC and MHD running in the same simulation with shared boundaries, and the ability to transfer information correctly across boundaries. Here a vertical flux tube is simulated with MHD in the lower and upper third of the simulation domain, while the central domain is simulated with a PIC code. The images show a cut through the center of the flux tube. Gyration of the particles modelled with the PIC code is not modelled by MHD and is absent in the MHD domains.

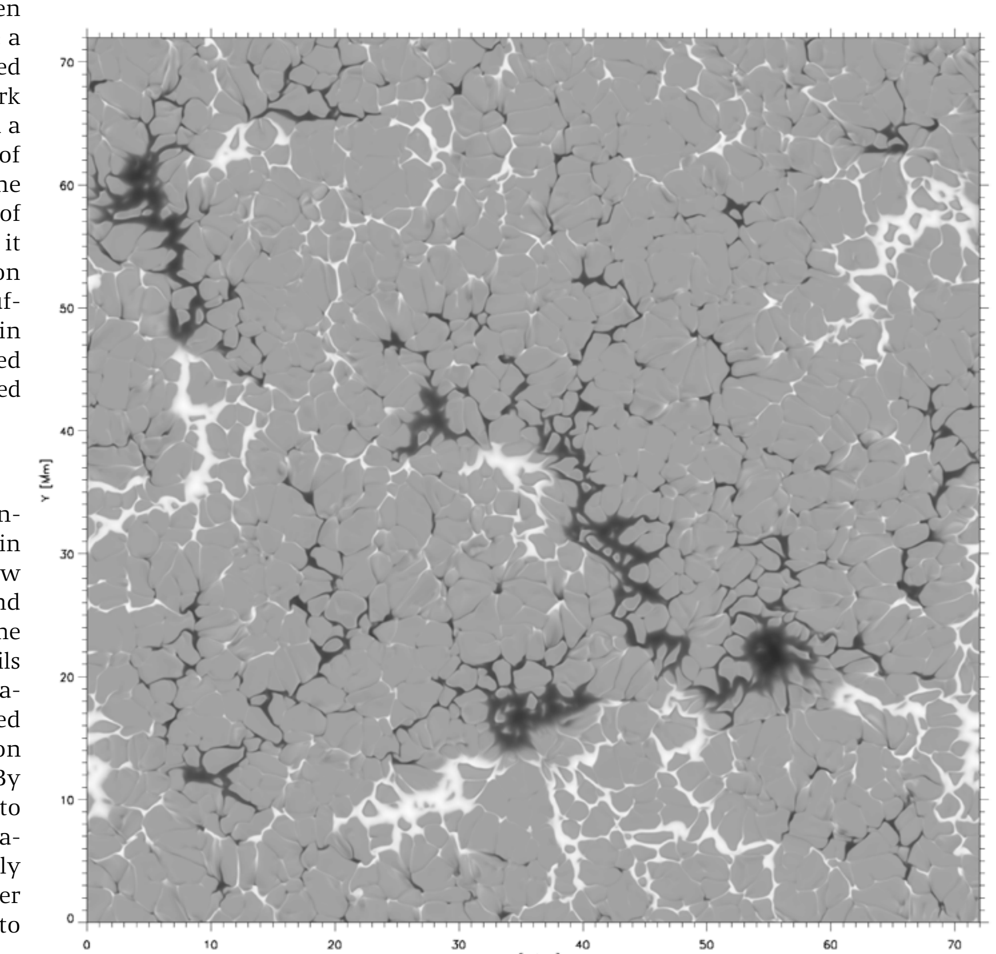
Regime switching

This path has been developing in sequence with the integration path, and should allow us to seamlessly switch from one physical regime to another. The borders between the physical regimes will naturally be a difficult problem, so it has been prioritised to be one of the first to be handled and work has started on the boundaries between a PIC description and MHD description of the physics of the solar corona. Since the PIC description provides a distribution of particle velocities and masses in a cell, it is important to find the correct location where a fluid, as in MHD, is again a sufficient description of the physics and in that case, how to translate the distributed values of the particles into the single valued fluid variables.

Large dimensions and magnetic flux

To run a simulation large enough to include supergranules one needs a domain that goes down to at least 9 Mm below the photosphere. Here the time scale and length scale are so much larger than in the photosphere that we can neglect the details of the photosphere to a first approximation until the deeper layers have adjusted to the radiative losses and the injection of enthropy at the bottom of the box. By having a resolution only good enough to resolve the deepest layers, the computational time remains short. By gradually increasing the resolution when the deeper layers have adjusted, means we start to simulate the not so deep layers correctly. In the end we have a simulation where the deep layers are well modelled as well as the photosphere, without wasting too much computational time. We have run two simulations which are 72 Mm square and 9 Mm deep. Both are running and producing interesting science already. We can investigate the formation of magnetic structures and sunspots through these models and have a basis for later simulations.

Magnetogram created from a high magnetic flux simulation including 9 Mm of the convection zone, to produce supergranular-like structures in the granulation pattern.



International Rosseland Visitor Programme

Many previous centres of excellence have concluded that visits from internationally leading scientists have been among the most valuable outcomes of having a centre. The International Rosseland Visitor Programme takes the international exchange even further by including funds for visits by researchers at professor, post-doctoral and PhD level to be used for shorter or longer visits to RoCS.

"Looking in the rear mirror and questioning myself what made the biggest change with the creation and the operation of CIR, I am tempted to say the Visiting Professor programme."

Ludvig M. Sollid, director of Centre for Immune Regulation (CIR). From CIR final report 2007-2017.

Rajashik Tarafder, final year master student at IISER-Kolkata, India. He did his master internship at RoCS January-March 2018 with Mats Carlsson. He was studying beam-heating during flares using the RADYN radiation hydrodynamics code.

Baptiste Pellorce, first-year master student at Claude Bernard University Lyon 1, France. He did his master internship from March to June 2018 with Tiago Pereira. He worked on the open source IRISpy and NDcube projects, developing Python tools to read and visualise IRIS observations.

Alberto Sainz Dalda, researcher at Bay Area Environmental Research Institute and Lockheed Martin Solar and Astrophysics Laboratory, visited in April, working with Tiago Pereira on synthesis of chromospheric lines with the RH 1.5D code.

Marouchka Froment, first-year master at ENS Paris-Saclay, France. She did her master internship from April, 16 to July, 27 2018 with Clara Froment. She analysed SDO and STEREO data in connection with coronal heating events. In particular, she performed thermal diagnostics of the coronal plasma for a combined event showing coronal rain and periodic prominence eruptions.

Åke Nordlund, professor at Copenhagen University. He visited in April and is working on implementing our codes within the DISPATCH framework.

Lyndsay Fletcher, professor at University of Glasgow, and Christopher Osborne, PhD student, visited in May, working with Mats Carlsson on understanding radiative transfer under flare conditions.

Patrick Antolin visited RoCS in June 2018 and worked with Clara Froment on the analysis of a coronal rain event observed with the SST and SDO. This visit initiated the development of a new code for the spectral characterisation of coronal rain. He also worked with Sven Wedemeyer and Shahin Jafarzadeh in connection with ALMA observations.

Juan Martínez Sykora, researcher at Bay Area Environmental Research Institute and Lockheed Martin Solar and Astrophysics Laboratory, visited in February-March, August and September. He is working on a multi fluid multi species code designed to study how the various elements and ions move in relation to each other in the collision poor chromosphere and the effects this has on heating and dynamics in the outer atmosphere.

Ineke De Moortel, professor at University of St.Andrews, visited in August. She is an expert on waves using both mathematical and numerical approaches to study their interaction and influence on the solar corona.

Jiajia Liu, postdoctoral research associate at the University of Sheffield. He visited in September-October working with Mats Carlsson on automatic detection of vortices in Bifrost simulations.

Members of the centre

The main resource of RoCS and its most important contributor is our staff. Everyone at our centre, scientific, administrative and technical, is handpicked because of their excellent qualifications and expertise. During 2018 we had eight doctoral research fellows, five postdocs, five researchers, two associate professors, three professors and one centre coordinator. In addition we had two adjunct professors, as well as six associated members in the administrative and technical staff. Our Scientific Advisory Committee consisted of 4 members. Owing to our privileged position as a centre of excellence, we are able to grow in numbers, hiring talented and exceptional researchers of a large number of nationalities. All our members are putting their best efforts into strengthening our scientific achievements, set forward new goals and reach even higher standards for our research.

Phd

Helle Bakke

Helle Bakke is a doctoral research fellow at RoCS. Helle is at the interface between observations and numerical models, and is focusing on the effect of accelerated particles in the solar atmosphere. She enjoys outreach and social activities, and one of her favourite parts of the job is being a teaching assistant.

Souvik Bose

Souvik Bose is a doctoral research fellow at RoCS. Souvik's research mainly focuses on the dynamics of the solar atmosphere, in particular the origin and the evolution of spicules in the solar chromosphere. He is mainly an observer and uses the data from both ground and space-based solar telescopes for his research. In addition he makes use of numerical radiative transfer codes for reproduction of synthetic data to compare with the observations.

Frederik Clemmensen

Frederik Clemmensen is a doctoral research fellow at RoCS. The primary topic of Frederik's research is the processes in the solar atmosphere that leads to highly energetic, accelerated particles. For this purpose, he uses new methods of numerical modelling which he is involved in developing. In general, Frederik is interested in programming and developments in computing.

Ainar Drews

Ainar Drews is a doctoral research fellow at RoCs and his research is focused on observations of the Sun. Some of his earlier work is dedicated to partial automation of solar observations using simple machine learning. Ainar's research revolves around the investigation of primarily chromospheric objects in the penumbrae of sunspots called Penumbral Microjets, employing both ground- and space- based instruments.

Henrik Eklund

Henrik Eklund is a doctoral research fellow at RoCS. His research is focused on determining optimal ways to utilise interferometric ALMA observations to study the solar atmosphere. A strong combination of numerical simulations and observations is used in this work. Henrik is also studying planetary formation through both simulations and interferometric observations.

Lars Frogner

Lars Frogner is a doctoral research fellow at RoCS. Lars' research is mainly concerned with numerical modelling of the solar atmosphere, in particular the origin, behavior and effect of accelerated particles. He is generally interested in a range of topics in software development, including numerical simulations and computer graphics.

Juan Camilo Guevara Gómez

Juan Camilo Guevara Gómez is a doctoral research fellow at RoCS. Juan is mainly analysing observational data taken by ALMA aimed to reveal further details of the physical processes contributing to the coronal heating as well as to understand and to describe the chromospheric dynamics at millimeter/submillimeter wavelengths. He also enjoys contributing in computational focused projects. Juan is also active in outreach activities and enjoys communicating science to the public.

Charalambos Kanella

Charalambos Kanella is a doctoral research fellow interested in the solar coronal heating problem, magnetic topology, heating mechanisms, magnetic reconnection, joule heating and generally the solar atmosphere. Besides that, he shows strong interest in space weather, astrophysical plasma and planetary science. He also likes to be updated on aurora activities. Charalambos Kanella successfully defended his PhD on October 10 2018.

Postdocs and researchers

Clara Froment

Clara Froment is a researcher at RoCS: Clara is mainly investigating the processes that heat the outer layer of the Solar atmosphere, the Corona. She is using both observations and numerical simulations to study the thermodynamics of active regions. Her main research topic focuses on the characterisation of evaporation and condensations cycles in coronal loops, which are the signature of a steady heating mainly concentrated in the lower atmosphere of the Sun. For that, Clara is using a combination of satellites and ground-based observations that span the different layer of the solar atmosphere. On top of that, she enjoys very much participating in public outreach activities.

Vasco Henriques

Vasco Henriques is a researcher at RoCS. Vasco investigates poorly understood dynamic processes at small-scales in our star, especially in active regions. For this, he primarily observes using the Swedish 1-meter Solar Telescope and then uses supercomputers to find models that reproduce those observations. He is also working on the connection across multiple layers in the Sun's atmosphere via jet-like features, which are ever-present but difficult to observe, especially in satellite data. Vasco has had a passion for astronomy since he would bring his small telescope to astronomy festivals in the Portuguese countryside as a teenager, and has a passion for new technologies for and beyond science.

Jayant Joshi

Jayant Joshi is a postdoctoral researcher at RoCS. Jayant's research is mostly focused on measuring the magnetic field in the solar lower atmosphere. He is mainly an observer, and he makes use of both, ground-based and spaceborne solar telescopes.

Daniel Nóbrega Siverio

Daniel Nóbrega-Siverio is a postdoctoral researcher at RoCS. He studies eruptive phenomena in the solar atmosphere associated with magnetic flux emergence processes, like surges, and the magnetic flux emergence process itself. In addition, he is very interested in unraveling the role of nonequilibrium and partial ionization effects in the chromosphere. His main approach is theoretical, through numerical experiments carried out using the state-of-the-art Bifrost code, combined with forward modeling to compare with observations.

Ada Ortiz-Carbonell

Ada Ortiz-Carbonell is a researcher at RoCS. She studies the process of magnetic flux emergence from the interior of the Sun into the outer solar atmosphere. She also studies the process known as reconnection. She is an observer with a big data analysis component, and uses a combination of ground-based and space-borne observations in order to cover a wider range of layers in the solar atmosphere. She is involved in the European Solar Telescope project, participating in the Science Advisory Group and being the EST Norwegian Communications officer.

Tiago M. D. Pereira

Tiago M. D. Pereira is a researcher at RoCS (PI and associate professor from February 1st 2019). He studies dynamic processes in stellar atmospheres. In particular, he is working on the solar chromosphere, the interface between the hot corona and the dense surface. Tiago leverages space and ground-based observations with detailed radiative transfer calculations from 3D models. With an interest in computational astrophysics, data analysis and visualisation, he works with high-performance computing and big data problems.

Shahin Jafarzadeh

Shahin Jafarzadeh is a researcher at RoCS. Shahin's main studies concern the lower-to-mid atmosphere of the Sun, regarding how magnetic fields structure dynamics of those layers – toward understanding the mysterious heating of the Sun's atmosphere. He is predominantly interested in characterisation of wave activities in the lower solar atmosphere. To this end, he works within the WaLSA international science team (https://WaLSA.team), of which, he is a coordinator. Shahin is an experienced observer and passionately engages in various public outreach activities.

Petra Kohutova

Petra Kohutova is a postdoctoral researcher at RoCS. Petra studies processes responsible for matter and energy transfer between different layers of solar atmosphere. She uses a technique called coronal seismology, which is based on using the properties of waves in the solar atmosphere for diagnostics of coronal parameters. To do this, she combines high-resolution solar observations with numerical simulations.

Andrius Popovas

Andrius Popovas, postdoctoral researcher at RoCS: numerical simulations of the Solar atmosphere are his working horse. He is upgrading the code Bifrost to make it exascale-ready and be able to work with many additional features, like adaptive mesh refinement, independent time-stepping, multi-solver-multi-physics, etc.

Mikolaj Szydlarski

Mikolaj Szydlarski is a researcher at RoCS. Physicist and Mathematician by education, but Computer Scientist by heart. Mikolaj is interested in the application of high-performance computing (HPC) to challenging problems in solar astrophysics. His fields of expertise include MHD simulations and Solar ALMA data reduction.

Professor II's and adjunct professors

Lyndsay Fletcher

Lyndsay Fletcher is adjunct professor at RoCS. Her main research interest is solar flares, specifically the transport of energy through the flare atmosphere, the energisation of the chromosphere and the interpretation of radiation signatures to help us understand this process. She works mostly on data analysis, figuring out ways to confront data with flare models. She teaches students at all levels in her home institute (University of Glasgow, UK) and leads efforts to increase the fraction of women and girls participating in physics and astronomy. She was a member of RoCS' Scientific Advisory Committee until the 30th of November 2018.

Bart De Pontieu

Bart De Pontieu is adjunct professor at RoCS. His main research interest lies in the heating of the outer solar atmosphere. He is an expert in interpreting high resolution observational data, both from space and from the ground, in the context of numerical models. Amongst many other topics he has done ground breaking work on the importance of spicules to our understanding of the energetics and dynamics of the chromosphere and corona. Bart is the PI of the IRIS satellite and manages a large group at Lockheed Martin Solar and Astrophysical Laboratory.

Centre leadership and administration

Mats Carlsson

Mats Carlsson is a professor and the director of RoCS. Main interests include chromospheric physics and radiation MHD. He is working with both large-scale simulations and observations from the ground and from space.

Boris Gudiksen

Boris Gudiksen is an associate professor and PI at RoCS with focus on the development of numerical codes used to run simulations of the solar atmosphere. His main interest is the solar corona and how it maintains its high temperature.

Viggo Hansteen

Viggo Hansteen is a professor and PI at RoCS. He works both on simulations and observations, from the ground and from space. He is interested in how the magnetic field is formed in the deep convection zone, how it rises to the photosphere, and how it forms the outer solar atmosphere. Coronal heating and chromospheric dynamics and energetics seen by numerical models and comparisons with high resolution, high quality, diagnostics are keywords.

Benedikte Fagerli Karlsen

Benedikte Fagerli Karlsen is the centre coordinator at RoCS. She is responsible for the administration of the centre and takes care of all practical tasks related to the centre's activity. Among her tasks are new employments, visitors, contracts, reporting and logistics at events.

Luc Rouppe van der Voort

Luc Rouppe van der Voort is a professor and PI at RoCS. Luc's main area of research is high-resolution observations of the Sun. He is a veteran observer at the Swedish 1-m Solar Telescope on the island of La Palma. After years of main focus on the lower parts of the solar atmosphere, he is extending his interest up into the transition region and corona through coordinated observations with the IRIS satellite.

Sven Wedemeyer

Sven Wedemeyer is an associate professor and PI at RoCS. Sven leads the research activities related to solar observations with ALMA and supporting simulations, which involves the ERC-funded SolarALMA project, an ESO-funded development study, and the SSALMONetwork. His research mostly focuses on the small-structure, dynamics and energy balance of the solar atmosphere with implications for other stellar types.

Technical and administrative associated staff

Martina D'Angelo

Martina D'Angelo is the communication advisor and press contact at the Institute of Theoretical Astrophysics (ITA) and RoCS. Martina's main responsibilities are internal communication, creating and coordinating outreach activities, writing popular science articles about the ongoing research and news at ITA and RoCS, web editor of ITA's and RoCS' web pages and related social media channels.

Terje Fredvik

Terje Fredvik is an engineer in the institute's Project Related IT Services Group. Terje is the lead of the development of the data pipeline for the SPICE instrument on Solar Orbiter. He is also a contributor to the operations of the Hinode Science Data Centre Europe, a member of the ITA FITS Working Group, and assists in the adaptation of the SOLARNET FITS mechanisms for both observational and simulated data.

Stein Vidar Haugan

Stein Vidar Haugan is the lead engineer in the institute's Project Related IT Services Group. Stein is the main contributor to the architecture and operations of the Hinode Science Data Centre Archive Europe, which also serves IRIS data and will later on also serve other data sets, from e.g. ALMA. He is also a member of the ITA FITS Working Group, acts as a liaison between RoCS and the SOLARNET project, and contributes to the development of the data pipeline for the SPICE instrument on Solar Orbiter.

Kristine Aa. S. Knudsen

Kristine Aa. S. Knudsen is the Head of Office at the Institute of Theoretical Astrophysics. She is the head of our administration, and cooperates closely with both the scientific, technical and administrative staff at RoCS and the Institute.

Torben Leifsen

Torben Leifsen is the head of IT at the institute. He is responsible for planning, building and running the IT systems together with the IT-group at the institute. We are currently operating one server room and are in the process of building a second to accomodate the needs of RoCS and other projects. Torben has a background in solar physics, and is a member of the Virgo team on the ESA spacecraft SOHO doing research in helioseismology in his spare time.

Martin Wiesmann

Martin Wiesmann is an engineer in the institute's Project Related IT Services Group: Martin is responsible for part of the IRIS pipeline as well as the adaptation of AIA and Hinode data to IRIS data. He also contributes to the Solar Orbiter SPICE pipeline and quicklook software. He is mainly a programmer, implementing requests and wishes from various scientists into the pipeline or as separate programs.

Scientific Advisory Committee

Tony Arber

Tony Arber is a computational plasma physicist whose interests span solar physics, space weather, laser-plasmas and QED-plasmas. He has been responsible for developing MHD codes for both solar physics and laser-driven fusion as well as kinetic codes for high-power plasma interactions. For all codes, he is interested in software development methods and uncertainty quantification.

Lyndsay Fletcher

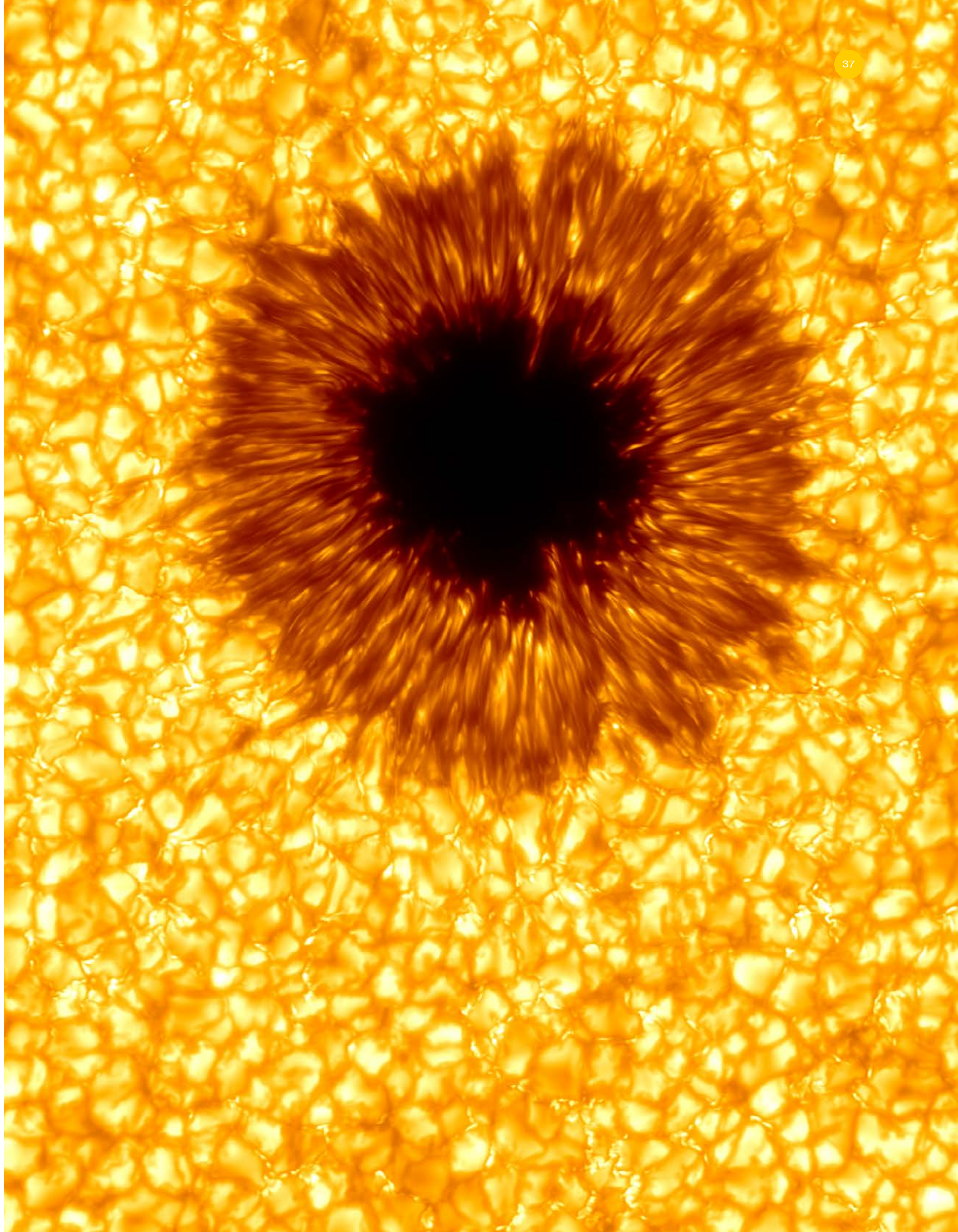
Professor Lyndsay Fletcher was a part of RoCS' Scientific Advisory Committee from the 1st of November 2017 until the 30th of November 2018, after which she took up an adjunct professor position at RoCS. Her main position is as a professor at the University of Glasgow. More information about professor Fletcher may be found under "Professor II's and adjunct professors".

Oskar Steiner

Oskar Steiner is a senior researcher at the Leibniz-Institut für Sonnenphysik (KIS) in Freiburg, Germany and at the Istituto Ricerche Solari Locarno (IRSOL) in Switzerland. His research focusses on the numerical simulation of magnetohydrodynamic processes in the solar and stellar atmospheres. He is also interested in polarimetry and numerical methods of radiative transfer.

Francesca Zuccarello

Francesca Zuccarello is an associate professor at the University of Catania (Italy). Francesca is involved in the study of emergence, evolution and decay of solar active regions, as well as in research related to solar eruptive events. Francesca is mainly an observer. She participated in several Coordinated Observational Campaigns.



Talks and presentations 2018

Carlsson, Mats.: Rosseland Senter for Solfysikk. Foredrag, Matematisk Naturvitenskapelig fakultet; 2018-01-18

Carlsson, Mats.: More realistic starting solutions for Radyn. ISSI meeting; 2018-02-12 - 2018-02-16

Carlsson, Mats.: Solen - din nærmeste stjerne. Åpen dag; 2018-03-08

Carlsson, Mats.: Modelling of the Chromosphere. ISSI meeting; 2018-03-13 - 2018-03-16

Carlsson, Mats.: Chromospheric Dynamics and Magnetism. EWASS; 2018-04-03 - 2018-04-06

Carlsson, Mats.: SRD: Report from WG2. EST Science Meeting; 2018-06-11 - 2018-06-15

Carlsson, Mats.: Optically thick diagnostics. IRIS-9; 2018-06-25 - 2018-06-29

Carlsson, Mats.: Radiative transfer. IRIS-9; 2018-06-25 - 2018-06-29

Carlsson, Mats.: An IRIS optically thin view of the dynamics of the solar chromosphere. IRIS-9; 2018-06-25 - 2018-06-29

Carlsson, Mats.: Chromospheric Structure, Heating and Dynamics. Workshop on modern methods in Solar Physics; 2018-08-29 - 2018-08-30

Carlsson, Mats.: Solfysikk. Foredrag, Nærings og fiskeridepartementets forsknings og innovasjonsavdeling; 2018-10-22

Carlsson, Mats.: Gode forskningsresultater og ERC SyG. Foredrag, SFF samling i Norges forskningsråd; 2018-11-22 - 2018-11-22

Carlsson, Mats.: Recent developments in modelling of the chromosphere. Seminar, Yunnan Solar Observatory; 2018-12-04

Carlsson, Mats.: Recent developments in modelling of the chromosphere. Seminar, National Astronomical Observatories of China; 2018-12-06

Carlsson, Mats.: Solar Radiation MHD, part I. Lecture, NAOC; 2018-12-06 Carlsson, Mats.: Solar Radiation MHD, part II. Lecture, NAOC; 2018-12-07

Carlsson, Mats.: Recent developments in modelling of the chromosphere. Seminar, Kavli Institute for Astronomy & Astrophysics; 2018-12-10

Fredvik, Terje.: SPICE Data Pipeline and Data Products. SPICE Consortium Meeting 3; 2018-04-19 - 2018-04-20

Fredvik, Terje.: Oslo SPICE Status. SPICE Consortium Meeting 2; 2018-11-13 - 2018-11-14

Fredvik, Terje.: SPICE FITS Hardcore. SPICE Operations Consortium Meeting 3; 2018-11-13 - 2018-11-14

Fredvik, Terje.: SPICE FITS 101. SPICE Operations Consortium Meeting 3; 2018-11-13 - 2018-11-14

Froment, Clara.: Evaporation and condensation cycles in coronal loops and heating of the solar corona. Seminar at IAS

Froment, Clara.: Long-period EUV Pulsations & Coronal Rain : Manifestations of Solar Coronal Loops Heating Properties. Seminar at the LPC2E

Froment, Clara.: Long-period intensity pulsations in coronal loops. BUKS workshop; 2018-09-03 - 2018-09-07

Froment, Clara; Antolin, Patrick; Henriques, V. M. J.; Rouppe van der Voort, Luc.: Multi-scale observations of thermal nonequilibrium cycles in coronal loops. Hinode 12 conference; 2018-09-10 - 2018-09-13

Froment, Clara; Antolin, Patrick; Henriques, V. M. J.; Rouppe van der Voort, Luc.: Multi-scale observations of thermal nonequilibrium cycles in coronal loops. Colloque Programme National Soleil-Terre; 2018-11-19 - 2018-11-21

Hansteen, Viggo.: Ion neutral effects in the solar chromosphere and type II spicules. Dynamic Sun II: Solar Magnetism from the interior to the corona; 2018-02-12 - 2018-02-16

Hansteen, Viggo.: The Heating of the Solar Chromosphere and Corona, What can "realistic" 3D Numerical Models teach us?. 17th Annual International Astrophysics Conference; 2018-03-05 - 2018-03-09

Hansteen, Viggo.: Chromospheric Dynamics and Heating Processes Ion-Neutral Effects in the Solar Chromosphere and Type II Spicules. Triannual Earth Sun Summit; 2018-05-20 - 2018-05-24

Hansteen, Viggo.: Modeling chromospheric heating and dynamics: What do we understand?. EST Science Meeting; 2018-06-11 - 2018-06-15

Hansteen, Viggo.: Ellerman bombs and UV bursts: reconnection at different atmospheric layers?. IRIS 9 konferanse; 2018-06-25 - 2018-06-29

Hansteen, Viggo.: Ellerman bombs and UV bursts: reconnection at different atmospheric layers?. SDO 2018 Science Workshop; 2018-10-29 - 2018-11-02

Hansteen, Viggo.: Mass and energy flows between the solar chromosphere, transition region and corona. AGU; 2018-12-11 - 2018-12-15

Jafarzadeh, Shahin.: Fibrillar Structures in the Solar Chromosphere. European Week of Astronomy and Space Science (EWASS) 2018; 2018-04-03 - 2018-04-06

Jafarzadeh, Shahin.: Propagation of transverse waves in small-scale magnetic elements through the lower solar atmosphere. DKIST Critical Science Plan Workshop on Wave Generation and Propagation; 2018-04-09 - 2018-04-11

Jafarzadeh, Shahin.: Kahoot quiz on Solar System. Astronomy on Tap Oslo; 2018-06-11

Jafarzadeh, Shahin.: Transverse kink waves in the solar chromosphere. ISSI Meeting on Towards Dynamic Solar Atmospheric Magneto-Seismology with New Generation Instrumentation; 2018-07-02 - 2018-07-06

Jafarzadeh, Shahin.: Kinematics of Magnetic Bright Features in the Solar Photosphere. XXXth General Assembly of the International Astronomical Union; 2018-08-20 - 2018-08-24

Jafarzadeh, Shahin.: Instrumentation for observing waves and instabilities, especially ALMA. BUKS2018: Waves and instabilities in the solar atmosphere: Confronting the current state-of-the-art; 2018-09-03 - 2018-09-07

Jafarzadeh, Shahin.: Observing the dynamic chromosphere. Solar Activity, Magnetism and Irradiance; 2018-10-16 - 2018-10-18

Jafarzadeh, Shahin.: Kahoot quiz with a focus on Earth and Mars. Astronomy on Tap Oslo; 2018-11-26

Mendes Domingos Pereira, Tiago.: Thermal coupling through the atmosphere. 9th IRIS workshop; 2018-06-25 - 2018-06-29

Rouppe van der Voort, Luc.: Alignment between IRIS and ground-based data. IRIS-9; 2018-06-25 - 2018-06-29

Rouppe van der Voort, Luc.: Spicules with SST. Modern techniques in solar physics; 2018-08-29 - 2018-08-30

Wedemeyer, Sven.: Experiences from applying for an ERC Consolidator Grant. ERC Consolidator seminar; 2018-01-19

Wedemeyer, Sven.: Solar Observations with ALMA. Imaging of Stellar Surfaces; 2018-03-05 - 2018-03-09

Wedemeyer, Sven.: Sola, din nærmeste stjerne. Ungforsk 2018; 2018-09-26 - 2018-09-27

Wedemeyer, Sven.: Oppvarming av solens atmosfære & solfysikkforskning i dag. Faglig-pedagogisk dag; 2018-10-31

Papers in refereed journals 2018

Antolin, P., Schmit, D., **Pereira, T. M. D., De Pontieu, B.**, & De Moortel, I.: 2018, The Astrophysical Journal 856, 44, Transverse Wave Induced Kelvin-Helmholtz Rolls in Spicules

Auchère, F., **Froment, C.**, Soubrié, E., Antolin, P., Oliver, R., & Pelouze, G.: 2018, The Astrophysical Journal 853, 176, The Coronal Monsoon: Thermal Nonequilibrium Revealed by Periodic Coronal Rain

Bakke, H., Frogner, L., & Gudiksen, B. V.: 2018, Astronomy and Astrophysics 620, L5, Non-thermal electrons from solar nanoflares. In a 3D radiative MHD simulation

Bastian, T. S., Chintzoglou, G., **De Pontieu, B.**, Shimojo, M., Schmit, D., Leenaarts, J., & Loukitcheva, M.: 2018, The Astrophysical Journal 860, L16, Erratum: A First Comparison of Millimeter Continuum and Mg II Ultraviolet Line Emission from the Solar Chromosphere

Bjørgen, J. P., Sukhorukov, A. V., Leenaarts, J., **Carlsson, M.**, de la Cruz Rodríguez, J., Scharmer, G. B., & Hansteen, V. H.: 2018, Astronomy and Astrophysics 611, A62, Three-dimensional modeling of the Ca II H and K lines in the solar atmosphere

Bose, S., & Nagaraju, K.: 2018, The Astrophysical Journal 862, 35, On the Variability of the Solar Mean Magnetic Field: Contributions from Various Magnetic Features on the Surface of the Sun

Bose, S., & Nagaraju, K.: 2018, IAU Symposium 340, 85, Role of the background regimes towards the Solar Mean Magnetic Field (SMMF)

Brajša, R., Sudar, D., Benz, A. O., Skokić, I., Bárta, M., **De Pontieu, B.**, Kim, S., Kobelski, A., Kuhar, M., Shimojo, M., Wedemeyer, S., White, S., et al.: 2018, Astronomy and Astrophysics 613, A17, First analysis of solar structures in 1.21 mm full-disc ALMA image of the Sun

Chintzoglou, G., **De Pontieu, B.**, Martínez-Sykora, J., **Pereira, T. M. D.**, Vourlidas, A., & Tun Beltran, S.: 2018, The Astrophysical Journal 857, 73, Bridging the Gap: Capturing the Ly Counterpart of a Type-II Spicule and Its Heating Evolution with VAULT2.0 and IRIS Observations

Freudenthal, J., von Essen, C., Dreizler, S., **Wedemeyer, S.**, Agol, E., Morris, B. M., Becker, A. C., Mallonn, M., Hoyer, S., Ofir, A., Tal-Or, L., Deeg, H. J., et al.: 2018, Astronomy and Astrophysics 618, A41, Kepler Object of Interest Network. II. Photodynamical modelling of Kepler-9 over 8 years of transit observations

Froment, C., Auchère, F., Mikić, Z., Aulanier, G., Bocchialini, K., Buchlin, E., Solomon, J., & Soubrié, E.: 2018, The Astrophysical Journal 855, 52, On the Occurrence of Thermal Nonequilibrium in Coronal Loops

Gošić, M., de la Cruz Rodríguez, J., **De Pontieu, B.**, Bellot Rubio, L. R., **Carlsson, M.**, Esteban Pozuelo, S., **Ortiz, A.**, & Polito, V.: 2018, The Astrophysical Journal 857, 48, Chromospheric Heating due to Cancellation of Quiet Sun Internetwork Fields

Hong, J., Ding, M. D., Li, Y., & **Carlsson, M.**: 2018, The Astrophysical Journal 857, L2, Non-LTE Calculations of the Fe I 6173 A Line in a Flaring Atmosphere

Joshi, J., & de la Cruz Rodríguez, J.: 2018, Astronomy and Astrophysics 619, A63, Magnetic field variations associated with umbral flashes and penumbral waves

Kanella, C., & Gudiksen, B. V.: 2018, Astronomy and Astrophysics 617, A50, Investigating 4D coronal heating events in magnetohydrodynamic simulations

Kianfar, S., **Jafarzadeh, S.**, Mirtorabi, M. T., & Riethmüller, T. L.: 2018, Solar Physics 293, 123, Linear Polarization Features in the Quiet-Sun Photosphere: Structure and Dynamics

Klevas, J., Kučinskas, A., **Wedemeyer, S.**, & Ludwig, H.-G.: 2018, Contributions of the Astronomical Observatory Skalnate Pleso 48, 280, Impact of magnetic fields on the structure of convective atmospheres of red giant stars

Kuridze, D., **Henriques, V. M. J.**, Mathioudakis, M., **Rouppe van der Voort, L.**, de la Cruz Rodríguez, J., & **Carlsson, M.**: 2018, The Astrophysical Journal 860, 10, Spectropolarimetric Inversions of the Ca II 8542 A Line in an M-class Solar Flare

Leenaarts, J., de la Cruz Rodríguez, J., Danilovic, S., Scharmer, G., & **Carlsson, M.**: 2018, Astronomy and Astrophysics 612, A28, Chromospheric heating during flux emergence in the solar atmosphere

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Moreno-Insertis, F., Martínez-Sykora, J., **Hansteen, V. H.**, & Muñoz, D.: 2018, The Astrophysical Journal 859, L26, Small-scale Magnetic Flux Emergence in the Quiet Sun

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Panesar, N. K., Sterling, A. C., Moore, R. L., Tiwari, S. K., **De Pontieu, B.**, & Norton, A. A.: 2018, The Astrophysical Journal 868, L27, IRIS and SDO Observations of Solar Jetlets Resulting from Network-edge Flux Cancelation

Pereira, T. M. D.: 2019, Advances in Space Research 63, 1434, The dynamic chromosphere: Pushing the boundaries of observations and models

Pereira, T. M. D., Rouppe van der Voort, L., Hansteen, V. H., & De Pontieu, B.: 2018, Astronomy and Astrophysics 611, L6, Chromospheric counterparts of solar transition region unresolved fine structure loops

Polito, V., Testa, P., Allred, J., **De Pontieu, B., Carlsson, M., Pereira, T. M. D.**, Gošić, M., & Reale, F.: 2018, The Astrophysical Journal 856, 178, Investigating the Response of Loop Plasma to Nanoflare Heating Using RADYN Simulations

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Stangalini, M., **Jafarzadeh, S.**, Ermolli, I., Erdélyi, R., Jess, D. B., Keys, P. H., Giorgi, F., Murabito, M., Berrilli, F., & Del Moro, D.: 2018, The Astrophysical Journal 869, 110, Propagating Spectropolarimetric Disturbances in a Large Sunspot

Tiwari, S. K., Moore, R. L., **De Pontieu, B.**, Tarbell, T. D., Panesar, N. K., Winebarger, A. R., & Sterling, A. C.: 2018, The Astrophysical Journal 869, 147, Evidence of Twisting and Mixed-polarity Solar Photospheric Magnetic Field in Large Penumbral Jets: IRIS and Hinode Observations

Trujillo Bueno, J., Stěpán, J., Belluzzi, L., Asensio Ramos, A., Manso Sainz, R., del Pino Alemán, T., Casini, R., Ishikawa, R., Kano, R., Winebarger, A., Auchère, F., Narukage, N., Kobayashi, K., Bando, T., Katsukawa, Y., Kubo, M., Ishikawa, S., Giono, G., Hara, H., Suematsu, Y., Shimizu, T., Sakao, T., Tsuneta, S., Ichimoto, K., Cirtain, J., Champey, P., **De Pontieu, B., Carlsson, M.**: 2018, The Astrophysical Journal 866, L15, CLASP Constraints on the Magnetization and Geometrical Complexity of the Chromosphere-Corona Transition Region

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Young, P. R., Tian, H., Peter, H., Rutten, R. J., Nelson, C. J., Huang, Z., Schmieder, B., Vissers, G. J. M., Toriumi, S., **Rouppe van der Voort, L. H. M.**, Madjarska, M. S., Danilovic, S., et al.: 2018, Space Science Reviews 214, 120, Solar Ultraviolet Bursts

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O Sun of Real Peace

O so amazing and broad—up there resplendent,
darting and burning!

O vision prophetic, stagger'd with weight of light!
with pouring glories!

Walt Whitman

Design: Anagram design, Trykk: Konsis

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