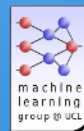
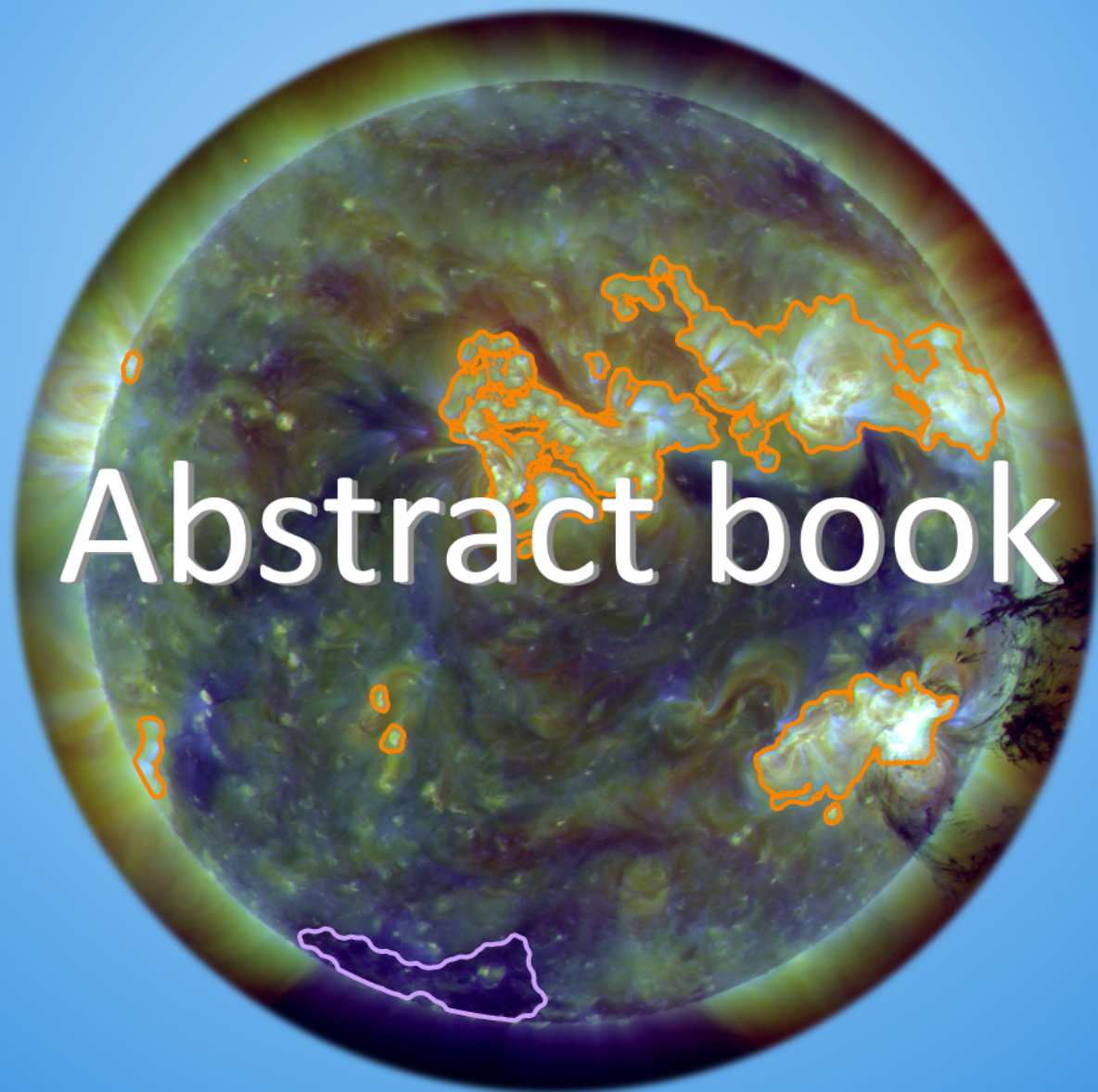


7th Solar Information Processing Workshop

La Roche en Ardenne, Belgium
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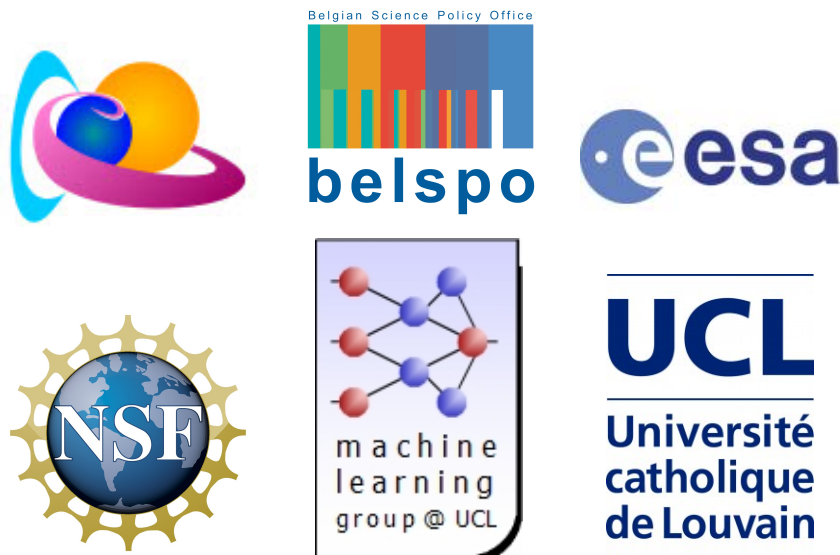


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Tutorials

Oral presentations

A whistle-stop tutorial on observational turbulence studies: Background and motivation for a statistical treatment (Invited)

Khurom Kiyani

University of Warwick

In this brief tutorial, I will attempt to motivate why one adopts a statistical approach when attempting to study turbulence - and why it is a consequence of the unpredictability of turbulent shear flows. In analogy with mean-field theories from statistical mechanics, we will cast the problem in terms of fluctuations and their affect on mean 'bulk' quantities. In the process of doing so, we will learn why the turbulence community is so obsessed by energy/power spectral densities. This will naturally take us to the foundations of such a study, in the form of statistical limit theorems - an organic and profound result of which are the statistical scaling laws, that will crop up often in the rest of the tutorial. Two of the key results in scaling studies of turbulence will be presented, with heuristic descriptions of the Karman Howarth equation and the 4/5'ths law; and a 'quick and dirty' derivation of the celebrated Kolmogorov 5/3'rds energy spectrum - a second order statistical quantity. A brief motivation from some real experimental data will help us realise that a turbulent life is far from Gaussian and that for a better description we need to look at higher-order statistics. Very closely related to this, and if I have time, I will present a short tour of fractal and multifractal models of turbulent intermittency. Lastly I will conclude with the key assumptions that are needed for such a bold analysis. This being chiefly the assumptions of statistical stationarity and ergodicity.

Tutorial On Supervised Learning (Invited)

Roberto D'Ambrosio

Université Catholique de Louvain

Pierre Dupont

Université Catholique de Louvain

Machine learning (ML) focuses on computer systems that learn some patterns or profiles from a data set and apply those to new data. This domain, which is originally a branch of artificial intelligence, has strong connections with statistics, mathematical optimization and signal processing.

There are many sub-fields of ML including supervised learning, unsupervised learning and reinforcement learning, to name a few. We focus here on supervised learning that consists in estimating a model of the link between some observed data X (the dependent variables) and a response or output variable Y . This link is typically observed first on a training or learning set. The model learned from the training set is subsequently used on new input data for which the response variable must be predicted. Such models are called classifiers, (respectively regression models), whenever the response variable is discrete or categorical (respectively continuous).

In this tutorial we present some prominent learning algorithms to estimate classification models in such a supervised setting. We discuss which are the common strategies and procedures to estimate these classifiers and to evaluate their performances at predicting the response on new samples. We furthermore provide some insight into the typical metrics that are used to evaluate quantitatively those performances.

SIP Challenges: future instrumentation

Oral presentations

Computational Spectral Imaging Techniques for High-Resolution and Instantaneous Observations of the Solar Corona (Invited)

Figen S. Oktem

University of Illinois at Urbana-Champaign

Farzad Kamalabadi [1], Joseph M. Davila [2]

[1] University of Illinois at Urbana-Champaign, [2] NASA Goddard Space Flight Center

Spectral imaging is a fundamental diagnostic technique for the study of the solar coronal plasma, and spectral data is routinely used to measure the temperature, density, and flow velocity in coronal features. However, obtaining the spectra of a multi-dimensional region with inherently two-dimensional detectors poses intrinsic limitations on the spatio-temporal extent of the technique. In particular, slit spectrographs suffer from a limited instantaneous field-of-view (IFOV), and filter-based spectral imagers offer only limited spectral range or temporal resolution.

Here we develop two novel spectral imaging techniques that enable capabilities beyond the reach of these conventional methods. Each development is based on computational imaging, which involves distributing the spectral imaging task between a physical and a computational system, and then digitally forming images of interest from multiplexed measurements by means of solving an inverse problem. In particular, in the first approach, a nonscanning spectral imaging technique is developed to enable performing spectroscopy over a two-dimensional instantaneous field-of-view. This technique combines a parametric estimation approach with a slitless spectrometer configuration. In the second approach, a spectral imaging technique with an optical device known as a photon sieve is developed to achieve superior spatial and spectral resolutions over the conventional filter-based spectral imagers, through wavelength-dependent focusing property of the photon sieve and multiplexed measurements recorded by a photon sieve imaging system with a moving detector.

In each of these two techniques, multiplexed measurements are combined with an image-formation model and then the resultant inverse problem is solved computationally for image reconstruction. The associated inverse problems, which can be viewed as multiframe image deblurring problems, are formulated in a Bayesian estimation framework to incorporate additional prior statistical knowledge of the targeted objects. Computationally efficient algorithms are then designed to solve the resulting nonlinear optimization

problems. Bayesian Cramer-Rao bounds are obtained to characterize the estimation uncertainties and performance limits. The developed spectral imaging techniques enable finer temporal, spatial, and spectral resolutions, and will facilitate the understanding of highly dynamic solar events such as flares, CMEs, and transient brightening.

Session 1

*Power laws in solar physics:
observations and proper estimation*

Oral presentations

On Power-law Distributions of Observed Solar Features (Invited)

Clare Parnell

University of St Andrews

Power-law distributions have been found for many different solar events such as the frequency of flare energies and the distribution of fluxes of magnetic features in the photosphere. Also broken power-law distributions are seen for the accelerated-particle energies from flares. The power-law indices associated with these different distributions have been determined from observations by many different authors and a wide range of results have been published. In order to reconcile the wide range of observed power-law indices found for one type of event, I will review the results of a number of the main solar power-law distributions. By carefully considering what observations, analysis tools and power-law fitting methods have been used in each case, I will investigate what effect different wavelengths, resolutions and sensitivities of observations, combined with varying approaches to analysing the data and different ways of determining the fitted power-law have on the resulting distributions that are found.

Bayesian Analysis of Power Law Models in High-Energy Astrophysics and in Solar Physics (Invited)

David van Dyk

Imperial College London (Statistics Section)

In recent years Bayesian statistical methods have become increasingly popular in a variety of scientific disciplines owing to their ability to flexibly handle sophisticated physical models and complex instrumentation in a mathematically principled manner. This talk will provide a general introduction to Bayesian statistical methods, emphasizing both their practical advantages and how they can be routinely implemented. Monte Carlo techniques for Bayesian model fitting, model checking, and model selection, including the Markov chain Monte Carlo will be discussed. Methods will be illustrated using multi-level statistical models used for photon count data in high-energy astrophysics that include power laws convolved with instrumental effects such as varying detector sensitivity, blurring of photon energies, and background contamination. We will discuss how such multi-level models can be designed to accommodate source models, sophisticated (but imperfect) instrumentation, and misclassified or partially classified events in solar physics.

Session 1

*Power laws in solar physics:
observations and proper estimation*

Posters

The influence of small sample sizes on the determination of power-laws

Elke D’Huys

Royal Observatory of Belgium

D.B. Seaton, D. Berghmans

Royal Observatory of Belgium

The frequency distributions of different solar parameters show a power-law behavior, often interpreted based on the concept of self-organized criticality (SOC, Bak et al. 1988). In the corona, Lu & Hamilton (1991) argued that a solar flare can be interpreted as an avalanche of many small reconnection events, resulting in a power-law distribution for the flare occurrence. This power-law implies that flares are scale-invariant: flares of all sizes are the result of the same physical process and their strength is determined by the number of elementary reconnection events involved. Similarly, Robbrecht et al. (2009) studied CME widths and, similarly found a power law behavior over a large range of angular widths.

We studied the scale invariance of the widths of CMEs that were not associated with EUV signatures in the low corona and observed that there is an important influence of the sample size on the derived slope (on a logarithmic scale). When selecting only a small sample of CMEs, the resulting slope is notably smaller than the one derived for a large number of CMEs by Robbrecht et al. This flatter distribution is not surprising as only a small random selection of many CMEs is made, and including a wide CME in such a small sample decreases the slope significantly. In reality the angular width distribution of CMEs is dominated by narrow events, which becomes clear when more detections are taken into account. Based on an artificial distribution, we investigate the influence of the sample size on the derived power-law for CME angular widths.

Modeling the space plasma microstates with power-law distribution functions

Marian Lazar

CMPA, KU Leuven

Stefan Poedts

CMPA, KU Leuven

The observations in space plasmas indicate two distinct models for the particle velocity distributions: the standard Maxwellian for the core populations, and the Kappa power-law for the enhanced high-energy (suprathermal) tails. But theoretical attempts to describe the observed distributions and their dispersion/stability properties are limited to idealized models, which either (a) ignore the suprathermal populations, or (b) minimize the role of the core, assuming this component cold, or (c) incorporates both the core and halo populations in a single global Kappa that is nearly Maxwellian at low energies, and decreases smoothly as power-law at high speeds. Here we propose to show to which extent these models are applicable in realistic conditions.

Session 2

*Optimal combination of in-situ and
imaging data*

Oral Presentations

Combining HI and in situ observations to constrain CME evolution (Invited)

Christian Moestl

Institute of Physics, University of Graz

Tanja Rollett

Space Research Institute, Austrian Academy of Sciences, Graz, Austria

Imaging and in situ observations of coronal mass ejections (CMEs) both have their strengths and drawbacks when one tries to understand their evolution between the Sun and the Earth. Images give a good global overview of general CME parameters, but are affected by Thompson scattering and lack information on the CME's magnetic structure. In situ data show in great detail the interplanetary CME magnetic field and plasma parameters, but are limited to a one-dimensional trajectory. In this talk I will review some recent methods which combine heliospheric imaging (HI), provided by STEREO, with in situ data observed by the Wind, ACE, STEREO, Venus Express, and MESSENGER missions. Essentially, either (1) CME parameters are predicted from the images and the validity of the results is checked against in situ observations, or (2) heliospheric imaging and in situ data are first combined using specific assumptions, which then lead to constrained results on e.g. the kinematics and global shape of CMEs. Creating a dataset suitable for these kinds of analyses is also a goal of a new European Union project called HELCATS. A focus is given on techniques which can be used with a single heliospheric imager like on Solar Orbiter.

Processing and Analyzing Images of Coronal Mass Ejections (Invited)

Tim Howard

Southwest Research Institute

CMEs are most commonly observed using visible white light imagery. Alternative imagery (e.g., EUV) is also used, but typically we can only observe a small segment of the CME or a nearby eruptive manifestation of CME activity (e.g. flares, filaments, post-eruptive arcades, etc). Each observation poses problems for CME detection, tracking, and analysis; partly due to the means of detection (e.g., Thomson scattering, optically thin media), and partly due to the nature of the CME itself (e.g., geometry, 3-D spatial extent, interaction with environment). Understanding how these effects culminate into an image of a CME is critical to a physically meaningful analysis of their images. I will present a brief review of these challenges and explore various means that have been adopted, either via instrumentation or post-processing, to overcome them. I will identify common misconceptions and traps that workers encounter and discuss the limits of our analysis capabilities. Some of these limits could be overcome with carefully-designed future instrumentation, while others are insurmountable regardless of image quality due to lack of information within the images.

Visual Verification of Coronal Mass Ejections in ENLIL Ensemble Simulations through Optical Flow Analysis

Alexander Bock

Linköping University

Anders Ynnerman, Timo Ropinski

Linköping University

The current technique of simulating coronal mass ejections in ENLIL simulations requires cone parameters that are manually derived from STEREO satellite imagery. This manual input is not perfect and introduces uncertainty into the simulation pipeline, leading to inaccurate predictions. We present a system that embeds satellite imagery from SOHO and STEREO A and B into a 3D volumetric rendering of ENLIL simulations. By extracting the optical flow from the images and renderings, we retrieve pairs of velocity fields that are utilized to derive a quality measure that is used to test the simulation against the ground truth satellite image data. The system provides a novel technique to simultaneously inspect the time-dependent quality measures of all observation instruments (SOHO [LASCO C3], STEREO A and B [Cor2, HI 1, and HI 2]) and allow the analyst to make an informed decision about the accuracy of the simulation. Lastly, we extend this system to deal with ensemble runs, generated by varying the cone parameters. The aforementioned quality measures are generated for each ensemble member and the system provides an interface to browser and assess the whole ensemble run at once, enabling the analyst to quickly select the ensemble member agreeing with the satellite data.

The new 'CORIMP' CME catalog & 3D reconstructions

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Institute for Astronomy, University of Hawaii

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[1]University of Aberystwyth, Wales, [2] Institute for Astronomy, University of Hawaii, [3]Trinity College Dublin, Ireland.

Coronal mass ejections (CMEs) represent the largest, most dynamic phenomena that originate from the Sun. Propagating at speeds of up to thousands of kilometres per second, with energies on the order of 10^{32} ergs, they can drive adverse space weather throughout the solar system. Given their potentially hazardous impact on Earth's geomagnetic environment, the physics governing their eruption and propagation needs to be understood. CMEs tend to be faint, transient phenomena, observed in white-light images that are prone to noise and user-dependent bias in their interpretation. To this end, a wealth of image processing techniques have been explored to characterise CME structure in remote-sensing image data, such as the coronagraphs onboard SOHO and STEREO. Indeed the large volume of data available has made it necessary to automate such techniques for detecting and tracking CMEs across images, and cataloging their kinematics and morphologies. A new such catalog has been built from a unique set of coronal image processing techniques, called CORIMP, that overcomes many of the limitations of current catalogs in operation. An online database has been produced for the SOHO/LASCO data and event detections therein; providing information on CME onset time, position angle, angular width, speed, acceleration, and mass, along with kinematic plots and observation movies. Thus by investigating the catalog output it is intended that this work will lead to an improved understanding of the dynamics of CMEs. A realtime version of the algorithm has been implemented to provide CME detection alerts to the interested space weather community. Furthermore, STEREO data has been providing the ability to perform 3D reconstructions of CMEs that are observed in image pairs. This allows a determination of the true 3D kinematics and morphologies of CMEs characterised in STEREO data via the 'elliptical tie-pointing' technique. This has also been extended to include SOHO as a 'third-eye' on the 3D reconstructions in order to improve their accuracy.

3D morphological reconstruction of CMEs and CME-driven shocks from SECCHI COR and HI1 observations and their link to in-situ measurements

Li Feng

Max Planck Institute for Solar System Research

Bernd, Inhester

Max Planck Institute for Solar System Research

We have developed a 3D mask-fitting reconstruction method to derive the morphology of a CME using coronagraph images from two or more different viewpoints (Feng et al., 2012, 2013). The method has the advantage of not a-priori constraining the CME shape. It is now extended to the HI 1 field of view (FOV) to study the 3D morphological evolution of a CME and its driven shock in a larger FOV. The assumption of a self-similar expansion of CMEs and the assumption of a bow-shock shape of the CME-driven shock are tested. The derived 3D CME and CME-driven shock evolution are compared with the drag model. During their propagation into the interplanetary space, the in-situ data observed by WIND/ACE, STEREO, Messenger, Venus Express are analysed as well when available.

Kinematic of CMEs using SECCHI/HI observations

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Udaipur Solar Observatory, PRL

Wageesh Mishra

Udaipur Solar Observatory, PRL

We present a study of the kinematics and arrival times of coronal mass ejections (CMEs) at Earth, derived from time-elongation maps (J-maps) constructed from STEREO/heliospheric imager (HI) observations. In this presentation, we compare the results of implementation of various reconstruction techniques, both from single or multiple vantage points, to estimate the dynamics of CMEs. We used the estimated kinematics as inputs to the Drag Based Model for the distance beyond which the CMEs cannot be tracked unambiguously in the J-maps. Further, we associated the CMEs, identified and tracked in the J-maps, with signatures observed in situ near 1 AU by the WIND spacecraft. By deriving the kinematic properties of each CME, using a variety of existing methods, we assess the relative performance of each method for the purpose of space weather forecasting. These studies have led to an improvement in relating imaging observations with in situ measurements. The results have been found useful to understand the signatures of interacting or colliding CMEs in the heliosphere. The analysis of a few cases of interacting CMEs will be presented. Our results highlight the significance of using HIs observations for the purpose of better space weather forecasting.

Session 2

*Optimal combination of in-situ and
imaging data*

Posters

The solar source of extreme space weather events

Laura Balmaceda

INPE (Brazil) - ICATE/CONICET (Argentina)

Alisson Dal Lago[1], Hebe Cremades[2], Ezequiel Echer[1], Ramish Rawat[1], Luis Eduardo A. Vieira[1].

[1] INPE (National Institute for Space Research, Brazil); [2] UTN/FRM - CONICET (Argentina)

Extreme space weather events, i.e. that cause very intense geomagnetic storms with $Dst < -400$ nT, such as the Carrington event in 1859 or the 1989 storm seldom occur during a solar cycle. On 23 July 2012, STEREO-A spacecraft observed an extremely fast coronal mass ejection (CME) that traveled a distance of about 1 AU in approximately 18 h. The event called the attention of the scientific community and became the target of several modeling studies which analyze the hypothetical response of the magnetosphere if this CME would have been directed to the Earth. The estimated Dst index for such a storm was less than -1000 nT. Here we investigate the morphological characteristics of the source on the solar surface and study the initial conditions that trigger the eruption. We use EUV images from STEREO and SDO in order to reconstruct the 3D structure of the CME in the lower corona and infer the true direction of propagation. We further examine the in-situ data in order to study its counterpart in the interplanetary medium. Finally, we compare the overall characteristics of this event with the November 2003 extreme event from previous solar cycle.

3D Extension to JHelioviewer

André Csillaghy

FHNW

**Daniel Müller [1], Simon Felix [2], Stefan Meier [2],
Simon Spörri [2]**

[1] ESA/ESTEC, [2] FHNW

With multiple spacecraft observing the Sun and its corona from different vantage points, 3D visualization is a useful complement to current two dimensional visualization systems. Furthermore, 3D visualization is useful to combine simulations of magnetic field lines with actual observations. Over the last year, we have developed new functionality to visualize such 3D models with JHelioviewer (JHV). JHV now supports a 3D mode that shows a three dimensional visualization of the sun, corona and additional metadata from other data sources. The implementation is based on a scene graph and a layering system to render scientifically useful graphics. Individual layers are rendered through generic, unified shaders, significantly simplifying the addition of future data sources. Popular plugins (such as the HEK plugin and the SDO-Cutout plugin) were also enhanced with 3D functionality. For the visualization of 3D magnetic field lines, a server side component has been added, running at FHNW. This server component uses the SSW PFSS package to download PFSS data and to generate field lines. We use the SunInTime daily image parameters, albeit with a higher resolution. The field lines are then transformed, compressed and stored on a storage server. The compressed field lines are then streamed to JHV over HTTP.

Visually Browsing the new RHESSI Flare Database using the HESPE Browser

Laszlo Istvan Etesi

Fachhochschule Nordwestschweiz

Andre Csillaghy, Nicky Hochmuth

Fachhochschule Nordwestschweiz

The Small Space Project "High-Energy Solar Physics in Europe" (HESPE), funded in the European FP7 framework, ended in December 2013. It produced a data processing framework that allows to autonomously reprocess the entire RHESSI flare catalogue using optimization techniques for imaging. For every flare observed by RHESSI, quick look images and science-grade data products are computed and published to a database. Researchers can browse the flare database using the HESPE browser at <http://www.hespe.eu/browser>. Firstly, metadata-based filters are applied to pre-select a set of interesting flares. Secondly, the remaining flares are inspected and evaluated in three presentation modules: light curve, interval selection, and preview. And thirdly, relevant flares are chosen for downloading and offline processing. All three presentation modules are linked in time to allow for a synchronous view of a flare from different perspectives: the light curve module shows the general flare evolution over time; the interval selection module shows the optimized time-energy grid on the spectrogram, i.e. a grid of time-energy bins for which data products exist; and the preview module shows all quick look images for the entire flare in one big viewable image map. With every step the level of detail increases, enabling researchers to explore RHESSI high-energy solar x-ray data contextually and visually. Once downloaded, the science data products can be used in publications, they can be compared to other data sources, or they can be used in extended statistical analyses with large flare data sets.

3D kinematics of two consecutive CMEs

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Vaibhav Pant[1], Luciano Rodriguez[2]

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The CME on December 27, 2008 was propagating into the 16N36E direction and it was a structured CME associated with the disappearance of a prominence. The CME on December 28, 2008 was directed towards 08N08E, as measured in the coronagraph images, it was a not structured stealth CME (flow like type). The two CMEs are followed in coronagraph and HI images on their way into the interplanetary space. We describe different pre-processing steps to isolate the CMEs from the coronal background. We also illustrate different reconstruction techniques (both in coronagraphs and heliospheric imagers) in order to derive the 3D kinematics of these dynamical events. Finally, a discussion on possible interaction of the two CMEs in the interplanetary space is carried out.

Automated tracking of coronal mass ejections using CACTus

Vaibhav Pant

Indian Institute of Astrophysics

Dipankar Banerjee[1], Marilena Mierla[2]

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Coronal Mass Ejections (CMEs) are responsible for most extreme space weather effect. They have been routinely detected by visual inspection of each Coronagraphic image by human operator, thus detection becomes very subjective. To make detections more objective, a software package called Computer Aided CME Tracking (CACTUS) is developed at Royal observatory of Belgium. CACTUS is a automated software which detects CMEs in Coronagraphic images and is compatible with LASCO and SECCHI (COR-2). It works on the principle of Hough transform, a technique of detecting straight line in noisy data. The output of software is the list of events similar to the classic catalogs. These CMEs detection by software can be faster, which is especially important in space weather context. I tried to expand the current limitations of CACTus to make it compatible with masked disk images of AIA and SWAP to track eruptions closer to limb and with Heliospheric Imager (HI) to track eruptions in heliosphere. Detection algorithm and possibility of using CACTus with masked disk images of AIA, SWAP and Heliospheric Imager (HI) with some preliminary results will be discussed.

HELCATS - Heliospheric Cataloguing, Analysis and Technique Service

Luciano Rodriguez

Royal Observatory of Belgium

**Jackie A. Davies [1], Richard A. Harrison [1],
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Understanding the evolution of the solar wind is fundamental to advancing our knowledge of energy and mass transport in the solar system, whilst also being crucial to space weather and its prediction. The advent of true wide-angle heliospheric imaging has, over the last 10 years or so, enabled direct observation of the evolution of both transient (coronal mass ejections: CMEs) and background (stream/co-rotating interaction regions: SIRs/CIRs) solar wind plasma structures as they propagate out to 1 AU and beyond. Prior to this, signatures of such features were mainly detected within a few tens of solar radii of the Sun and in the vicinity of the few near-Earth and interplanetary probes making in-situ solar wind measurements. The FP7 Heliospheric Cataloguing, Analysis and Technique Service (HELCATS) project (start date 1st May 2014; duration 3 years) capitalises on expertise in the analysis of heliospheric imaging that has been built up in Europe over the last decade, particularly driven by lead involvement in NASA's STEREO mission, whilst also exploiting the vast wealth of long-established European expertise in such areas as solar and coronal imaging, as well as the interpretation of in-situ and radio diagnostic measurements of solar wind phenomena. The general aims of the HELCATS project are:

- To catalogue both transient (CMEs) and background (SIRs/CIRs) solar wind structures observed in the heliosphere by the UK-led STEREO/Heliospheric Imager (HI) instruments, including estimates of their kinematic properties based on a variety of established modelling techniques and the prototyping of other, more speculative, approaches;
- To verify these kinematic properties, and thereby assess the validity of

these techniques, through comparison both with solar source observations and in-situ measurements at multiple points throughout the heliosphere;

- To assess the potential for initialising advanced numerical models based on the derived kinematic properties of both the transient and background solar wind structures;

- To assess the complementarity of using radio observations to detect structures and diagnose processes in the heliosphere (in particular Type II radio bursts and interplanetary scintillation) in combination with heliospheric imaging observations.

Viewpoints of space weather based on current image data

Freek Verstringe

Royal Observatory Belgium

Bogdan Nicula, David Berghmans, Bram Bourgoignie

Royal Observatory Belgium

Upcoming deep space missions exploring the inner heliosphere, such as Solar Probe and Solar Orbiter, will have much more rapidly changing viewing perspectives as what we are used to with the STEREO spacecraft. Co-alignments with the Earth and with each other, as well as quadratures and oppositions will quickly follow each other.

In some cases, we will be able to use imagery from the Earth to optimise the science planning of the remote sensing instruments onboard Solar Orbiter. Science planners will want to know the best 'guess' of where active regions will be in say a few days from now as seen from the perspective that Solar Orbiter will have at that time. We demonstrate how to combine several recently developed services into a tool that allows to see how the Sun would look at a given location and time interval by properly reprojecting the most currently data available, from wherever it was taken.

The application of such a tool goes beyond the science operations of Solar Orbiter, but will also be relevant for science analysis (what was under Solar Probe?) and for space weather forecasting. An early version of our development was used to estimate solar irradiance on Venus (roughly in quadrature above the solar West limb) during the aerobraking manoeuvres of Venus Express, spring 2014.

The main services used are an observation geometry software package that was expanded to allow requests over the network and the recent developments of Space Weather Helioviewer (SWHV, ESTEC Contract No. 4000107325/12/NL/AK, an extension of JHelioviewer (jhelioviewer.org))

Session 3

*How well can we predict solar
eruptions and disturbances?*

Oral presentations

The Physics Behind Flare Prediction and Present Methods for Flare Forecasting (Invited)

Graham Barnes

NWRA/CoRA

KD Leka

NWRA/CoRA

During a solar flare, energy stored in the coronal magnetic field is rapidly released, eventually manifesting mainly as radiation, largely at short wavelengths. I will give an overview of some of the typical properties of flares, and summarize what we think we know about the physical processes that may be important in both the build-up of the energy needed to power a flare, and in what triggers the onset of the magnetic reconnection believed to transform the stored magnetic energy into other forms.

Most flare forecasting methods are based on a parameterization of the properties of the solar photosphere in an active region, where concentrations of strong magnetic field pass through the photosphere. The parameters are often "physics inspired", but are not typically based on modeling a particular active region. Using historical data to train, a variety of techniques have been used to make a prediction based on the values of one or more parameters. I will summarize many of the present methods, highlighting the lack of independent information in the parameters most often computed, provide a brief overview of how the performance of the methods is quantified, and the challenges in making meaningful comparisons among different methods. Despite the disparate ways of parameterizing active regions and of turning the parameters into forecasts, most methods perform fairly similarly.

Funding for this work was provided by NASA/LWS contract NNH09CE72C and NASA/GI contract NNH12CG10C.

Machine Learning for Solar Flare Prediction (Invited)

Roberto D'Ambrosio

Université Catholique de Louvain

Pierre Dupont

Université Catholique de Louvain

Machine learning (ML) concerns the construction of computer programs that improve with experience. This domain, which is originally a branch of artificial intelligence, has strong connections with statistics, mathematical optimization and signal processing.

From a ML viewpoint, solar flare prediction can be seen as a binary classification problem to discriminate between big and small flares. Standard ML techniques, such as support vector machines, logistic regression, nearest neighbors, ensemble methods,... can be used to address this supervised classification problem. Yet, several issues need to be considered to produce accurate predictive models.

Flare prediction is indeed an unbalanced classification problem since only 10% of the active solar regions will eventually lead to big flares. Such an unbalanced class prior distribution may impact drastically the prediction performance of the models estimated from past events. We will specifically discuss how such an imbalance can be taken into account when learning the predictive models and/or using such a model to predict the class of a new event. The class imbalance also need to be considered in the evaluation metric and the computational protocols used to assess the quality of the models.

Finally, the quality of a predictive model is also strongly tied to the actual measurements used as input features, also known as predictor variables. In this context, we will briefly sketch how multivariate feature selection techniques could outperform a univariate analysis.

Solar Demon - Detecting Flares, Dimmings and EUV waves on SDO/AIA images

Emil Kraaikamp

Royal Observatory of Belgium

Cis Verbeeck

Royal Observatory of Belgium

Solar Demon consists of several modules that automatically detect and describe flares, dimmings and EUV waves on Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) data. To provide near real-time detection and science quality event catalogues, events are detected using a combination of image processing techniques on both quick-look and synoptic science data respectively.

The output of Solar Demon is available on the Solar Demon website <http://solardemon.oma.be>. As a dedicated module in the automatic COME-SEP alert system, Solar Demon also provides flare locations which are used to predict geomagnetic and Solar Energetic Particle (SEP) radiation storms.

Here we present a brief overview of the Solar Demon system, and in more detail describe the image processing techniques used to automatically detect and characterize EUV waves in SDO/AIA EUV images. One of the most important EUV wave characteristics estimated by Solar Demon is the propagation speed of the EUV waves.

Systematic measurements of global variations in the coronal magnetic field using EIT waves”

David Long

UCL-MSSL

**David Williams[1], Stephane Régnier[2], Iain
Hannah[3]**

[1]UCL-MSSL, [2]UCLan, [3]University of Glasgow

By studying how globally-propagating disturbances (commonly called EIT waves”) propagate through the low solar corona, it is possible to examine the magnetic field of the plasma through which they travel. Although traditionally measured using loop oscillations induced by the passage of the wavefront, this produces very localised estimates of the magnetic field threading the loop itself. An alternative approach is to combine the measured kinematics of the wavefront with densities obtained from spectroscopic observations to estimate the magnetic field strength (cf., Long et al., 2013), however this is dependent on very rare spectroscopic observations of the pulse. Here, we present a new approach for direct estimation of the magnetic field strength in the low corona. The automated Coronal Pulse Identification and Tracking Algorithm (CorPITA; Long et al., 2014) is used to identify, track and examine the EIT wave”, allowing an unbiased estimation of its kinematics. These kinematics are combined with a global density map estimated using emission measure calculated from a regularised inversion technique applied to AIA images from the *Solar Dynamics Observatory*. This combination allows a global estimation of the magnetic field of the plasma into which the wavefront propagates. Magnetic field maps are computed for a series of events and compared to global magnetic field extrapolations, providing an independent confirmation of this approach.

Image patch analysis and clustering of sunspots: A dimensionality reduction approach

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Current classification of sunspot groups is visually based and suffers from bias. Supervised learning methods can reduce human bias but fail to optimally capitalize on the information present in sunspot images. We use two image modalities (continuum and magnetogram) from the MDI instrument to characterize the spatial and modal interactions of sunspot and magnetic active region images and present a new approach to cluster the images. Specifically, in the framework of image patch analysis, we estimate the number of intrinsic parameters required to describe the spatial and modal dependencies, the correlation between the two modalities and the corresponding spatial patterns, and examine the phenomena at different scales within the images. To do this, we use linear and nonlinear intrinsic dimension estimators, canonical correlation analysis, and multiresolution analysis of intrinsic dimension. We then use this information to cluster the images and compare the results to the Mt Wilson classification scheme.

Automated Detection of δ spots.

Sreejith Padinhatteeri

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Sunspot groups that contain opposite-polarity umbrae surrounded by a common penumbra are known as δ spots in the modified Mount Wilson classification scheme. These magnetically complex sunspot groups are associated with many major solar flares, so the formation of a δ spot can be a precursor of an active region's potential for major flaring. We have developed an algorithm (SMART Delta Finder; SMART-DF) to automatically detect δ spots from simultaneous continuum intensity and magnetogram observations. The success rate of the algorithm is determined using SDO/HMI data from 2011 to 2013 and a comparison to the list of δ spots reported by NOAA's Space Weather Prediction Center. The algorithm, its test results and a statistical study of the relation between SMART-DF δ spots and solar flares will be discussed in this presentation.

Session 3

*How well can we predict solar
eruptions and disturbances?*

Posters

Analysis of dynamic events detected by SoFAST in SWAP EUV images

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CmPA, KU Leuven

David Berghmans [1], Anik De Groof [2], Stefaan Poedts [3]

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The Solar Feature Automated Search Tool (SoFAST, Bonte et al 2013) detects dynamic events in SWAP EUV images. SWAP is a 17.4 nm EUV imager on the PROBA2 satellite.

The SoFAST algorithm continuously runs on the latest SWAP data, resulting in the real-time list of SoFAST EUV events available online (www.sidc.be/sofast). We have built the first SoFAST EUV event catalogue by running the tool over more than 3 years of SWAP data, taken during the period from April 2010 to June 2013. The catalogue provides timing, heliographic position and a customised classification as well as movies and graphs of more than 2000 EUV events.

In this presentation we introduce results from the recently defended PhD thesis. For the validation of the SoFAST tool, we compare its output with associated events, mainly from the NOAA GOES catalogue. We describe the variety of typical dynamic EUV events detected, ranging from AR transient brightenings to large plasma eruptions. We statistically analyse the temporal and the spatial distribution of the SoFAST events during the rise of solar cycle 24. Our analysis shows that SoFAST output is well correlated with other indicators of solar activity. In addition, we investigate whether space weather important CMEs can be correlated with a SoFAST EUV event as potential low coronal signature.

Our results indicate not only that it is possible to detect EUV events automatically in an acquired dataset, but as well that quantifying the visibility of an event in the SWAP images is feasible. These strengths of SoFAST make the package suitable for distinguishing portions of data containing well observed major solar events from other data, in an automated way. Such automated data selection has become a pressing challenge, given the continuous flow of data we receive from contemporary solar-observing spacecraft and the necessity for onboard data selection in future missions (e.g. Solar Orbiter).

Polar plumes' orientation and the Sun's global magnetic field

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LAM - Laboratoire d'Astrophysique de Marseille

Bernd Inhester and Robert Cameron

Max Planck Institute for Solar System Research, Germany

To characterize the configuration of the open field near the Sun surface, two quantities can be used: the magnetic pole location where the field lines are perpendicular to the surface and the magnetic opening. Since polar plumes can be used as a tracer of the large-scale coronal magnetic field configuration, we measure the magnetic pole location and the magnetic opening by identifying plumes in North and South polar cap. The plumes identification is done by performing the Hough-wavelet transform in a series of STEREO/EUVI images at 17.1nm. The magnetic poles locations and the magnetic opening are then identified during one year in 2007-2008. The same procedure is applied to the polar cap field inclination derived from an extrapolation of magnetograms generated by a surface flux transport model. We observe that the position where the magnetic field is radial (the Sun's magnetic poles) reflects the global organization of magnetic field on the solar surface. and we suggest that this opens the possibility of both detecting flux emergence anywhere on the solar surface (including the far side), and the possibility of better constraining the reorganization of the corona after flux emergence.

Predicting Flaring Activity through Supervised Classification on Predictor Variables

Ruben De Visscher

Royal Observatory of Belgium

Véronique Delouille

Royal Observatory of Belgium

Recent years have seen a resurgence in the field of solar flare prediction. Most of these methods aim at evaluating a flare probability in the next 24h based on the current or past status of an active region. In this project sequences of magnetogram and continuum images are used to distinguish active regions with strong flaring activity.

A homogeneous dataset of magnetogram and continuum images of active regions in their growth phase is produced. These images are summarized into various scalar predictor variables, which are used as the input for the supervised classification methods. These methods take into account the time evolution of the active regions through lagged values of the predictors. The performance of various supervised classification algorithms as well as the predictive power of each predictor variable are assessed. Special care is taken to handle the imbalance between the number of active regions with and without strong flaring activity.

In our poster we will discuss preliminary results from this project.

Numerical models of ICMEs interaction

Ricardo Francisco Gonzalez Dominguez

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We present hydrodynamical models of interacting Coronal Mass Ejections (CMEs) that are supported by recent observational evidence, the event of May 23th, 2010. During this event, two CMEs were expelled into the interplanetary medium (IPM) separated by an interval of time of some hours. We show through numerical simulations that the CMEs interaction occurs before their arrival to the Earth. In this work, we assume that during the eruptions the flow parameters (ejection velocity and density) increase with respect to the standard solar wind (SW) parameters. Such variability results in the formation of two-shock wave structures (called working surfaces) that travel into the IPM. Here, we show that, after the collision of the working surfaces, a merged single structure is formed. The arrival time, velocity and density of the merged region are predicted and compared with observations at 1 AU of this event. We found that the theoretical predictions and observations are in good agreement. Thus, our models give a physical insight into the dynamical evolution of CMEs interaction.

A method for automated detection of solar eruptions

Neal Hurlburt

Lockheed Martin Solar and Astrophysics Lab

Any observation of the solar atmosphere reveals a wide range of real and apparent motions, from small scale jets and spicules to global-scale coronal mass ejections. Identifying and characterizing these motions are essential to advance our understanding the drivers of space weather. Both automated and visual identifications are used in identifying CMEs. To date, the precursors to these, eruptions near the solar surface (either from filaments or otherwise), have been identified primarily by visual inspection. We report on the Eruption Patroller, which is designed to automatically identify eruptions from data collected by SDO/AIA. Here we describe the method and compare it to previously identifications found in the HEK.

The Real Time Flare Monitor System at HSOS

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Yuanyong Deng, Juan Guo

National Astronomical Observatories, CAS, China

A Real Time Flare Monitor System has been founded and put into use at Huairou Solar Observing Station (HSOS) in 2013. In RTFMS, an adaptive threshold algorithm for real time flare detection is designed based on morphological methods and statistical results from the historical observations. In order to reduce the false detections caused by clouds or unintended operations, the raw data from CCD to RTFMS must go through rigorous steps. From 12 May 2013 to 19 Nov 2013, in the observable periods, RTFMS detected 34 flares (All Goes X-Ray above C5.0 Flares) and sent 241 alert Emails. Besides the routine observation mode, RTFMS has a flare mode for high cadence observation, when there is a flare, the local data covered flare could be recorded at the rate of 2f/s and the full disk image at the rate of 1 f/m.

Towards Automated Tracking and Characterization of Off-Limb EUV Coronal Shocks

Kamen Kozarev

Smithsonian Astrophysical Observatory

The Atmospheric Imaging Assembly (AIA) instrument on the Solar Dynamics Observatory has provided an unprecedented view of the initial stages of solar eruptions, in terms of spatial, temporal, and wavelength resolution. Its observations have given us a wealth of information about EUV waves and shocks, which are relevant to solar energetic particle (SEP) acceleration and heliospheric propagation. To that end, some of the most important questions that these observations may help answer are: 1) How abundant are shocks in the corona? 2) What are their characteristics? 3) How efficient are the observed shocks at accelerating SEPs? We can give better answers to these questions by improving the quality and quantity of EUV coronal shock observations. We have begun a concentrated effort towards developing and adapting algorithms for time-dependent tracking and characterization of off-limb shock waves observed with AIA. The tools include an adaptation of the yet another feature tracking algorithm (YAFTA; (Welsch and Longcope, 2003) to tracking the shape of off-limb EUV waves, and a 3D geometric shock surface model, combined with the PFSS model to track the time-dependent shock-to-field orientation and longitudinal extent of SEPs, low in the corona, for the very early stages of solar eruptions. In addition, the framework implements the Aschwanden et al. (2013) DEM model for estimating the time-dependent shock density jump. We present the current state of this effort and outline future directions of work. The ultimate goal of this work is to develop models for SEP acceleration that will produce initial spectra low in the corona, and give predictions for SEP fluxes in the heliosphere for space weather forecasting.

Using long-term temperature distributions of active regions to predict flare activity

Andrew Leonard

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Solar flares are associated with very rapid heating in the corona, often producing temperatures of $> 10\text{MK}$. However, few studies have investigated how the temperatures of flaring active regions behave prior to the flare. We present here a method which tracks flaring active regions and visualises their long-term temperature distribution. The aim of this study is to determine attempt to find signatures of large flares in the temperature profiles of active regions before the flares occur.

This method uses SunPy, a free, open-source Python library for solar physics.

A statistical study of quiescent and eruptive prominences at solar minimum via an automated tracking system.

Ivan Loboda

Lebedev Physics Institute of R.A.S.

Sergey Bogachev

Lebedev Physics Institute of R.A.S.

Despite vast amounts of data provided by a number of modern solar telescopes, most present-day studies of prominences limit themselves to only examining individual and usually most prominent events. In this way, however, one risks to miss smaller prominences, which are of great interest still, and to obtain an incomplete picture of these phenomena. Thus, to make use of the whole amount of data available, and to study the entire set of prominences, special tracking and processing algorithms need to be applied.

Following this line of thought, we have developed an automated system capable of precisely finding quiescent prominences on single He II 304 Å shots. First, this tracking system goes over the whole set of images and builds intensity map of undisturbed corona. After that, handling one shot at a time, it finds bright kernels and expands them, based on specifics of intensity distribution in prominences, up to their sharp boundaries, which are well distinguished from gradual intensity decrease characteristic of active regions. Having found position, visible size and brightness, as well as rough estimates of mass and gravitational energy of each prominence, the system then builds a synoptic map, which allows it to identify the same events on multiple shots and measure their velocities. Apart from that, this system can recognize eruptive prominences among those detected and obtain the same characteristics for each erupted portion of a prominence.

We have employed this system to process 4 months of TESIS data, from August to November 2009, which corresponds to the end of a prolonged minimum between 23rd and 24th solar cycles. Low solar activity and high sensitivity of the system have allowed us to obtain characteristics of smaller prominences (the smallest of those detected being 25×25 Mm in size) and perform a statistical study of the whole ensemble. Apart from obtaining the distributions of prominences' positions, lifetimes and velocities, we have found mean gravitational energy to be equally distributed among prominences of different size inside the sensitivity range of the system.

Because of relatively short operation time of TESIS our next goal is to

adapt our tracking system to streaming processing of data from other satellites, primarily SDO and STEREO, so that to be able to examine prominences on much larger time scales and thus to detect variations of their characteristics throughout the solar cycle.

Automated Coalignment of Multi-instrument Data

Joseph Plowman

High Altitude Observatory

Analysis of solar data often requires using images from multiple instruments which differ in their pointing, resolution, cadence, and spectral response. These differences can make it difficult to coalign the images or otherwise compare them directly. Such coalignment is often done manually, but I demonstrate that, with careful handling, such data can often be coaligned in a fully automated fashion. As examples, I show coalignment of data from the Coronal Multichannel Polarimeter (CoMP) and the EUV Imaging Spectrometer (EIS) on Hinode with the Atmospheric Imaging Assembly Instrument (AIA) on SDO. In both cases, Powell's method is used to minimize chi squared between the AIA data and the EIS (or CoMP) data. For the coalignment to be successful, care must be taken to ensure that the images used for coalignment are as similar as possible. In the case of EIS/AIA coalignment, this involves creating a synthetic raster from the AIA images which matches the EIS raster in space and time, as well as integrating the EIS spectra to emulate the AIA channel (193 Å) used for coalignment. For CoMP, we choose the AIA channel most similar to the CoMP wavelength response (211 Å), use the closest available images in time, and resample the AIA image to CoMP resolution. Satisfactory results are obtained (and shown) in both cases.

Tracking and kinematical characterization of CME events in 3D using a supervised texture-based technique combined with automatic tie-point triangulation

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Carlos Braga, Alisson Dal Lago

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The identification of Coronal Mass Ejections events (CME) in white-light coronagraph images can simply be addressed as a bi-partitioning segmentation problem. Goussies et al., 2010 showed that the overall spatial relationship of the gray levels (i.e., the texture) can be used as a discriminant to separate the CME feature from the background. As defined, the texture content is given by the relative probabilities that two neighboring pixels separated by a certain distance have specific gray levels. Their study allowed them to design a supervised technique to detect and track coronal events by means of their texture on a coronagraph field of view (a.k.a. CORSET: CORonal SEGmentation Technique). Later, to contribute to the implementation of a pseudo-automatic tool to unambiguously characterize the CME events, Braga et al., 2013 extended the capabilities of CORSET by adding new routines to determine several morphological and kinematical parameters (as projected onto the plane of the sky) without human intervention. Nowadays, with the advent of multiple white-light imagery at vantage observing points in space along with the development of customized 3D reconstruction techniques, the solar community can infer the real shape and direction of propagation of CME events (of utmost importance for space weather purposes). In this work, we took advantage of one particular 3D reconstruction tool ("Sunloop", Liever et al., 2009) to derive the "true" kinematics of CMEs pseudo-automatically. Sunloop uses manually-defined tie points to derive the 3D localization of the apex of the event via triangulation. Such approach can be tedious if the user aims to de-project the leading edge (LE) of the CME feature on each frame. To make the procedure faster and more objective, we integrated Sunloop into CORSET. In this way, the tie-points used to delimit the LE of the event on the different frames are generated fully automatically. The CORSET-3D technique does not have any geometric constraint, and hence CME features of practically any shape can be reconstructed. In this presentation, we briefly describe the technique and show the results obtained

when applied to a few Earth-directed CMEs observed by the COR2 coronagraphs on both SECCHI A and SECCHI B S/C between 2008 and 2011. In particular, we reconstructed the "apex" of the CMEs as a function of time and derived their "true" velocity and direction of propagation. Our findings are put in context with previous results.

Bayesian Analysis of the Solar Cycle Using Multiple Proxy Variables

David Stenning

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Sunspot numbers form a long-duration proxy of solar activity, with records starting in the early seventeenth century. Other proxies of solar activity, such as sunspot areas and the 10.7cm flux, show similar patterns and correlations as the sunspot numbers. We model solar activity using data from proxies that have become available more recently, while also taking advantage of the long history of observation of sunspot numbers. We propose a Bayesian multilevel model of the solar cycle, which incorporates a Markov structure that generates the amplitude, duration, and time of rise to maximum for a cycle, given the values from the previous cycle. Since proxies have different temporal coverage, we devise a multiple-imputation scheme to account for missing data. We take advantage of strong linear correlations between proxies by using principal component analysis to produce a univariate summary of solar activity at each time point. We compare fits of the model using multiple proxies and the sunspot numbers alone, finding significant differences in the inferred cycle properties between the two model fits. Specifically, we find that the model fit with multiple proxies has shorter falling times and shorter overall cycle lengths than the model fit with the sunspot numbers alone. We also find that fitting the model with multiple proxies results in a fitted solar cycle with an extended period of minimum activity prior to the start of cycle 24; this feature is absent when the model is fit with only the sunspot numbers. Future work will focus on extending the model to capture North-South asymmetry in solar activity.

Session 4

*Tracking of small scale magnetic
features and its applications*

Oral presentations

Small-scale magnetic structure at the solar surface (Invited)

Manfred Schüssler

Max Planck Institute for Solar System Research

The solar magnetic field covers a wide range of spatial scales, reaching from global scales comparable with the solar radius down to the length scales of resistive and viscous dissipation. Small-scale structure at the solar surface mainly results from the interaction between convective motions and magnetic field. This includes the kilogauss flux concentrations observed in intergranular lanes, the filamentary structure of sunspot penumbrae, umbral dots, and the small-scale mixed-polarity structure of the internetwork field. Tracking such structures and observing their spatial distributions has the potential to provide insights into their evolution and into the properties of the associated flows, into subsurface dynamics (e.g., during flux emergence), into the evolution of large-scale magnetic structure as well as possibly into the existence or otherwise of small-scale dynamo action. The talk will give a brief overview of the dynamics of small-scale magnetic structure from a physics point of view.

Tracking of small scale features from image sequences (Invited)

Thomas Corpetti

CNRS, France

Tracking objects in images sequences has been a great challenge in computer vision over the past three decades with many applications related to video coding (internet, TV), video understanding (scene analysis, action recognition), surveillance,... A panel of efficient techniques has been proposed based on variational or stochastic formalism. However, when one wants to apply such approaches on images of physical flows, many problems are likely to occur since we are often dealing with deformable objects with specific behaviors, strong deformations, short life cycle,... This is particularly true with turbulent and/or magnetic structures. To deal with this issue, a solution consists in enriching existing tools with prior knowledges in order to constraint the solution to be consistent with some physics. In this talk, I will briefly introduce the main principles of tracking techniques and will present some methods specifically designed to track physical small-scales structures.

Continuous Solar Magnetic Carpet

Andrei Gorobets

Kiepenheuer Institut fuer Sonnenphysik, Germany

Christoph Keller

Leiden Observatory, the Netherlands

The standard algorithms of tracking of small scale magnetic features suffering from the ambiguity due to intrinsic complexity of the feature interactions being, in its turn, entangled by the random field of the photospheric convective flows. We present an alternative concept in study of the photospheric magnetic features evolution excluding uncertainties of the direct feature following. The essence of the new method is to consider magnetic fluxes evolution in a time-ordered-sequence of magnetograms pixelwise: the pixel flux above the noise cut-off with prescribed minimal lifetime is being traced; then, flux change in time at separate pixels is analyzed but particular dynamics of the extended magnetic features the pixel belongs to is ignored. In this way, we obtain statistics of pixel flux random increments by treating the magnetograms as if they were snapshots of the instant microstate configuration of a "gas" of pixels (continuum medium).

In the framework of gas kinetic theory, we show that pixel fluxes obey geometrical random walk model, we estimate master and Fokker-Plank equations for the pixel flux increment probability density function and discuss theoretical consequences supported by the data analysis.

Using methods of thermodynamics we show applicability of the fluctuation theorem and present a measure of irreversibility in the pixel flux stochastic dynamics.

A comparative application of the new method will be presented for small-scale magnetic features of the quiet Sun registered by SDO/HMI, Sunrise/IMaX instruments and MHD simulations.

Analysis of long-term magnetic flux transport on the solar surface by auto-tracking technique of patches

Yusuke Iida
ISAS/JAXA

Spatial displacement of patch structure on the solar surface is investigated based on satellite data and auto-tracking technique.

Magneto-convection system on the solar surface is thought to be important not only as a cause of various solar activities but also as an actual observable magneto-convection on the stellar surface. One important issue is how magnetic flux is transported there. In global scale, the transport of magnetic field is treated as a diffusion from Leighton et al.(1964). However recent papers reveals the transport is significantly different from the high-temporal and spatial ground-observation data. Despite So I investigate the magnetic by using the longest magnetogram obtained by Hinode with an aim of understanding the treatment of magnetic field transport in global scale.

In the observational data, number of tracked patches is enough for statistical study, more than 40000. The obtained dependence show a different character above and below the point of $L \sim 10^4$ km. I investigate the dependence of mean-square displacement on elapsed time by using auto-tracking technique, which is one of the critical characteristics for global-scale description of transport. Below that scale, it has a power-law dependence with an index of ~ -1.4 , namely super-diffusion scheme, which is consistent with the recent ground observation. However, in the larger scale, it is newly found that the power-law dependence becomes ~ -0.6 , namely sub-diffusion scheme. These characters can be explained by the network flow pattern qualitatively. In the presentation, I will discuss this interpretation and the effect of sub-diffusion on the transport in global scale.

Magnetic Feature Tracking and the Small-Scale Solar Dynamo

Derek Lamb

Southwest Research Institute

Craig DeForest, Tim Howard

Southwest Research Institute

We discriminate between shallow and deep small-scale dynamo models by tracking magnetic features. We consider a number of shallow-dynamo scenarios by which an existing strong network concentration can influence the formation and polarity of nearby small-scale magnetic features. These scenarios have measurable signatures, for which we test using magnetograms from the Narrowband Filter Imager (NFI) on board Hinode. We find no statistical tendency for newly formed magnetic features to cluster around or away from network concentrations, nor do we find any statistical relationship between their polarities. We conclude that there is no shallow or "surface" dynamo on the spatial scales observable by Hinode/NFI-the birth locations of new magnetic features do not have the spatial locality properties one would expect from a shallow dynamo model. In light of these results, we offer a scenario in which the subsurface field in a deep solar dynamo is stretched and distorted via turbulence, allowing the small-scale field to emerge at random locations on the photosphere.

Calculating solar differential rotation by automatic tracking of CBPs with hybrid PSO-Snake algorithm

Ehsan Shahamatnia

CA3-UNINOVA, Universidade Nova de Lisboa

Ivan Dorotovic[1,2], Jose Fonseca [1], Rita Ribeiro[1]

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With new space missions such as SDO, solar images are being produced in unprecedented volumes. To capitalize on that huge data availability, the scientific community needs a new generation of software tools, which enable automatic and efficient data processing. At CA3-UNINOVA, we have been developing a working prototype of a modular framework for solar feature detection, characterization and tracking. To develop an efficient system capable of automatic solar feature tracking and measuring, a hybrid approach, combining specialized image processing, evolutionary optimization and soft computing algorithms is being followed. By using a specialized hybrid tracking algorithm for tracking solar features we can achieve automatic feature tracking while gathering characterization details about the tracked features. The PSO-Snake hybrid model on one hand takes advantage of Snake model, a specialized image processing algorithm widely used in applications such as boundary delineation, image segmentation, and object tracking and on the other hand, it exploits the flexibility and efficiency of Particle Swarm Optimization (PSO) method. The proposed tool was already tested for tracking sunspots and coronal bright points. The results obtained and details about the tool can be found in [1, 2]. In this work, we discuss the application of the PSO-Snake algorithm for the calculation of sidereal rotational angular velocity of the rotation of the solar corona, w , with relation to latitude, b (equation 1 in [5]). By tracing Coronal Bright Points (CBPs) in total of 636 measurements from a time series of SDO/AIA 94A images from September and October 2010, constant coefficients A , B and C in the equation above are estimated as 14.25, -0.68, -3.44. It is comparable with results obtained by Wohl et al [3] (14.5, -2.54, -0.77), Brajsa et al [4] (14.45, -2.22, -2.22) and Lorenc et al [5] (14.56, 0.0, -5.71). We are aware that the result is limited due to the small number of measurements. However, it demonstrates the promising capacity of the tool for processing solar images. A brief introduction to the underlying techniques and a use case demonstration will be presented.

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Can flux cancellation build-up magnetic flux ropes?

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**Lucie Green [1], David Williams [1], Lidia van
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Flux cancellation, which is observed in small-scale opposite polarity fragments, that converge, collide and disappear in the photosphere, is considered to be important in the formation of filaments. It has been identified as playing a key role in the build-up of shear and twist in magnetic field structures leading to the creation of flux ropes. In many cases these flux ropes erupt to form a coronal mass ejection (CME) and it is important to understand their exact magnetic configuration so that the CME initiation mechanisms can be identified. In addition, it is important to quantify the amount of magnetic flux ejected in to the solar system due to the geoeffective consequences of flux ropes when they impact the magnetosphere. We have written an algorithm to analyse, track and quantify magnetic flux cancellation regions in line-of-sight magnetograms produced by the Helioseismic and Magnetic Imager (HMI). This algorithm has proven successful in calculating the magnetic flux of these small-scale cancelling fragments, allowing the flux being built into the flux ropes to be quantified and the timescales over which the ropes form in relation to their eruption to be probed.

Session 4

*Tracking of small scale magnetic
features and its applications*

Posters

Solar rotation measured by SDO/AIA coronal bright points

Roman Brajsa

Hvar Observatory, Univ. Zagreb, Croatia

Davor Sudar, Ivica Skokic, Steven Saar

Preliminary data from Atmospheric Imaging Assembly (AIA) instrument on board Solar Dynamics Observatory (SDO) satellite were used. To obtain positional information of coronal bright points (CBPs) a segmentation algorithm, which uses all available AIA channels in search for intensity enhancements in EUV and X-ray parts of the spectrum compared to the background intensity, was applied. More than 60000 position measurements of more than 10000 identified CBPs covering two days (1st and 2nd of January 2011) were analysed. Rotational and meridional velocities were determined by tracking identified CBPs. Various filters were used to exclude erroneous results. Proper motions of CBPs and distribution of errors according to position of CBPs on solar disc were also investigated. Preliminary results include information about solar differential rotation profile, latitudinal dependence of meridional motion and Reynolds stress and analysis of proper motions of CBPs using a random walk model.

Polarity Inversion Line Applications

Alexander Engell

Montana State University

The polarity inversion line (PIL) has historically been used by the solar community to approximate where reconnection during flares occur. Because of this several methods of utilizing PIL parameters such as gradients (Falconer) and total flux within a certain distance to the PIL (Shrijver) have been explored and bench marked using MDI magnetograms. With the arrival of SDO and NASA's Feature Finding Team PIL maps are available at unprecedented cadence (12 minutes) and resolution (4kx4k) for the full-disk of the Sun.

The PIL module runs in near-real-time at LMSAL with a latency of 30 min. The repository of PIL save files (soon to be hosted by Georgia State University) have locations of PILs, active regions (Stanford's HARPs) that can be linked to NOAA ARs, and their associated photospheric and transverse field gradient measurements.

We showcase PIL overlays on HMI magnetograms (ARs) to illustrate the fine details of PIL evolution leading to flaring events. We also overlay the PIL onto 304A and H-Alpha images showing how filament characteristics can be more accurately described.

If you have any requested dates for PIL data between May 2010 and Jan 2013 please email Alec (aengell@physics.montana.edu) so that he may bring that data to the meeting to share and demo. 1 hour of PIL save files is 80 MB.

Augmenting a magnetic feature tracking code

Milan Gosic

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Luis R. Bellot Rubio

Instituto de Astrofísica de Andalucía (IAA-CSIC)

Automatic feature tracking algorithms have become an indispensable tool for understanding the solar magnetism on a wide range of temporal and spatial scales. They provide an efficient way to analyze the huge amounts of data gathered by ever improving solar instruments, particularly those on spaceborne platforms. Despite their usefulness, tracking codes have many shortcomings. Some of them stand out clearly in highly populated regions of the solar surface such as the internetwork, where magnetic elements frequently interact with each other. In those cases tracking codes fail to properly identify interactions between magnetic patches, which may severely bias their results. To overcome this problem, we have implemented additional constraints to an automatic feature tracking code. These improvements have allowed us to evaluate in a direct way the importance of small-scale internetwork fields for the maintenance of the quiet Sun magnetic flux.

Recognizing Morphological Diversity in Solar EUV Images

Michael Kirk

NASA Goddard Space Flight Center

C. Alex Young

NASA Goddard Space Flight Center

The information contained in solar images is usually complex, containing several categories of features simultaneously. Because of this inherent complexity, no single transform is optimal to effectively represent all the contained features in a single image. Generic multi-scale decomposition of images has been codified into several libraries, each excelling at characterizing specific types of features. Not restricting our analysis to a single decomposition library, we employ wavelets, curvelets and spatial band-pass filtering to isolate solar features of a specific scale from the original data. At each scale, it is then possible to estimate and subtract a noise contribution and amplify a desired signal. We apply this approach to time series of high-resolution solar EUV images. Using a multi-scale analysis of solar images coupled with a high time cadence, we are able to extract independently evolving morphological components as the solar environment changes.

A fast Python-based Ellerman bomb tracking algorithm.

Stuart Mumford

The University of Sheffield

Chris Nelson[1,2], Robertus Erdélyi[1], Gerry Doyle[2]

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Recent advances in the capabilities of ground-based solar instrumentation have lead to a thriving community of analysts who study the lower solar atmosphere on scales of tens of kilometers. Combining such resolutions with high-cadence data (often below ten seconds) means that many small-scale events in the photosphere (such as magnetic bright points or Ellerman Bombs) appear to propagate horizontally, often moving over a pixel per frame. In order to fully research these events, therefore, complex tracking algorithms must be developed. In this presentation, we discuss an example of a tracking algorithm developed using the scientific python eco-system which was exploited to follow Ellerman Bombs through the H-alpha line wings. The algorithm was developed specifically in order to reduce the false detection of events and allow comparisons simultaneously across a number of wavelengths. Individual events were saved by the code to allow further analysis of each Ellerman Bomb to test for other physical traits, such as oscillations. Due to the readability of the code, it is foreseeable that other datasets could be exploited easily by a wide variety of researchers within the community with minimal effort.

Sunspot group areas, tilt-angles and magnetic-field reconstruction for historical cycles

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Leibniz Institute for Astrophysics, Germany

Dr. Rainer Arlt

Leibniz Institute for Astrophysics, Germany

The study of sunspots with latitudes, areas and group properties like tilt-angles over many solar cycles can help us understand the relation between the dynamo and surface magnetic fields, polar fields and open flux. We are aiming at a statistical approach to these quantities over centuries using historical observations of the Sun. During 1825-1867, Samuel Heinrich Schwabe recorded sunspots in drawings. This large amount of data has been digitized and measured. The sizes of the sunspots have been determined using 12 different circular-shaped cursors. Now we have estimated the areas of those sunspots through a statistical comparison with modern data. With the areas and positions of individual spots, tilt angles of sunspot groups were calculated. Together with the latitudinal distribution, we are planning to simulate the surface flux transport during that period and obtain better relations for polar-field and open-flux reconstructions of even earlier cycles.

Session 5

*Origin of variability and prediction
of solar wind*

Oral presentations

Turbulence, nonlinear dynamics, and sources of intermittency and variability in the solar wind. (Invited)

William Matthaeus

University of Delaware

Solar wind fluctuations in density, velocities, temperature and electromagnetic field span a wide range of space and time scales. Variability that is observed at any position in the heliosphere may be influenced both by local processes and by the dynamics of the corona, photosphere and solar interior. Various effects associated with turbulence and nonlinear dynamics can lead to several types of variability that occur over the requisite wide range of scales. Here, we first review the observed properties of solar wind turbulence that provide a consistent picture of the in-situ dynamical effects. The observational data constrain transport formulations that enable reasonably accurate (and improving) statistical prediction for the distribution of turbulence properties throughout the heliosphere. This is essential for improving prediction of the transport of energetic particles, both of solar and galactic origin. Second, we will examine the generation by local turbulence of inertial range and smaller scale intermittency, or burstiness of gradients, leading to coherent structures such as current sheets and sharp flux tube boundaries. These may be the sites of kinetic dissipation that heat the corona, producing the solar wind. Furthermore, coherent current structures, in conjunction with associated random reconnection events, can have a significant influence on magnetic connectivity, with important implications for predictive models. Finally we examine evidence for very low frequency variability such as that associated with $1/f$ noise, observed in the photosphere, corona and solar wind. This low frequency variability is associated with long-time correlations and represents another face of intermittency. Its origins may lie in scale invariant activity in the solar atmosphere, or in nonlocal-in-scale dynamics in the solar interior, in both, or perhaps in some other unknown effect. Very low frequency variations may set limits to standard prediction but also provide clues concerning the drivers of solar activity. The presentation leads to a discussion on how Solar Probe and Solar Orbiter measurements will address all three of these aspects of variability in the solar atmosphere.

A multi-scale approach to the analysis of anisotropic plasma turbulence (or studying turbulence wearing wavelet spectacles) (Invited)

Khurom Kiyani

University of Warwick

The multi-scale nature of turbulence is well-known. The business of decoupling these scales to reveal their physics, however, is more of a black art. Traditionally this has been done through a Fourier representation, where the self-interaction of the shear flow can be better represented as a problem of many-body or mode-coupling theory. However, as nice as some of the formalism is, a Fourier representation - the basis being eigenmodes of linear dynamical systems - is not a unique decomposition of a highly non-linear system. In fact, we can equally move to another basis. The majority of this presentation will be devoted to forms of this other possible basis - forms which will be catered to the physics of the particular aspect of the phenomenon that we are interested in. I will introduce wavelets (multi-resolution analysis) as a particularly well-suited decomposition basis, where the basis functions are not only functions of scale, but also of space/time. They thus retain event locality and allow us to pinpoint the location of these events, at a particular scale - an important property when investigating coherent structures in turbulence. I will motivate the use of wavelets through the ostensibly benign problem of picking a suitable background magnetic field when faced with highly stochastic signals, where a such a field is hard to define. I hope to convince you that wavelet transforms can help us do this self-consistently. Once we leave the sanctuary of the Fourier domain, however, we are confronted with a veritable zoo of these wavelets (and variations on this zoo), with many pitfalls that could ensnare us. Thus, I will discuss some of these pitfalls and instruct you on how to befriend and tame the right wavelet beast for your needs - ones which will always help you to also get back to the Fourier sanctuary where many of our theories reside. The last quarter of my presentation will be devoted to some other pitfalls which come about when studying higher-order statistics in turbulence data - chiefly the pitfalls of non-Gaussian heavy tailed statistics; and how rarely sampled extreme events can dramatically spoil ones otherwise happy statistical endeavours. I will discuss possible ways of correcting this particular rare-event misdemeanour in the context of the calculation of scaling exponents. On the way, we might

also look at asking how one can hope to do decent statistical inference in the presence of such heavy-tailed statistics.

A multifractal analysis of air temperature signals based on the wavelet leaders method

Adrien Delière

University of Liège

Samuel Nicolay

University of Liège

We present the wavelet leaders method (introduced by S. Jaffard) as a tool to study the Hölder regularity of signals, which is closely related to some functional spaces. We use the associated multifractal formalism to show that surface air temperature signals are monofractal, i.e. these are regularly irregular. Then we use this result to establish a climate classification of weather stations in Europe which matches the Köppen-Geiger climate classification. This result could give rise to new criteria to determine the effectiveness of current climatic models.

Session 5

*Origin of variability and prediction
of solar wind*

Posters

Towards understanding the role of waves in the solar corona using spectroscopic techniques

Laurent Dolla

Royal Observatory of Belgium - STCE

Yuriy Voitenko[1], Viviane Pierrard[1], Andrei Zhukov[2][3]

[1] Belgian Institute for Space Aeronomy -STCE, [2] Royal Observatory of Belgium - STCE, [3] Skobeltsyn Institute of Nuclear Physics, Moscow State University

To heat the corona or accelerate the solar wind, many models use MHD waves. In absence of in situ measurements in the very low solar corona, one has to rely on remote sensing observations only. We present a method using line profile analysis to both constrain the potential source of energy (the Alfvén wave amplitude as a function of altitude) and measure the effects of wave absorption on ions species of different charge and mass (the spectral distribution of the wave power). We apply this method on data from SOHO/SUMER and Hinode/EIS spectrometers, acquired below 1.3 Rs. The observed preferential heating of minor ions must still be explained: resonance with ion cyclotron waves, with kinetic Alfvén waves or other wave-particle interactions?

Operational forecast of solar wind streams

Ljubomir Nikolic

Natural Resources Canada

Ljubomir Nikolic, Larisa Trichtchenko, Lidia Nikitina

Natural Resources Canada

The high-speed solar wind streams associated with coronal holes are one of the Space Weather phenomena that are particularly important to Canada. These solar wind streams are often a source of geomagnetic disturbances to which Canada, due to its location, is susceptible. We present work of the Canadian Space Weather Forecast Centre on an operational forecast of the solar wind. The core of the forecast, which runs every three hours, is based on potential field source surface and Schatten current sheet models to obtain a coronal magnetic field using solar magnetograms as an input. Following a known idea (Wang, Sheeley, Arge, Hakamada), the solar wind streams are assigned to open magnetic field lines using an empirical relation. We discuss an agreement between numerically modelled and observed coronal holes, and the relation that connects the solar wind speed with open magnetic field lines. Furthermore, we compare forecasted and observed solar wind speed at Earth, and discuss the performance of the forecast for 2008-2013.

Geometrical properties of coronal holes and filament channels extracted from SDO/AIA 193Å images

Martin Reiß

IGAM, Institute of Physics, University of Graz

**Manuela Temmer, Thomas Rotter, Stefan Hofmeister,
Astrid Veronig**

IGAM, Institute of Physics, University of Graz

It is well known that coronal holes play an important role in geomagnetic storm activity. They coincide with rapidly expanding open magnetic fields and are the source regions of the high speed solar wind streams. Due to the lower temperature and density compared to the ambient coronal plasma, coronal holes appear as dark areas in X-ray and extreme-ultraviolet (EUV) images of the Sun. In a previous study, we presented an automated method for the identification and extraction of coronal hole regions in SoHO/EIT 195Å images. For a case study, the method was also successfully applied to PROBA2/SWAP 174Å data. Currently it is used on SDO/AIA 193Å data for the automatic extraction of coronal hole areas and forecasting of solar wind speed at 1 AU. The testing phase demonstrated that filament channels are sometimes identified by the algorithm as coronal holes, which leads to errors in the forecasts of high-speed solar wind streams. To improve the solar wind forecasting method we need to distinguish filament channels from coronal holes. Although previous research has been carried out on this subject, no study exists which pays attention to the intrinsic geometry of these features. Based on differences in their topology, we investigate the benefit from geometrical classification methods for improving the distinction between coronal holes and filament channels. Using SDO/AIA 193Å image data, we present two new geometrical classification methods in comparison with well known shape measures from literature. The results of this research support the idea that geometrical methods have the potential to decrease coronal hole classification errors and could be used as an applied screening technique in our solar wind forecast algorithm.

Second order statistics for the analysis of textural properties of coronal holes and filament channels in SDO/HMI and SDO/AIA 193Å images

Martin Reiß

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**Stefan Hofmeister[1], Manuela Temmer [1], Astrid
Veronig[1], Ruben De Visscher[2], Veronique
Delouille[2], Thomas Rotter[1]**

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Coronal holes, as sources of high-speed solar wind streams, are the dominant contributors to space weather disturbances at times of quiet solar activity. We apply an automated method for the identification and extraction of coronal hole regions in SDO/AIA 193Å images to digest the values into a tool which empirically relates the area of coronal holes and the solar wind parameters at a distance of 1AU. This enables us to forecast the solar wind speed at 1AU with a lead time of about 4 days. Due to the almost equally low intensity of coronal holes and filament channels in solar EUV images, filament channels are sometimes erroneously identified as coronal holes which affects the quality of the forecasts. Hence, to improve the solar wind forecasting method we need to distinguish filament channels from coronal holes.

Contrarily to coronal holes, filament channels are regions of closed magnetic field lines along a polarity inversion line and are therefore different in their magnetic field configuration. In this study we investigate the benefits from Haralick's textural features to analyze the intrinsic texture information of coronal holes and filament channels in AIA 193Å and HMI images. We analyzed a set of low intensity regions automatically extracted over the time range 2011-2013. Based on visual inspection of H-alpha filtergrams from Kanzelhöhe Observatory, we obtain a set manually labelled coronal holes and filament channels. We use these labels on a set of shape measures, first order, and second order texture statistics in order to obtain the most suitable decision rule for a differentiation. We present the first results from a comparison of supervised machine learning algorithms applied on this problem.

SunPy, time series, and statistical analysis

Posters

A Bayesian Approach to Supervised Segmentation of Solar Regions

Ruben De Visscher

Royal Observatory of Belgium

**Véronique Delouille[1], Pierre Dupont[2],
Charles-Alban Deledalle[3]**

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Bordeaux

The Sun as seen by Extreme Ultraviolet (EUV) telescopes exhibits a variety of large-scale structures. Of particular interest for space weather purpose is the extraction of active regions (AR) of high magnetic activity, and of regions where the fast solar wind departs, called Coronal Holes (CH). In this poster we present our work on supervised segmentation of EUV images into three classes: AR, CH, and the remaining part called Quiet Sun (QS). A Bayesian classifier is used, allowing for the introduction of prior information on position, size, and total coverage of each class. Noise structure in EUV images is non-trivial and the classification must be robust to wrongly label pixels. This suggests the use of a kernel density estimator to fit the intensity distribution within each class. We evaluated the performance and robustness of the method as the number of training points decreases, and as wrongly labeled pixels are introduced.

Making of composites out of multiple solar datasets: a Bayesian multiscale approach

Thierry Dudok de Wit

LPC2E, CNRS/University of Orléans

Micha Schöll, Matthieu Kretzschmar

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What is the best way of stitching together a set of disparate and incomplete records in order to end up with one single and consistent composite? This stitching problem is one of the major challenges encountered in the reconstruction of long-term solar activity. A typical example is the making of a single total solar irradiance (TSI) record out of the dozen existing observations that disagree, not only in their absolute level, but also partly in their time evolution. Averaging clearly is not a good solution, and often does not apply anyway because of the numerous data gaps. Similar problems are encountered in other fields, such as the making of paleoclimate temperature records out of proxies such as tree rings, ice core data, etc. This problem of integrating multiple data and knowledge into a single composite is called multi-sensor data fusion, which has recently become a very active field of research.

Here, we concentrate on the making of a single solar spectral irradiance dataset, and rely for that on multiple direct observations, on proxy data, and on solar irradiance models. The approach we have started implementing is a Bayesian multiscale one. First the data are decomposed into different time scales, because the correspondence between different records is often time scale-dependent. Most observations, for example, exhibit very similar variations associated with the 27-day solar rotation, but disagree on decadal time scales, for which instrumental trends tend to dominate. Secondly, the data are combined in a probabilistic sense, by using Bayesian inference. The main advantage of this approach is its unified rationale for extracting information, in which all underlying assumptions are explicated. Its computational complexity, however, can be a challenge.

We have so far used this approach for building a TSI composite, and also a composite MgII index. These examples will be detailed, and the multiple advantages (and also challenges) of this approach will be illustrated.

The solar butterfly diagram: from a phase space portrait to a predator-prey model

Thierry Dudok de Wit

LPC2E, CNRS/University of Orléans

The butterfly diagram (i.e. the latitudinally-dependent distribution of sunspots) is of key importance for understanding how the solar dynamo evolves in time and yet, it has received much less attention than the sunspot number, arguably because the analysis of a 2D distribution is more challenging than that of a just a time series. Several attempts have already been made to reduce this butterfly diagram to simpler representations by searching for patterns. Principal component analysis, for example, suggests that one can describe it in terms of a limited number of "modes" only. The problem with such approaches is that they give unphysical results because the modes we find can be negative.

We revisit this problem by using a recent Bayesian positive source separation approach to decompose the butterfly diagram in a series of positive and independent modes. Interestingly, we find that only two of them are needed to capture the salient features of the diagram. This basically means that the dynamics of the whole diagram can be reduced to two time series only, which considerably eases the analysis. These two modes respectively describe the sunspot distribution at high, and at low latitudes.

These new modes open many interesting perspectives. By plotting one against the other, we obtain a phase space representation of the solar cycle, which allows to compare cycles in much more detail than by using sunspot numbers only. This representation also shows precisely when the onset of a new cycle occurs and thus helps in the timing of cycles. More importantly, it tells us what are the patterns in the equator-ward motion of sunspots that lead to a strong cycle, and as such helps in predicting the solar cycle strength.

This empirical model of the butterfly diagram can also be interpreted physically after noticing the strong similarity of its phase space with that of predator-prey models. We show how this comparison allows us to interpret the conversion of the solar poloidal magnetic flux into a toroidal one, and vice-versa.

You can do solar data analysis using SunPy

Jack Ireland

NASA's GSFC / ADNET Systems, Inc.

Stuart Mumford, Steven Christe, The SunPy

Collaboration

University of Sheffield, NASA's GSFC, The SunPy Collaboration

Python is becoming widely used for scientific data analysis thanks to a suite of popular, well-supported libraries. These libraries, along with SunPy, a community-developed free and open-source software package for solar physics, make it possible to perform solar data analysis using the Python programming language. SunPy/Python is particularly well placed to take advantage of several advanced image processing, machine learning and time-series libraries. We outline the capabilities of some relevant data analysis packages of particular interest to the SIPWork and solar communities, and give some examples of their application in solar data analysis.

Reconstruction of the solar Extreme Ultra Violet (EUV) irradiance using EUV images

Benjamin Mampaey

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Margit Haberreiter[1], Véronique Delouille[2]

[1]Physikalisch-Meteorologisches Observatorium and World Radiation Center, [2]Royal Observatory of Belgium

The SPoCA2 tool is used to segment EUV images from the SOHO/EIT and SDO/AIA space telescopes, in separates coronal features, according to a fixed brightness classification scheme. The SolMod code is then used to calculate intensity spectra for 10 to 100 nm for each of the coronal features. Weighting the intensity spectra with the area covered by each of the feature yields the temporal variation of the EUV spectrum. The reconstructed spectrum is then validated against the spectral irradiance as observed with SOHO/SEM and ISS/SolACES respectively.

We will present these reconstructions and some of the problems we encountered.

Time dependent tomographic reconstruction of the solar corona

Christelle Peillon

LAM - Laboratoire d'Astrophysique de Marseille

Didier Vibert [1], Richard Frazin [2], Philippe Lamy [1], Judith de Patoul [1]

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The distribution of the electron density in the corona is crucial to advance the knowledge in understanding the nature of solar coronal phenomena. Several methods for the reconstruction of 3D density of the solar corona from projection data have been proposed. One of the major difficulties is the problem of the restrictive assumption that the structure of the corona does not vary with time. The solar temporal evolution introduces a lot of errors in classic tomographic reconstruction. In this poster we present a new time dependent tomography method by adding a spatial, temporal and rotational regularization matrix. We perform the method on images from a 3D MHD model of the corona during a period of 14 days in November 2008. We compute the normalized error between the model and the reconstruction in order to estimate the quality of the reconstruction. We also perform the developed tomography methods on polarized brightness images of the SOHO/LASCO instrument. We show that the new time dependent method decrease the number of artifacts by comparing our results with classic static tomographic reconstruction. In particular, we show that the spatial and temporal regularization matrices improves significantly the reconstruction and that the rotational regularization is useful when using a large amount of images during the 14 days period.

Detector Statistics and Interpretation of Images

Joseph Plowman

High Altitude Observatory

Detector Statistics and Interpretation of Images: The detector statistics of CCD-based imagers are fairly well understood and are straightforward to model as a combination of read and Poisson (photon counting) noise. I demonstrate how an understanding of these statistics can be employed to spatially or temporally process solar images, clearly distinguishing instrument noise from dynamics and structure on the Sun. In the examples shown, the image(s) are first filtered (spatially or temporally) with a median smoothing or Gaussian blur. The residual between each pixel value and its corresponding filtered value is then computed, assuming that the detector statistics (read and shot noise) are given by the filtered value. These residuals clearly show where the Sun is changing in the processed data, and can also be used for noise reduction. The images and animations presented demonstrate both of these uses.

SunPy: New Scientific Analysis Capabilities for GOES Observations

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The SunPy project is a new open-source software library for solar physics using the Python programming language. As SunPy continues to be developed, it is becoming increasingly useful for scientific analysis by the solar physics community. Sunpy's latest improvement is its capability to use GOES/XRS observations to derive the temperature, emission measure and other thermal properties of solar coronal plasma. The GOES/XRS series has been consistently observing the Sun at soft X-ray wavelengths since the mid-1970's. In that time, it has become the most popular way in which to analyse the thermal solar coronal plasma, particularly in solar flares. Thus this new capability represents a significant step forward in making python and SunPy a viable alternative for all aspects of solar physics analysis.

First Steps towards a Homogeneous Solar Spectral Irradiance Dataset : Selection, Merging and Quality Assessment

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The sun varies over different timescales, from minutes to month, decades and millennia. Its variation is an important driver to terrestrial climate changes and as such an important input to climate models. While several observation exists to date over a broad frequency range, they are sparse over both time and frequency.

As part of the SOLID (First European comprehensive Solar Irradiance Data Exploitation) project we present the homogenized data set of available UV solar spectral irradiance

We present the data used, together with preliminary error-estimates and self-consistent quality assessments, gap-filling methods and selection criteria. In a next step, we utilize a combination of observed solar spectral irradiance from several missions starting with OSO III in 1967 together with available proxy data, to further quantify the data quality.

SOLID project is part of the seventh European framework programme. It aims to join a large variety of different solar spectral irradiance data sets and combine them into one dataset and to reconstruct the spectral solar variability further back in time. The overall goal is to deliver a dataset that can be used by e.g. climate researchers in order to account for the non-constant solar forcing.

Reconstruction of the solar spectral irradiance from solar magnetograms: a data-driven approach

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Various models have been developed for reconstructing the solar spectral irradiance (SSI), which is a key quantity for understanding the solar radiative output, and yet, suffers from a severe lack of observations. The UV band is of particular interest, because of its role in the Sun-climate connection, and also because its proper measurement is so challenging.

The most successful SSI reconstruction models are semi-empirical ones, which assume that variations in the SSI are driven by the solar surface magnetic field. All these models proceed by segmenting solar magnetograms and then assigning theoretical spectra to the different classes of features. Two drawbacks of this approach are its sensitivity to the absolute magnetic field calibration, and the prespecified spectra. To overcome these, we consider a different, and more empirical approach.

First, we identify the different classes of solar features according to their area (instead of amplitude), which alleviates the need for absolute calibration. Secondly, we estimate the spectra associated with each class from the observations, using 4 years of data from SORCE, TIMED and SDO. In this data-driven approach, we also explore how many classes are actually needed to properly reconstruct the observed SSI, and find that two only suffice for the UV band. Interestingly, a decomposition into two different time scales (rotational and long-term variations) significantly improves the reconstruction of extreme-UV band. We are now turning this model into an operational tool that works in real-time. Overall, the performance of this empirical model is comparable to other existing ones, although we cannot assess it yet on time scales beyond a solar cycle.

In this presentation, we shall focus on the model definition, with the segmentation procedure, and the validation.

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