HELCATS First Annual Open Workshop

Heliospheric Imaging -

A new era of space science and space weather observations

Göttingen, May 19-22, 2015

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Heliospheric Imaging – A new era of space science and space weather observations

The first Annual Open Workshop of the EU FP7 project HELCATS (HELIOSPHERIC CATALOGUING, ANALYSIS & TECHNIQUES SERVICE) will take place on May 19-22, 2015 at the Georg-August-University of Göttingen, Germany. It takes place directly after the second HELCATS bi-annual project meeting/technical review to be held on May 18-19. The Annual Open Workshop is open to anyone who wishes to attend. The meeting organisers are Volker Bothmer (Göttingen, Germany), Richard Harrison and Jackie Davies (both of the Rutherford Appleton Laboratory, UK), the HELCATS Team, and the EU office at the University of Göttingen.

The HELCATS project (see http://www.helcats-fp7.eu/) is providing revolutionary new insights into solar wind structure through combining the comprehensive analysis of heliospheric imaging observations from the NASA STEREO spacecraft, in concert with associated remote-sensing and in-situ measurements, with a thorough assessment of appropriate techniques and models. The project recognises that the advent of wide-angle imaging of the inner heliosphere has revolutionised the study of transient and quasi-stationary structures in the solar wind, in particular Coronal Mass Ejections (CMEs) and Co-rotating Interaction Regions (CIRs). Prior to the development of wide-angle imaging of the inner heliosphere, signatures of such solar wind features could only be observed within a few solar radii of the Sun, and in the vicinity of a few near-Earth and interplanetary probes making in-situ measurements of the solar wind. Heliospheric imaging has, for the first time, filled that vast and crucial observational gap.

Welcome Address

Dear colleagues,

Welcome to the University of Göttingen meeting facility adjacent to the historical observatory of Carl Friedrich Gauss.

In 1830, the mathematician and director of the „Göttinger Sternwarte“, Carl Friedrich Gauss, made the first detailed measurements of the Earth’s magnetic field based on recommendations by Alexander von Humboldt, who had recorded geomagnetic fluctuations during the appearance of aurora in the sky above Berlin[1,2,3]. Since 1834, systematic measurements of the variation of the Earth’s magnetic field have been made at the „Göttinger magnetischer Verein“ (founded by Gauss and Wilhelm Eduard Weber) in conjunction with observations of the „Northern Lights“ - termed „magnetische Ungewitter“ in German. Having produced a mathematical description of the Earth’s magnetic field in terms of separate internal and external components, Gauss recognised that these short-term fluctuations of the magnetic field must have had external causes; he called these fluctuations the „Rätselhafte Hieroglyphenschrift der Natur“[2,4,5]:

„Wir müssen vorerst unser Bestreben nur sein lassen, Abschriften von dem, was sich darbietet zu sammeln, und denselben immer mehr Zuverlässigkeit, Treue und Mannigfaltigkeit zu verschaffen: reichem Stoff wird, wie wir zuversichtlich hoffen dürfen, dereinst auch die Entzifferung nicht fehlen… Es wird der Triumph der Wissenschaft sein, wenn es dereinst gelingt, das bunte Gewirr der Erscheinungen zu ordnen, die einzelnen Kräfte, von denen sie das zusammengesetzte Resultat sind, auseinander zu legen, und einer jeden Sitz und Maß nachzuweisen’’[4,5].

Of course now we understand that these mysterious geomagnetic variations (including those large variations that we term geomagnetic storms) are caused by the impact of solar wind phenomena, not least coronal mass ejections (CMEs), on the Earth’s magnetic field[7].

Today, the solar wind is observed routinely by satellites, and the SECCHI heliospheric imagers on board the twin STEREO satellites are providing unprecedented imagery of transient and background structures therein.

We think that this historical meeting place is a most appropriate place for the first workshop on „Heliospheric Imaging - A new era of space science and space weather observations”.

We wish you a successful meeting and a pleasant stay in Göttingen.

Sincerely yours,

Volker Bothmer, Richard Harrison and Jackie Davies

Göttingen, May 2015

1,2 Kertz, W., Einführung in die Geophysik Bd. 1 u. 2, BI Hochschultaschenbücher, 275, 535, 1985.

3 Bothmer, V., The Solar Atmosphere and Space Weather, in Solar System Update, Eds. P. Bondel , J.W. Mason, Springer/Praxis, 1, 2006.

4, 5 Gauss, C.F., Resultate aus den Beobachtungen des Magnetischen Vereins im Jahre 1836, Göttingen 1837, 98 u. 100.

6 Bothmer, V., R. Gräve, “Sonne und Erde im Visier von STEREO – Sun and Earth in STEREO focus”, DLR newsletter, Countdown 12.

7 Bothmer, V., I.A. Daglis, Eds. “Space Weather – Physics and Effects”, Springer/Praxis, 2007.

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14:40	Dynamic evolution of coronal mass ejections ***(Invited)***	M. Temmer
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15:40	**Coffee/tea**	
16:00	Heliospheric Imaging: the status quo and the future ***(Invited)***	T. Howard & C. DeForest
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17:40	Comparing HELCATS CIR catalogues derived from white-light images and in-situ measurements	I. Plotnikov & A. Rouillard
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09:40	Three-dimensional evolution of fast and slow CMEs from the Sun to 1 AU	A. Isavnin, S. Käki & E. Kilpua
10:00	Visualizations of the HI CME catalogue and solar wind magnetic field data	C. Möstl, P. Boakes, A. Isavnin, E. Kilpua & J. Davies
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11:20	Internal structure of interplanetary coronal mass ejections and relation to remote sensing observations	E. Kilpua, A. Isavnin, A. Vourlidas, H. Koskinen & L. Rodriguez
11:40	Comparing interplanetary and in-situ properties of CME driven shocks	L. Volpes & V. Bothmer
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	Estimation of the 3D electron density distributions in the solar corona for more realistic solar wind	J. de Patoul, C. Foullon, D. Vibert, P. Lamy, C. Peillon & R. Frazin
Thursday 21st May		
Session 4: Development and application of heliospheric observations and techniques for scientific and space weather usage		
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16:20	The new CORIMP CME catalogue & 3D reconstructions	J. Byrne, H. Morgan, S. Habbal & P. Gallagher
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09:40	Carrington-L5: The next generation space weather monitoring mission	M. Trichas
10:00	INSTANT (INvestigation of Solar-Terrestrial Activity aNd Transients)	B. Lavraud, Y. Liu & the INSTANT team
10:20	**Coffee/tea**	
10:40	The PROBA-3 mission and its contribution to space weather studies ***(Invited)***	A. Zhukov & the PROBA-3/ASPIICS team
11:20	The Wide-field Imager for Solar PRobe+ (WISPR)	V. Bothmer, R.A. Howard & A. Vourlidas
11:40	Coronal and heliospheric imaging instrumentation development at RAL Space	J. Davies, C. Eyles, D. Griffin, R. Harrison, K. Middleton, A. Richards, J. Rogers, J. Tappin, I. Tosh & N. Waltham
12:00	**Wrap up (end of meeting)**	

Invited talks: 30 mins plus 10 mins discussion; contributed talks: 15 mins plus 5 mins discussion.

Session 1: Heliospheric imaging observations of solar wind structure (e.g. CMEs, CIRs, turbulence): introductory and review talks.

HELCATS – Heliospheric Cataloguing, Analysis and Techniques Service

Richard A Harrison, Jackie A Davies and the HELCATS Steering Committee

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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, rendering it crucial to space weather and its prediction. The advent of truly wide-angle heliospheric imaging has revolutionised the study of both transient (CMEs) and background (SIRs/CIRs) solar wind plasma structures, by enabling their direct and continuous observation out to 1 AU and beyond. The EU-funded FP7 HELCATS project combines European expertise in heliospheric imaging, built up in particular through lead involvement in NASA's STEREO mission, with expertise in solar and coronal imaging as well as in-situ and radio measurements of solar wind phenomena, in a programme of work that will enable a much wider exploitation and understanding of heliospheric imaging observations.

With HELCATS, we are (1.) cataloguing transient and background solar wind structures imaged in the heliosphere by STEREO/HI, since launch in late October 2006 to date, including estimates of their kinematic properties based on a variety of established techniques and more speculative, approaches; (2.) evaluating these kinematic properties, and thereby the validity of these techniques, through comparison with solar source observations and in-situ measurements made at multiple points throughout the heliosphere; (3.) appraising the potential for initialising advanced numerical models based on these kinematic properties; (4.) assessing the complementarity of radio observations (in particular of Type II radio bursts and interplanetary scintillation) in combination with heliospheric imagery.

We will, in this presentation, provide an overview of the HELCATS project and its progress in the first year.

Dynamic evolution of coronal mass ejections

Manuela Temmer

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Coronal mass ejections are the most dynamic phenomena in our solar system. They abruptly disrupt the continuous outflow of solar wind by expelling huge clouds of magnetized plasma into interplanetary space with velocities enabling to cross the Sun-Earth distance within a few days. Earth-directed CMEs may cause severe geomagnetic storms when their embedded magnetic fields and the shocks ahead compress and reconnect with the Earth's magnetic field. The transit times and impacts in detail depend on the initial CME velocity, size, and mass, as well as on the conditions and coupling processes with the ambient solar wind flow in interplanetary space.

This review talk is dedicated to present the current understanding of the physical processes that CMEs encounter when propagating from Sun to Earth and beyond. It will cover results from a wealth of observational data from multiple viewpoints, over a wide range of wavelengths, and over large distance ranges, as well as simulations. Also the process of CME acceleration close to the Sun will be addressed.

ENLIL Modeling Support to HELCATS Project

Dusan Odstrcil

GMU & NASA/GSFC, dusan.odstrcil@gmail.com

Numerical 3-D MHD code ENLIL can routinely simulate propagation of CMEs in the inner heliosphere. I will provide a brief overview of the recent enhancements (version 2.8) and introduce the experimental prediction website and repository of simulation results for all CMEs in 2011-2015 (http://helioweather.net/).

This site provides overview animations, temporal profiles at planets and spacecraft, synthetic white-light images and J-maps, and SEP alert plots. Comments and suggestions on how to make these outputs more convenient, efficient, and suitable to the HELCATS project needs would be very appreciated.

Heliospheric Imaging: The Status Quo and Future

Tim Howard and Craig DeForest

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Heliospheric imaging has come of age. From the original concept of white light photometry with the Helios spacecraft through SMEI and the HIs on board STEREO, heliospheric imagers have enabled important developments in our understanding of the solar wind and transients within, such as coronal mass ejections. Their wide fields of view provide more information than is available in their coronagraph counterparts, but also present additional challenges regarding background removal, feature detection and measurement, and geometric interpretation.

As the STEREO mission has reached a critical juncture with the passage of the spacecraft behind the Sun, it is timely to review the contributions of heliospheric imaging to science and space weather forecasting and to explore future directions for the field. I will present a review of the status quo of heliospheric imaging and the latest developments in feature detection and measurement, and describe future steps to advance the field to the next level.

Thomson scattering revisted

Bernd Inhester

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Thomson and Compton scattering were discovered almost a century ago and their physics is well understood. The application to the solar corona was described already in 1930 by Minneart in the form still used today.

However, the interpretation of coronagraph images, especially of data from the wide-angle Heliospheric Imagers on board the STEREO space craft, has caused some controversies about the detectability of Thomson scattered signals from the near-Sun heliosphere.

In our talk, we attempt to clarify some of these issues and we will also point out where additional effects might cause observations which have not been taken account of in Minneart's formalism.

Comprehensive Analysis Of Coronal Mass Ejection Propagation Speeds in STEREO COR2 and HI1 instruments

A.Pluta[1], *V.Bothmer*[1], *E.Bosman*[1], *J.Davies*[2], *L.Volpes*[1]

M.Venzmer[1], *N.Mrotzek*[1], *R.Harrison*[2], *C.Möstl*[3], *P.Boakes*[3]

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A better understanding of the evolution of propagation speeds of coronal mass ejections (CMEs) in interplanetary space is of major importance for the accuracy of space weather forecasts. The SECCHI suite on board the twin STEREO satellites has enabled for the first time stereoscopic observations of CMEs all the way from Sun to Earth.

The heliospheric imagers (HI) of the SECCHI suite allow for the first time remote sensing observations at distances larger than those achieved with previous imaging instruments, i.e. beyond 30 solar radii above the Sun. As part of the European Union FP7 project HELCATS (Heliospheric Cataloguing, Analysis & Techniques Service) we derived the deprojected 3D speed of CMEs in the field of view of the SECCHI COR 2 coronagraph by applying the Graduated Cylindrical Shell model to time series of white light observations. For those CMEs which were also identified in HI images, the COR 2 speeds were compared to those derived from analysis of HI data by an application of the fixed-phi, harmonic mean, and self-similar expansion fitting methods.

We present results from the analysis of more than 100 CME events studied so far. For a selected number of earth-directed CMEs we further compared the derived remote sensing speeds with the in-situ solar wind measurements from the ACE satellite near 1 AU. The implications of the results for CME propagation models are discussed in the context of space weather applications.

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[2] STFC Rutherford Appleton Laboratory

[3] Space Research Institute, Austrian Academy of Sciences; Institute of Physics, University of Graz

Comparing HELCATS CIR catalogues derived from white-light images and in-situ measurements

I Plotnikov[1,2], A.P. Rouillard[1,2]

The CIR catalogue derived by the HELCATS teams using white-light images from the HIs on STEREO are compared to CIR catalogues derived from in-situ measurements. We compare the predicted arrival time and speed of the density structures embedded in CIRs with the arrival of density peaks and the stream interfaces located in the CIR compression regions. We discuss the usefulness of heliospheric imagery at localizing CIRs in 3-D and predicting their arrival time at Earth. This is work is supported by the FP7 project #606692 (HELCATS).

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Session 2: Debating standards for making CME associations

Linking CMEs to Associated Solar Phenomena

Peter T. Gallagher, Pietro Zucca, Eoin P. Carley

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CMEs can be associated with a range of solar phenomena, such as flares, coronal waves, SEPs and radio bursts. These phenomena can be physically linked by combining data from a multitude of ground- and space-based instruments and theoretical models. For automated systems, these linkages can be challenging to discern.

In HELCATS, we therefore aim to develop a set of 'rules' so that all events can be treated with a standard approach. In this talk, I will provide a review of event associations in the solar transient field, and discuss the history of such associations and on how we aim to progress the field in HELCATS.

A review of the use of event associations in CME onset studies from SMM, SOHO and STEREO, leading to suggested standards for the future

Richard A Harrison

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Many researchers that have studied the onset of Coronal Mass Ejections (CMEs) have examined the apparent association in space and time of other transient events such as flares and promi- nence eruptions. The methods that we have used to assess such associations and their meaning for the CME onset process have varied wildly and there has never been an accepted standard for defining events as being ‘associated’. However, we have a long heritage in CME onset studies from missions such as SMM, SOHO and STEREO, and it is timely to examine the range of meth- ods used and to assess their success. Clearly, we must minimise the bias introduced by making false associations, but we need to ensure that any ‘rules of association’ that we do adopt, bring out the true associations that will reveal the physical processes that we aim to study. We report here on experiences gained from SMM, SOHO and STEREO in an effort to address this issue.

Session 3: Remote-sensing/in-situ observations of heliospheric phenomena and their sources and impacts

The most generic shape of interplanetary CMEs: a comparison of models and interplanetary event catalogues.

M. Janvier, P. Demoulin, S. Dasso

The physical properties of Interplanetary Coronal Mass Ejections (ICMEs) and therefore of Magnetic Clouds (a sub-class of ICMEs, hereafter MCs) and their preceding shocks can be measured locally by interplanetary spacecraft. However, those data are local, and they do not provide the global shape of those structures a priori.

In a series of work reviewed in this talk, we have proposed a new approach using statistical methods to investigate a data-constrained shape both for the flux rope axis in magnetic clouds and for the ICME shocks. These methods rely on the computation from the data of a parameter that defines the location of the interplanetary spacecraft along the detected structures. From the distribution of this parameter, we derive the generic shape of the structures considered.

Then, taking different models, we compared how some synthetic distributions can very well fit the observed distributions of different catalogues of interplanetary events. Moreover, similar results are found for those different catalogues, although created by different authors and different studies (magnetic clouds and ICME shocks).

We will conclude by showing how statistical studies of the different physical parameters of ICMEs allow us to construct a generic shape of an ICME at Earth.

Three-dimensional evolution of fast and slow CMEs from the Sun to 1 AU

Alexey Isavnin, Sebastian Käki, Emilia Kilpua

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The evolution of a flux-rope coronal mass ejection (CME) is defined by the processes that change its geometrical and morphological properties, which include deflection, rotation, expansion and distortion. The CME evolution is associated with its interaction with the magnetic field of the Sun and with the background solar wind and/or surrounding magnetic structures embedded in the solar wind. By combining extreme ultraviolet, white-light and in-situ observations a method for analysis of three-dimensional evolution of flux rope CMEs was developed (Isavnin et al., 2013, 2014). We present two case studies of CMEs characterized by relatively low and high propagation speeds, respectively.

Visualizations of the HI CME catalogue and solar wind magnetic field data

Christian Möstl[1], Peter Boakes[1], Alexey Isavnin[2], Emilia Kilpua[3] and Jackie Davies[3]

We present visualizations of (1) the HI CME catalogue as circular fronts propagating in the ecliptic plane, based on the Self-Similar Expansion Fitting techniques, and (2) of the in situ magnetic field data of all 5 spacecraft MESSENGER, Venus Express, Wind, STEREO-A and STEREO-B for the year 2012, which we choose as a time interval for testing. They can also be shown along with the spacecraft positions and the predicted arrival times from the HI catalogue.

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The properties of the very slow solar wind measured inside 0.7 AU

E. Sanchez-Diaz[1,2], K. Segura[1,2], A. Rouillard[1,2],

R. Pinto[1,2], B. Lavraud[1,2]

Measurements near 1AU of the bulk and compositional properties of the interplanetary plasma point to the existence of two solar winds that can be classified by their speeds,V, the fast (V>400 km s-1) and slow winds (300<V<400 km s^-1). Here we report on the properties of a very slow solar wind (150<V<300 km s-1) mostly detected inside 0.7 AU by the HELIOS spacecraft during solar maximum (1980-1981). This very slow wind usually contains the very dense heliospheric plasma sheet as well as the heliospheric current sheet and its helium abundance is higher than the slow wind. The very low speeds nearly disappear completely by 1AU due to the interaction with the faster plasma. The compositional signatures and the high densities remain however, and add to the variability of the measured slow wind. Combining a Potential Field Source Surface (PFSS) to a ballistic backmapping, we find that, contrary to the slow solar wind (300<V<400 km s-1), the speeds of the very slow wind are correlated with the expansion factor and anticorrelated with the distance to the coronal neutral line. Taking advantage of the big range of distances continuously sampled by HELIOS 1 and 2 (from 0.29 AU to 1 AU), we also perform a statistical analysis of the relative properties of alpha particles and protons evolution of the different ambiant winds. In contrast to the fast solar wind where alpha particles are faster than protons, the speed of alpha particles in the very slow wind appears lower by some 5 km s-1 to the speed of protons. Like in the fast and slow winds, the ratio of alpha to proton temperatures increases with heliocentric distance in the very slow wind.
This is work is supported by the FP7 project #606692 (HELCATS).

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Tracking the CME-driven Shock Wave on 2012 March 5 and Radio Triangulation of Associated Radio Emission

Jasmina Magdalenic[1], C. Marque[1], V. Krupar[2], M. Mierla[1],

A. Zhukov[1], L. Rodriguez[1], M. Maksimovic[3], B. Cecconi[3]

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We present a multiwavelength study of the 2012 March 05 solar eruptive event, with the emphasis on the radio triangulation of the associated radio bursts. The main scopes of the study are the reconstruction of the propagation of the CME-driven shock wave using radio observations, and finding the relative positions of the CME, CME-driven shock wave and its radio signatures. For the first time radio triangulation is applied for different types of radio bursts in the same event and performed in a detailed way using goniopolarimetric observations of STEREO and WIND spacecraft. The event on the 2012 March 05 was associated with a X1.1 flare, a full halo CME and long-lasting interplanetary type II radio burst. The results of the three dimensional reconstruction of the CME (using SOHO/LASCO, STEREO COR and HI observations), and modelling with the ENLIL cone model suggest that the CME-driven shock wave arrived at 1 AU at about 12:00 UT on March 07 (as observed by SOHO/CELIAS). The results of radio triangulation show that the source of the type II radio burst was situated at the southern flank of the CME. This gives indication that the interaction of the shock wave and a nearby coronal streamer resulted in the enhanced emission of the interplanetary type II radio burst.

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Internal structure of interplanetary coronal mass ejections and relation to remote sensing observations.

Kilpua, E.K.J., A. Isavnin, A. Vourlidas, H.E.J. Koskinen, and L. Rodriguez

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Interplanetary coronal mass ejections (ICMEs) are complex structures. The view that all ICMEs would originate as magnetic flux ropes has received increasing attention, although near the orbit of the Earth only about one-third of ICMEs show clear flux rope signatures. We present examples of ICMEs where it is not straightforward to determine which part belong to the sheath and which to the flux rope that has deformed and/or eroded during the interplanetary propagation. We show results from a systematic comparison of the cases where ICME and flux rope signatures coincided and where ICME signatures extended significantly beyond the MC boundaries. We found clear differences in the ICME properties (eg., speed, magnetic field magnitude), in the ambient solar wind structure, and in the solar cycle dependence for these two event types. We show that the flux rope and the regions of ICME-related plasma in front and behind the flux rope have all distinct characteristics enforcing the conception that they have intrinsically different origin or evolve differently. Our study shows that the erosion of magnetic flux in front of the ICME may also reconfigure the initial three- part CME seen in white-light images to a more complex ICME, but the geometrical effect (i.e. the encounter through the CME leg and/or far from the flux rope center) has little contribution to the observed mismatch in the flux rope and ICME boundary times

Comparing interplanetary and in-situ properties of CME driven shocks

L.Volpes, V. Bothmer

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MHD shocks driven by coronal mass ejections (CMEs) form when the CME propagation speed in the solar wind frame is higher than the Alfvén speed. The interaction between CME-driven shocks and the turbulent solar wind is the cause of particle acceleration in solar energetic particle events (SEP). The fastest CMEs, more likely to drive shocks, are the most geoeffective.

We present the analysis of STEREO COR2 and HI observation of 4 fast CMEs, which drove shocks detected in difference images. For each event we identify the properties of the source region and the signatures of onset. We model the CME geometry via the graduated cylindrical shell model (GCS), extending the COR2 results to the field of view of HI to test the assumption of self similar expansion. We determine the interplanetary evolution of the CME and the shock by applying the stereoscopic self similar expansion model (SSSEM) to time-elongations plots obtained from STEREO A and B observations. We infer arrival time and speed and compared them to ACE in-situ measurements.

Exploiting these results and combining them with models for the location of the shock we can derive the time evolution of the compression ratio and the Mach number. An extrapolation to the location of ACE allows to validate the results against in-situ measurements.

This analysis shows that geometrical modeling and triangulation techniques can be used to determine the properties of CME-driven shocks at locations not accessible to in-situ instruments.

First results of CME arrival time prediction at different planetary locations and their comparison to the in-situ data within the HELCATS project

Peter Boakes[1], Christian Moestl[1,2], Jackie Davies[3], Richard Harrison[3], Jason Byrne[3], David Barnes[3], Alexey Isavnin[4], Emilia Kilpua[4], Tanja Rollett[2]

We present the first results of CME arrival time prediction at different planetary locations and their comparison to the in situ data within the HELCATS project.

The EU FP7 HELCATS (Heliospheric Cataloguing, Analysis & Techniques Service) is a European effort to consolidate the exploitation of the maturing field of heliospheric imaging. HELCATS aims to cata- logue solar wind transients, observed by the NASA STEREO Heliospheric Imager (HI) instruments, and validate different methods for the determination of their kinematic properties. This validation includes comparison with arrivals at Earth, and elsewhere in the heliosphere, as well as onsets at the Sun (http://www.helcats-fp7.eu/).

A preliminary catalogue of manually identified CMEs, with over 1000 separate events, has been created from observations made by the STEREO/HI instruments covering the years 2007-2013. Initial speeds and directions of each CME have been derived through fitting the time elongation profile to the state of the art Self-Similar Expansion Fitting (SSEF) geometric technique (Davies et al., 2012). The technique assumes that, in the plane corresponding to the position angle of interest, CMEs can be modelled as circles subtending a fixed angular width to Sun-center and propagating anti-sunward in a fixed direction at a constant speed (we use an angular width of 30 degrees in our initial results). The model has advantages over previous geometric models (e.g. harmonic mean or fixed phi) as it allows one to predict whether a CME will 'hit' a specific heliospheric location, as well as to what degree (e.g. direct assault or glancing blow). We use correction formulae (Möstl and Davies, 2013) to convert CME speeds, direction and launch time to speed and

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arrival time at any in situ location. From the preliminary CME dataset, we derive arrival times for over 400 Earth-directed CMEs, and for over 100 Mercury-, Venus-, Mars- and Saturn-directed CMEs predicted to impact each planet.

We present statistics of predicted CME arrival properties. In addition, we independently identify CME arrival at in situ locations using magnetic field data from the Venus Express, Messenger, and Ulysses spacecraft and show first comparisons to predicted arrival times. The results hold important implications for space weather prediction at Earth and other locations, allowing model and predicted CME parameters to be compared to their in situ counterparts.

Assessing the complementary nature of radio measurements of solar wind transients: HELCATS WP7

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The primary aim of the HELCATS project is to add value to the STEREO heliospheric imaging observations by cataloguing phenomena such as coronal mass ejections and stream interaction regions, by producing derived 'metadata' products, by applying computer modeling techniques and finally by comparing with other datasets. The specific goal of HELCATS work package 7 is to assess the potential for combining white-light imaging of the inner heliosphere with ground- and space-based radio data, in particular Interplanetary Scintillation (IPS) and Type II radio bursts. In this contribution we describe the goals of WP7 in the context of the overall project, and outline the planned activities that will be undertaken during the remainder of the project. To illustrate this, analysis of initial case studies of radio emission associated with events in the provisional HELCATS catalogue will be presented.

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MESSENGER and Venus Express observations of magnetic clouds

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We present preliminary findings from a recently compiled catalogue of magnetic clouds observed by MESSENGER and Venus Express. Despite their planetary focus, both spacecraft spent significant amounts of time in the solar wind, allowing transient solar wind structures such as magnetic clouds to be observed. The catalogued clouds were observed at a range of heliocentric distances (at 0.72 AU by Venus Express, and from 1 to 0.3 AU by MESSENGER) over the course of a significant fraction of a solar cycle (2006 to 2013 by Venus Express, and 2007 to 2012 by MESSENGER). Neither spacecraft carried a dedicated solar wind plasma instrument, and so the clouds have been identified using magnetic field data only. We consider how the magnetic field magnitude and structure observed within the clouds vary with heliocentric distance. Minimum longitudinal extents have been determined for those events that appear at both spacecraft, or at either spacecraft and at 1 AU (at STEREO-A, -B or ACE and Wind).

Estimation of the 3D electron density distributions in the solar corona for more realistic solar wind modelling

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Knowledge of the electron density distribution in the solar corona put constraints on the magnetic field configurations for coronal modelling, and on initial conditions for solar wind modelling, thus providing valuable information on large-scale structures such as coronal holes, active regions and streamers.

We work with polarised SOHO/LASCO-C2 images from the last two recent minima of solar activity (1996-1997 and 2008-2010), devoid of Coronal Mass Ejections and with heights from 2.5 to 6 Rsun above the solar surface. We derive 3D electron density distributions by applying a newly developed time-dependent tomography reconstruction method to the data. From the 3D distributions, we extract the temporal evolution of the density for polar and equatorial regions, and compare the results between the two solar minima. We discuss their relevance for constructing more realistic models of the solar corona including the density profile with height of Saito and the Potential Field Source Surface model.

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Session 4: Development and application of heliospheric observations and techniques for scientific and space weather usage

Initiation and evolution of CMEs in the inner heliosphere

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Coronal mass ejections (CMEs) are important drivers of the space weather. Therefore, most studies focus on the fastest and thus most dangerous ICME events. However, the `typical' or average CME propagates at a velocity only slightly higher than the slow solar wind speed and, especially during solar minimum, fast CMEs are in fact rather exceptional. Yet, also the magnetic clouds associated to the slower CMEs are recognized to be able to cause significant geomagnetic disturbances.

We will discuss 2.5D (axi-symmetric) magnetic flux rope models and 2.5D and 3D self-consistent magnetohydrodynamics (MHD) simulation models for the onset of CMEs under solar minimum conditions, and for their interaction with coronal streamers and subsequent evolution up to 1AU. The flux-rope models take into account the inner magnetic structure of the CMEs and quantify its effect on their IP evolution and interaction with the background solar wind, including erosion (due to magnetic reconnection), deformation (due to slow wind interaction), deflection (due to neighboring streamer interaction), etc. The self-similar CMEs are initiated by magnetic flux emergence/cancellation and/or by shearing the magnetic foot points of a magnetic arcade which is positioned above or below the equatorial plane and embedded in a larger helmet streamer. The overlying magnetic streamer field then deflects the CMEs towards the equator, and the deflection path is dependent on the driving velocity. The core of the CME, created during the onset process, contains a magnetic flux rope and the synthetic white light images often show the typical three-part CME structure. Observations are used to constrain the models by providing initial and boundary conditions. These solar observations, as well as the resulting characteristic plasma parameters they produce at 1AU compared to (ACE) observations, provide excellent tools to validate the models. These advanced CME models are now being integrated in the new inner heliosphere model Euhforia (the 'European ENLIL' model) we are developing. We are in the process of validating the model by comparing with observational data of a selection of well-documented cases as well as with ENLIL results. The current state-of-the-art will be reviewed.

Simulating the solar wind to the inner boundary of ENLIL

R. F. Pinto[1,2], *A. Rouillard*[1,2]

The cyclic variations of the strength and geometry of the global background magnetic field strongly affect the solar wind flow and cause the segregation between the fast and slow wind flows. Fast wind flows develop exclusively within coronal holes, while the slow solar wind streams from the vicinities of the coronal hole boundaries (i.e, around streamers and pseudo- streamers) and/or active regions. Besides, the fast and slow wind components display different acceleration profiles, types of oscillations/waves, and ion composition, despite the respective wind heating and acceleration mechanisms being probably similar. We investigate these problems jointly by performing numerical simulations of the corona and solar wind covering an 11 yr activity cycle. The wind speeds we obtain are in agreement with in-situ measurements (ULYSSES) and radio maps (IPS). The wind speeds at all latitudes and moments of the cycle depend on two simple parameters (related to the magnetic field amplitude and inclination along the flux tube), in addition to the traditional expansion ratios in the WSA law. These results were tested using different heating scenarios. We also found that the calculated Alfvén radii varies with the level of activity, and we propose a fast numerical procedure to compute maps of solar wind parameters at the inner boundary of ENLIL (22.5 Rs). This is work is supported by the FP7 project #606692 (HELCATS).

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Three dimensional morphology and dynamics of CMEs and CME-driven shocks

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The propagation of coronal mass ejections (CMEs) and CME-driven shocks is crucial to predict their geo-effectiveness. We have developed a mask fitting technique to derive the 3D morphology of a CME from the observations taken by SECCHI/COR and SO-HO/LASCO. It allows us to derive the 3D CME without any a-priori shape assumption. This technique is now extended to the SEC- CHI/HI1 observations for not only CMEs but also the CME-driven shocks. The developed technique have been applied to two CME Events. The derived 3D CME morphology is used to study the dynamics and mass evolution of CMEs. The obtained 3D shock morphology is compared to the 3D shock reconstruction based on a bow-shock model. The relation between the CME and the CME-driven shock is investigated. Besides the remote sensing analyses, their link to in-situ data is also included. We have used the ACE/WIND, Messenger, and Venus Express data to follow the CME and shock evolution in the interplanetary space.

The propagation and space weather tools

A. Rouillard[1,2], R. Pinto[1,2], B. Lavraud[1,2], V. Genot[1,2]

We present the 'propagation tool' that allows users to track the propagation of Coronal Mass Ejections (CMEs) and Corotating Interaction Regions (CIRs) to 1AU. This tool provides access to maps of solar wind outflows from the Sun to 1AU and offers different ways to estimate the location and speed of CMEs and CIRs with time. It also provides access to catalogues of CIRs and CMEs that have been derived by the HELCATS project. Another tool ('space-weather tool') allows users to run a magnetically-driven model that simulates the propagation of a magnetic flux rope from the Sun to 1AU and to extract the magnetic field components measured at any probe or planet situated in the inner heliosphere. The tool offers the flexibility to change the amount of magnetic energy injected in the flux rope as well as its orientation in 3-D. This is work is supported by the FP7 project #606692 (HELCATS).

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The New CORIMP CME Catalogue & 3D Reconstructions

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Coronal mass ejections (CMEs) tend to be faint, transient phenomena, observed in white-light images that are prone to noise and user-dependent biases in their interpretation. A wealth of image processing techniques have been explored to characterise CME structure in coronagraph data from observatories like SOHO and STEREO. The increasing volume of data available has made it necessary to automate such techniques for detecting and tracking CMEs, and cataloguing their kinematics and morphologies. A new such catalogue has been developed, called CORIMP, that overcomes many of the limitations of current catalogues in operation. An online database has so far been produced for the SOHO/LASCO observations, providing information on CME onset time, position angle, angular width, mass, speed and acceleration. A realtime version of the algorithm has been implemented to provide CME detection alerts to the interested space weather community. Furthermore, STEREO data provides the ability to perform 3D reconstructions of CMEs that are observed in image pairs. This work will lead to an improved understanding of the dynamics of CMEs.

Tomographic Reconstruction of CME Densities in the Ecliptic using STEREO HI1

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The two viewpoints provided by the Heliospheric Imagers (HIs) on the STEREO spacecraft provide a means to infer the density distribution within solar wind structures by reducing the line of sight ambiguities that arise from a single viewpoint alone. Electron densities in the ecliptic may be estimated via the tomographic inversion of images from both space- craft, which are assumed to represent Thomson scattered light from the photosphere. A grid is defined in the region of space common to the fields of view of both spacecraft, which allows the problem to be formulated as an inverse equation. The equation is then solved using an iterative algorithm to produce an array of densities that most closely fit the data. The method is applied to two Earth directed Coronal Mass Ejections (CMEs) that occurred during phases of the mission when the spacecraft were sufficiently separated. The resulting densities from successive images are then used to determine how the CMEs evolve through the heliosphere and to make estimates of their speed and density at Earth, which are compared with in situ measurements from the Wind spacecraft at L1.

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Towards an operational F-corona model for future heliospheric imaging instruments

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Both Solar Probe Plus (SPP) and Solar Orbiter will carry white-light heliospheric imaging instrument for observations of solar wind structures from unprecedented viewing directions: WISPR and SoloHI, respectively. Owing to the rapidly changing fields-of-view of WISPR's two telescopes, a novel approach for removing the dust-scattered sunlight (F corona) is needed.

We will present first results from our currently developed F-corona model (FCM). The model combines a 3-d size-dependent dust density distribution (based ESA's IMEM model) and Mie scattering from spherical dust particles to compute the intensity of scattered light on the detector. The FCM is also capable to compute the Stokes parameter Q, which can be used to produce linear polarization maps. The polarization capability could be used for science preparation of the planned PHELIX instrument onboard the INSTANT mission, as recently proposed as a joint ESA/CAS S-class mission.

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Determination of the Photometric Calibration and Large-Scale Flatfield of the STEREO HI-2 Cameras

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We describe the methods used to determine the absolute photometric calibration parameters of the HI-2 imagers on the STEREO spacecraft from measurements of background stars, and present those values, which represent small corrections to the values predicted from pre-launch calibrations. Conversion factors to physical units are also derived. We determine the degradation of those instruments over the course of the mission to date, which is found to be around an order of magnitude slower than for white-light instruments on other spacecraft. We compute a correction to the large-scale flatfield for HI-2A, including allowing for vignetting in the outer parts of the images. In addition we consider the effects of pixel saturation and the implications for the use of the HI-2 instruments for stellar photometry and discuss the limitations of the currently-employed geometrical projection assumptions.

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Ongoing Radio Space-Weather Science Studies Using the LOw Frequency ARray (LOFAR)

M.M. Bisi[1], *R.A. Fallows*[2], *C. Sobey*[2], *T. Eftekhari*[2,3],

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We will provide the latest updates on our progress using the LOw Frequency ARray (LOFAR) next-generation radio telescope for space-weather related activities. Updates will include observations of interplanetary scintillation (IPS) and the first tests of observing heliospheric Faraday rotation (FR) in the inner heliosphere. IPS has been used for over half a century now to study structures (both transient and quiescent) throughout the inner heliosphere. Much progress has been made in recent years for using IPS in space-weather science and forecasting. FR for space-weather purposes is particularly novel. FR is typically an astrophysical technique that uses pulsars and extragalactic radio sources to study the galactic magnetic field. The determination of heliospheric FR, combined with observations of IPS, can deliver essential information on the Sun's extended magnetic-field structure throughout the inner heliosphere. This is especially the case when these two radio techniques are also combined with other forms of remote-sensing/heliospheric imaging data as well as in-situ measurements. We present work-in-progress IPS and heliospheric FR results and compare, where possible, with pertinent forms of modelling (such as tomographic techniques and MHS numerical simulations). LOFAR is an interferometric phased-array radio telescope that can be used to observe between ~10 MHz (depending on

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ionospheric conditions) and ~240 MHz. The LOFAR system consists of many relatively-low-cost antennas. These antennas are organized into ‘stations’ located primarily in an area of ~100km diameter in the North-East corner of The Netherlands. In addition, there are separate “international” stations spread across central and Western parts of Europe (five in Germany, one in France, one Sweden, and one in the UK) with several more in the planning stages (three in Poland, two more in Germany, one is hoped for Ireland, and possibly one more in the UK). In addition to LOFAR, but based on LOFAR technology, lies a reconfigured LOFAR station in Finland inside the arctic circle on the tri-border with Sweden and Norway; this system is called the Kilpisjärvi Atmospheric Imaging Receiver Array (KAIRA). KAIRA completed its build and commissioning phase towards the end of 2014 and is now fully operational.

Session 5: Future heliospheric and space weather instruments/missions

Operational Forecasting – what's required in the heliosphere

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In this talk, I'll describe the current & future needs of users and how this relates to heliospheric features. I'll describe the process and timelines involved to ensure that users receive the right forecasts and warnings. I'll also address the challenges faced by forecasters particularly in this period of limited data, utilizing experience from both SWPC and Met Office and set out where we'd like to be in the near future.

Carrington-L5: The Next Generation Space Weather Monitoring Mission

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Airbus Defence and Space (UK) has carried out a study to investigate the possibilities for an operational space weather mission, in collaboration with the Met Office, RAL Space, MSSL and Imperial College London. The study looked at the user requirements for an operational mission, a model instrument payload, and a mission/spacecraft concept. A particular focus is cost effectiveness and timelineness of the data, suitable for 24/7 operational forecasting needs. We have focussed on a mission at L5 assuming that a mission to L1 will already occur, on the basis that L5 (Earth trailing) offers the greatest benefit for the earliest possible warning on hazardous space weather events (SWE). The baseline payload has been selected to address UK Met Office/NOAA requirements for L5 using instruments with extensive UK/USA heritage, consisting of: heliospheric imager, coronagraph, magnetograph, EUV imager, magnetometer, solar wind analyser and radiation monitor. The platform and subsystems are based on extensive re-use from past Airbus Defence and Space spacecraft to minimize the development cost and a Falcon-9 launcher has been selected on the same basis. A schedule analysis shows that the earliest launch that could be achieved would be 2020, assuming Phase A kick-off in 2015-2016. The study team has selected the name “Carrington” for the mission, reflecting the UK’s proud history in this domain.

INSTANT (INvestigation of Solar-Terrestrial Activity aNd Transients

B. Lavraud, Y. Liu and the 180+ INSTANT team

INSTANT is a joint mission project between the European Space Agency (ESA) and the Chinese Academy of Sciences (CAS). In the scope of the CAS-ESA call for a small mission, INSTANT proposes an innovative space observatory at the Lagrangian L5 point dedicated to the observation of the Sun-Earth interaction. It will pro- vide novel observations and address fundamental questions in solar, heliospheric and space weather sciences. If selected, the launch of this S-class mission is scheduled for 2021 and the nominal science operations will last 2.5 years.

The PROBA-3 Mission and Its Contribution to Space Weather Studies

Andrei Zhukov and the PROBA-3/ASPIICS team Royal

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PROBA-3 is the next ESA mission in the PROBA line, to be launched in 2018. Its main goal is in-orbit demonstration of formation flying techniques and technologies. PROBA-3 will consist of two spacecraft together forming a giant coronagraph called ASPIICS (Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun). The main spacecraft will host the telescope, and the other one will carry the external occulter of the coronagraph. ASPIICS heralds the next generation of coronagraphs for solar research, exploiting formation flying to gain access to the inner corona under eclipse-like conditions for long periods of time. The PROBA-3 mission profile will be reviewed, the ASPIICS instrument design will be described, and the scientific objectives of the mission will be discussed. A special attention will be paid to the ASPIICS contribution to space weather studies.

The Wide-Field Imager for Solar Probe+ (WISPR)

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Solar Probe Plus (SPP) is a NASA mission scheduled for launch in 2018, which will facilitate mankind’s first visit of the atmosphere of a star, the solar corona. The prime mission goals are to understand how the Sun's corona is heated and how the solar wind is accelerated. The WISPR (Wide-Field Imager for Solar Probe+) camera led by the Naval Research Laboratory, Washington, DC, USA, of the SPP mission will provide coronal and heliospheric observations from 0.25 AU to as close as 7 million km (9.86 solar radii) from Sun center. WISPR has a 95º radial by 58º transverse field of view. The WISPR design facilitates the collection of images at high time cadences of 2.5.-5 min. at the SPP perihelia. WISPR will be very sensitive to the emission from plasma close to the spacecraft in contrast to the situation for imaging from Earth orbit. As a ‘local imager’ it will be capable of directly detecting the density enhancement at CME-driven shocks. This presentation will highlight the advances that WISPR will provide and what the capabilities will be for the new era of heliospheric imaging and space weather applications. It will also provide a brief overview of the CGAUSS (Coronagraphic German and US Solar Probe Plus Survey) project which is the German contribution to the SPP mission.

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Coronal and heliospheric imaging instrumentation development at RAL Space

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RAL Space is enhancing its development programme for visible-light coronal and heliospheric imaging instrumentation in response to opportunities such as the European Space Agency's Space Situational Awareness programme and S2 small-mission call. This draws on heritage from scientific instruments such as LASCO (Large Angle and Spectrometric Coronagraph) on the SOHO spacecraft, SMEI (Solar Mass Ejection Imager) on the Coriolis spacecraft and the HI (Heliospheric Imager) instruments on STEREO. Such visible-light coronal and heliospheric imaging of solar wind phenomena, such as coronal mass ejections and interaction regions, is of critical importance to space weather, both operationally and in terms of enabling the underpinning research to be performed. We discuss the determination of instrument requirements, key design trade- offs and the evolution of base-line designs for the coronal and heliospheric regimes, focussing in particular on such aspects as the exploitation of polarimetry and the analytical determination of baffle geometry.

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