RAS Specialist Discussion Meeting

A Comparison of Solar Eruption Models from Local and Global Perspectives: Observation and Theory

13 January 2012
10:25-15:30 in the RAS Lecture Theatre, Burlington House, Piccadilly, London W1J 0BQ
http://www.mssl.ucl.ac.uk/~bhk/ras2012.htm

Organisers: Prof J. Len Culhane (MSSL)
Prof Alan W. Hood (St Andrews)
Dr Bernhard Kliem (MSSL & Potsdam)

Programme

10:00 **Registration & Coffee**

MORNING SESSION (Chair: Alan Hood)

10:25 **Bernhard Kliem** (MSSL)
Welcome

10:30 **Guillaume Aulanier** (Observatoire de Paris)
Triggering Solar Eruptions: How Magnetic Pressure Explosively Wins Over Magnetic Tension

11:10 **Lucie M. Green** (MSSL)
Remote Sensing of CME Source Regions: What can we Learn About the Magnetic Configuration?

11:50 **Peter T. Gallagher** (Trinity College, Dublin)
The Energetics and Dynamics of Coronal Mass Ejections

12:10 **Caroline Alexander** (UCLan)
A Large Polar-crown Filament Eruption Observed by SDO/AIA and STEREO-A/EUVI

12:25 **Vasilis Archontis** (St Andrews)
Flux Emergence and Coronal Eruptions

12:40 **Clare Parnell** (St Andrews)
The Interaction of Emerging Flux With Coronal Fields

12:55 **LUNCH & POSTERS**

AFTERNOON SESSION (Chair: Len Culhane)

13:55 **Duncan Mackay** (St Andrews)
Global Solar Magnetic Fields and CMEs

14:30 **Anthony Yeates** (Durham)
Flux Rope Eruptions over a Solar Cycle

14:45 **Deborah Baker** (MSSL)
Forecasting a CME by Spectroscopic Precursor?

15:00 **Maria Madjarska** (Armagh)
Kinematics and Helicity Evolution of a Loop-like Eruptive Prominence

15:15 **David R. Williams** (MSSL)
Mass Estimates of Rapidly-moving Prominence Material from High-cadence EUV Images

15:30 **TEA** will be available in the Lower Library of the Geological Society for those attending the Open (Monthly A&G) Meeting of the Royal Astronomical Society **& Posters**

16:00 **Open (Monthly A&G) Meeting**

Posters

Wayne Arter (Culham)
A Blue Sky Solution to the Magnetohydrodynamic Trigger Problem

Gert J.J. Botha, Tony D. Arber (Warwick), Alan W. Hood (St Andrews) and A. K. Srivastava (ARIES)
Coronal Kink Instability With Parallel Thermal Conduction

Eoin P. Carley, R. T. James McAteer and Peter T. Gallagher (Trinity College, Dublin)
Coronal Mass Ejection Mass, Energy, and Force Estimates Using STEREO

Peng Fei Chen (Nanjing University & MSSL)
Where do Flare Ribbons Stop?

Hugh Hudson (UC Berkeley & Glasgow)
Hard X-ray Diagnostics of Solar Eruptions

Bernhard Kliem (MSSL), Tibor Török (PSI) and Terry G. Forbes (UNH)
CME-flare Relationship and the Topology of the Erupting Field

Bernhard Kliem and Lucie M. Green (MSSL)
Bald-patch Versus X-type Sigmoids: Implications for the Magnetic Topology at the Onset of Solar Eruptions

Sophie A. Murray, D. Shaun Bloomfield and Peter T. Gallagher (Trinity College, Dublin)
3D Sunspot Magnetic Field Evolution During Solar Flare Activity

Abstracts

Triggering Solar Eruptions: How Magnetic Pressure Explosively Wins Over Magnetic Tension

Invited review

Guillaume Aulanier

Observatoire de Paris, LESIA, 5 place Jules Janssen, F-92195 Meudon, France

Abstract. Solar eruptions eject large clouds of magnetized plasma from the Sun's corona to the heliosphere. Both theory and observations show that these eruptions must result from the sudden release of free magnetic energy, which has slowly been accumulated in the corona for a long time before the eruption itself. The first model proposed for these astrophysical phenomena was the loss-of-equilibrium model. It was initially put forward in the 70's, using the physical approach of electric wires and Laplace forces. I will show that, in the solar corona, the wire approach must be replaced by the physics of MHD, and I will compare the driving and stabilizing forces with both views. This analogy results in the conclusion that most eruptions are driven by the magnetic pressure force, being due to current-carrying magnetic fields, and that this pressure eventually overcomes the stabilizing tension force. A large variety of new analytical and numerical storage-and-release MHD models have been developed in the past 20 years or so. While all these models rely on the slow increase of currents and/or the slow decrease of the restraining magnetic tension preceding the eruption, they all put the emphasis on different physical mechanisms, both to achieve the pre-eruptive evolution, and to suddenly trigger and later drive the eruption. Nevertheless, all the models share many common features. And all the latter models describe many individual observed aspects of solar eruptions. It is therefore not always clear which of all the suggested mechanisms, if any, do really account for the triggering of observed events in general. Also, these mechanisms should arguably not be as numerous as the models themselves, owing to the common occurence of eruptions. In order to shed some light on this challenging – but still unripe – topic, I will rediscuss the applicability of the models to the Sun, and most of all I will re-order the most sensitive ones in a common frame, so as to find common denominators. I will elaborate on the idea that, in all cases, the eruptive threshold is determined either by the vertical gradient of the magnetic field in the low-beta corona (just like the usual convection threshold is determined by the temperature gradient in a stratified medium), or by the removal of a sufficient amount of overlying tension through high-altitude magnetic reconnection. I will then argue that most – if not all – of the other proposed triggering mechanisms may actually only be considered as different ways to apply a "final push", which puts the system beyond its eruptive threshold.

Remote Sensing of CME Source Regions: What can we Learn About the Magnetic Configuration?

Invited review

Lucie M. Green

Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking RH5 6NT, UK

Abstract. Not yet available.

The Energetics and Dynamics of Coronal Mass Ejections

Invited contribution

Peter T. Gallagher

Astrophysics Research Group, School of Physics, SNIAM, Trinity College Dublin, Dublin 2, Ireland

Abstract. Not yet available.

A Large Polar-crown Filament Eruption Observed by SDO/AIA and STEREO-A/EUVI

Caroline Alexander, Stéphane Régnier and Robert Walsh

Jeremiah Horrocks Institute for Astrophysics, University of Central Lancashire, Preston, UK

Abstract. Using the two points-of-view of SDO/AIA and STEREO-A/EUVI (about 70 degrees apart), we observed a large-scale polar crown filament eruption on 13 June 2010 in the Northern hemisphere. Comparing the plasma at 80 000 K and at 0.6 MK, we deduce the structure of the filament/prominence and its evolution. The polar-crown is composed of hot and cool plasma sitting at the bottom of a cavity in upwardly concave magnetic field lines. We also study the different possible initiation processes leading to the eruption by looking at local and global events which can destabilise the filament such as weak filament activity in a nearby active region, a flare and the associated CME wave starting in the Southern hemisphere, existence of a trans- equatorial loop, instability of the filament (kink, torus, mass loading). We discuss the contribution and timing of each initiation process to the filament eruption: the mass loading scenario and movement of the tethering barbs seem to play the biggest role.

Flux Emergence and Coronal Eruptions

Vasilis Archontis

Mathematical Institute, University of St Andrews, St Andrews KY16 9SS, UK

Abstract. We model the emergence of magnetized plasma from the top of the convection zone to the lower corona. We find that coronal flux ropes form after the emergence at the photosphere via the combined action of shearing/converging motions and reconnection. We investigate the eruption of these coronal flux ropes and we study the dependence of their rising motion to the initial parameters of the emerging magnetic flux system.

The Interaction of Emerging Flux With Coronal Fields

Clare Parnell

Mathematical Institute, University of St Andrews, St Andrews KY16 9SS, UK

Abstract. 3D resistive MHD simulations following the emergence of flux from the convection zone into the corona are analysed in detail to reveal the nature of the interaction between the emerging magnetic field and the overlying coronal field. In particular, we focus on the location and cause for any energy release (heating). In order to do this the magnetic skeleton at each time step is determined. Its evolution is extremely complex and does not follow the simple interaction imagined by many in the past. The highly dynamic evolution of the magnetic skeleton reveals that the emerging and coronal overlying flux interact (reconnect) at a multitude of magnetic separators that lying in a thin arched current sheet. Furthermore, a comparison of the magnetic skeleton with properties of the plasma reveal that this reconnection is the source of the main heating in the simulation. Furthermore, the reconnection results in large-scale fast out flow jets reminiscent of a bi-directional X-ray jet. The consequences for coronal heating of magnetic reconnection at multiple separators will also be discussed.

Global Solar Magnetic Fields and CMEs

Invited review

Duncan Mackay

Mathematical Institute, University of St Andrews, St Andrews KY16 9SS, UK

Abstract. Over the years a number of possible theories on the origin of CMEs have been put forward. Two such models are the flux rope ejection model and the magnetic breakout model. The review will first discuss the basic concepts behind these models. Following on from this global, long-term non-linear force-free simulations of the Suns magnetic field will be considered where the frequency of occurrence of magnetic configurations relevant to both models are discussed. Finally recent developments in the global modelling of CMEs with MHD simulations will be described.

Flux Rope Eruptions over a Solar Cycle

Anthony Yeates

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Abstract. One of the leading models for solar eruptions is the loss-of-equilibrium of coronal magnetic flux ropes. These ropes are formed as magnetic helicity is built up and transported by flux emergence and large-scale photospheric motions. Much has been learned in recent years from in-depth numerical studies, but these almost all focus on an individual flux rope, over a timescale of only days. Here we explore the phenomenon from a global perspective, over a full 11-year Solar Cycle. With some simplifying assumptions, we are able to model the continuous evolution of the non-potential coronal magnetic field over this extended period, including the formation and sudden eruption of many flux ropes. Automated analysis techniques reveal an eruption rate in the model

of up to 1.5 per day, sufficient to account for about a quarter of observed CMEs. By changing parameters in the model, we aim to extract the key physical effects that control this eruption rate and its variation over the Solar Cycle.

Forecasting a CME by Spectroscopic Precursor?

Deborah Baker, Lucie M. Green and Lidia van Driel-Gesztelyi

Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking RH5 6NT, UK

Abstract. Multi-temperature plasma flows resulting from the interaction between a mature active region (AR) inside an equatorial coronal hole (CH) are investigated. Outflow velocities observed by Hinode EIS ranged from a few to 13 $\mathrm{km\,s^{-1}}$ for three days at the AR's eastern and western edges. However, on the fourth day, velocities intensified up to 20 $\mathrm{km\,s^{-1}}$ at the AR's western foot-point about six hours prior to a CME. 3D MHD numerical simulations of the observed magnetic configuration of the AR-CH complex showed that the expansion of the mature AR's loops drives persistent outflows along the neighboring CH field (Murray et al., 2010, Solar Phys., 261, 253). Based on these simulations, intensification of outflows observed pre-eruption on the AR's western side where same-polarity AR and CH field interface, is interpreted to be the result of the expansion of a sigmoidal AR, in particular, a flux rope containing a filament that provides stronger compression of the neighboring CH field on this side of the AR. Intensification of outflows in the AR is proposed as a new type of CME precursor.

Kinematics and Helicity Evolution of a Loop-like Eruptive Prominence

Maria Madjarska

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Abstract. We investigate the role of magnetic helicity in a possible kink-induced prominence destabilisation and follow-up eruption. We use multi-instrument observations from AIA/SDO, EUVI/STEREO and LASCO/SoHO taken on 2010 March 30 at the north-east limb. The kinematic, morphological, geometrical, and helicity evolution of a loop-like eruptive prominence are studied in the context of the magnetic flux rope model of solar prominences.

Mass Estimates of Rapidly-moving Prominence Material from High-cadence EUV Images

David R. Williams, Deborah Baker and Lidia Van Driel-Gesztelyi

Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking RH5 6NT, UK

Abstract. Much of the work on filament/prominence structure can be broken down along lines described by Heinzel et al. (2008), namely: studies that use a poly-chromatic approach with targeted campaign observations; and those that use synoptic observations, frequently in only one or two wavelengths. The superior time resolution, sensitivity and near-synchronicity of data from the Solar

Dynamics Observatory's Advanced Imaging Assembly allow use to combine these two techniques using photoionisation continuum opacity to the, allowing us to determine the spatial distribution of hydrogen in filament material which erupted during the spectacular coronal mass ejection on 2011 June 07. The techniques offer a powerful way to track partially ionised gas as it erupts through the solar atmosphere on a regular basis, without the need for co-ordinated observations, thereby offering realistic mass distribution estimates to models of these erupting structures.

Poster Abstracts

A Blue Sky Solution to the Magnetohydrodynamic Trigger Problem

Wayne Arter

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Abstract. The trigger problem in magnetohydrodynamics (MHD) concerns the timescale for the release of a large fraction of the energy in a magnetic field. The specific problem of the 'tokamak sawteeth' is here treated in terms of classical dynamics in potential wells, and can be explained by the appearance of an inflexion point in such wells. However, the trigger problem is posed primarily as an abstract mathematical problem, so its solution has to be presented in the same terms. Translating from the physical language of potential wells, triggering is found most likely to be a consequence of homoclinic bifurcation in Hamiltonian dynamical systems.

Coronal Kink Instability With Parallel Thermal Conduction

Gert J.J. Botha[1], Tony D. Arber[1], Alan W. Hood[2] and A. K. Srivastava[3]

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[2]Mathematical Institute, University of St Andrews, St Andrews KY16 9SS, UK
[3]Aryabhatta Research Institute of Observational Sciences, India

Abstract. Thermal conduction along magnetic field lines plays an important role in the evolution of the kink instability in coronal loops. In the nonlinear phase of the instability, local heating occurs due to reconnection, so that the plasma reaches high temperatures. To study the effect of parallel thermal conduction in this process, the 3D nonlinear magnetohydrodynamic (MHD) equations are solved for an initially unstable equilibrium. The initial state is a cylindrical loop with zero net current. Parallel thermal conduction reduces the local temperature, which leads to temperatures that are an order of magnitude lower than those obtained without thermal conduction. This process is important on the timescale of fast MHD phenomena; it reduces the kinetic energy released by an order of magnitude. The impact of this process on observational signatures is presented. Synthetic observables are generated that include spatial and temporal averaging to account for the resolution and exposure times of TRACE images. It was found that the inclusion of parallel thermal conductivity does not have as large an impact on observables as the order of magnitude reduction in the maximum temperature would suggest. The reason is that response functions sample a broad range of temperatures, so that the net effect of parallel thermal conduction is a blurring of internal features of the loop structure.

Coronal Mass Ejection Mass, Energy, and Force Estimates Using STEREO

Eoin P. Carley, R. T. James McAteer and Peter T. Gallagher

Astrophysics Research Group, School of Physics, SNIAM, Trinity College Dublin, Dublin 2, Ireland

Abstract. Understanding coronal mass ejection (CME) mass and dynamics has been a long-standing problem. Although previous observational estimates of the energies and forces involved in CME propagation have been made, such studies were hindered by large uncertainties in CME mass. In this study, we use the twin SECCHI COR1 and COR2 coronagraphs on board the Solar Terrestrial Relations Observatory (STEREO) to accurately estimate the mass of the 2008 December 12 CME. Acceleration estimates derived from the position of the CME front in 3D are combined with the mass estimates in order to calculate the magnitude of the kinetic energy and driving force at different stages of the CME evolution. The CME asymptotically approaches a mass of $(3.4 \pm 1.0) \times 10^{15}$ g beyond $\sim 10\ R_{\odot}$. The kinetic energy shows an initial rise towards $(6.3 \pm 3.7) \times 10^{29}$ ergs at $\sim 3\ R_{\odot}$, beyond which it rises steadily to $(4.6 \pm 2.6) \times 10^{30}$ ergs at $\sim 18\ R_{\odot}$. The dynamics are described by an early phase of strong acceleration below $7\ R_{\odot}$ dominated by a force of peak magnitude of $(3.4 \pm 2.2) \times 10^{19}$ dyn at $\sim 3\ R_{\odot}$.

Hard X-ray Diagnostics of Solar Eruptions

Hugh Hudson[1,2]

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[2]School of Physics and Astronomy, University of Glasgow, G12 8QQ, UK

Abstract. In addition to the well-known radio-spectrographic signatures (e.g., burst types II-V) of particle acceleration during solar eruptions, we now have hard X-ray signatures as well (e.g., Kiplinger, 1995; Krucker et al., 2008). Because the bremsstrahlung process is not an efficient energy-loss mechanism, merely to observe hard X-rays immediately means large energy fractions in the accelerated particles. In some cases we have found that the non-thermal particle pressure may dominate over the thermal plasma pressure and the particles may need to be be considered self-consistently in dynamical theories of the eruptions. I review the development of our ideas about this with special emphasis on RHESSI, for which Krucker estimates that 1/3 of all CME events can be thus detected. Sensitivity restrictions probably prevent us from seeing all CMEs in this manner.

Where do Flare Ribbons Stop?

Peng Fei Chen[1,2]

[1]Dept. of Astronomy, Nanjing University, Nanjing, Jiangsu 210093, China
[2]Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking RH5 6NT, UK

Abstract. The standard flare model, which was proposed based on observations and MHD theory, can successfully explain many observational features of solar flares. However, this model is just a framework, with many details awaiting to be filled in, including how reconnection is triggered.

In this paper, we address an unanswered question: where do flare ribbons stop? With the data analysis of the 2003 May 29 flare event, we tentatively confirmed our conjecture that flare ribbons finally stop at the intersection of separatrices (or quasi-separatrix layer in a general case) with the solar surface. Once verified, such a conjecture can be used to predict the final size and even the lifetime of solar flares.

CME-flare Relationship and the Topology of the Erupting Field

Bernhard Kliem[1,2], **Tibor Török**[3] **and Terry G. Forbes**[4]

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[2]Institute of Physics & Astronomy, University of Potsdam, 14476 Potsdam, Germany
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Abstract. Observations of coronal mass ejections (CMEs) and solar flares often show a correlation between the acceleration of the ejecta and the plasma heating and particle acceleration signified by the soft and hard X-ray emissions of the associated flare (the latter are thought to result from magnetic reconnection). This finding has stimulated the discussion of the CME-flare relationship, but at the same time it has made it difficult to find a conclusive answer as to whether an ideal MHD instability or magnetic reconnection is the prime cause of the eruptions. Numerical simulations of unstable flux ropes will be presented which successfully model CMEs. Some of these show a high degree of synchronization between the initial exponential acceleration of the flux rope, due to the ideal MHD instability, and the rise of reconnection. However, in others the reconnection sets in with a delay which can extend up to the phase after the flux rope's acceleration peak. In addition, the reconnection flows generally lag behind the motions driven by the ideal instability, especially when the flux rope rise velocity nears the saturation phase. These properties suggest that the ideal MHD process is the primary driver of the coupled CME-flare phenomenon. The strong differences in the degree of synchronization are related to the magnetic topology prior to the eruption. Observations of CME vs. flare timing thus allow to infer which of the two basic flux rope topologies is relevant in a given event.

Bald-patch Versus X-type Sigmoids: Implications for the Magnetic Topology at the Onset of Solar Eruptions

Bernhard Kliem[1,2] **and Lucie M. Green**[1]

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[2]Institute of Physics & Astronomy, University of Potsdam, 14476 Potsdam, Germany

Abstract. Sigmoidal soft X-ray and EUV sources are formed by dissipation in current-carrying coronal magnetic fields. Thus, they may reveal the topology of the field prior to and in the course of eruptions. Recent research has led to improved understanding whether a sigmoid outlines field lines of arcade or of flux rope structure, but the specific topology in case of an underlying flux rope remains debated. A pure O-type topology with a "bald-patch separatrix surface (BPS)" in the interface to the ambient flux competes with a mixed topology, which includes an X-type structure referred to as "hyperbolic flux tube (HFT)" between the flux rope and the photospheric boundary. We analyse a small sample of eruptive sigmoidal sources, including their development toward the

eruption over several days. All events occurred in decaying active regions which showed ongoing flux cancellation. Properties like the inverse crossing of the photospheric polarity inversion line by the sigmoid centre and the stationarity and (at least partial) survival of the sigmoid through the eruption demonstrate that most sigmoids in the sample belong to the BPS category. However, one case is clearly of HFT structure. Possible reasons for the dominance of BPS sigmoids in the sample will be discussed.

3D Sunspot Magnetic Field Evolution During Solar Flare Activity

Sophie A. Murray, D. Shaun Bloomfield and Peter T. Gallagher

Astrophysics Research Group, School of Physics, SNIAM, Trinity College Dublin, Dublin 2, Ireland

Abstract. Solar flares occur due to the sudden release of energy stored in active-region magnetic fields. To date, pre-cursors to flaring are still not fully understood, although there is evidence that flaring is related to changes in the topology or complexity of sunspot magnetic fields. High spatial resolution observations of the solar magnetic-field vector can now provide more in-depth information on the true topological complexities.

NOAA 10953 was examined using data from Hinode/SOT-SP, over a period of 12 hours leading up to and after a B1.0-class flare. Pre- and post-flare changes in vertical field strength, vertical current density and inclination angle were observed in flux elements surrounding the primary sunspot. 3D topology was investigated in order to fully understand the evolution of the field lines. Results from field line connectivity analysis obtained from NLFF extrapolations show the field does not completely relax to a potential state after the flare. A Taylor relaxation process is suggested, with the final relaxed state given by a LFFF. Free magnetic energy calculations were also obtained for the region of flare brightening.