Understanding Magnetic Structure in the Solar Corona through Topological Analysis

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Abstract

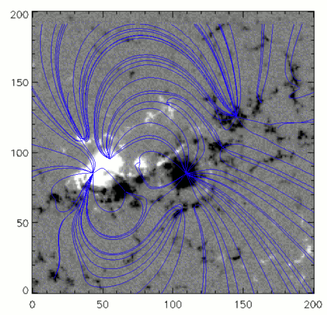
The next generation of solar telescopes will quickly produce a huge quantity of high-quality vector magnetogram data requiring analysis. Realistic magnetic fieldline extrapolations (e.g. nonlinear force-free) are useful but can be overcrowded and difficult to interpret, as well as time consuming. Focussing on the magnetic topology is an elegant way to pick out the key features of the structure and connectivity of the magnetic fieldlines. This technique allows easy and clear visualisation of 3D magnetic structures in the solar atmosphere, highlighting the important regions where dynamical and energetic processes will be concentrated. A new topological code currently being developed at St Andrews will enable the construction of the magnetic field topology from observational or computational magnetic field measurements, providing a new way of understanding both observational data and results from numerical (MHD) simulations.

1) New Horizons with Solar-B

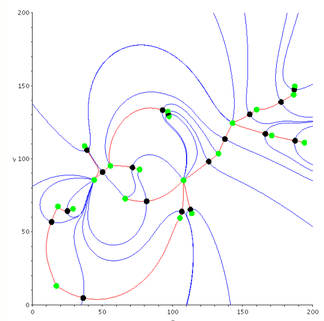
- launch 2nd half 2006
- visible light, EUV, and X-rays
- Solar Optical Telescope produces vector magnetograms
- 5 minute time cadence
- 0.25″ spatial resolution
- 1-5G (longitudinal) and 30-50G (transverse) accuracy in **B**
- *important new opportunity to further our understanding of the structure and evolution of the coronal magnetic field*

2) Benefits of Topology Approach

- realistic magnetic fieldline extrapolations difficult to interpret
- *extracting **topological skeleton** allows clear visualisation of structure and connectivity of* **B**



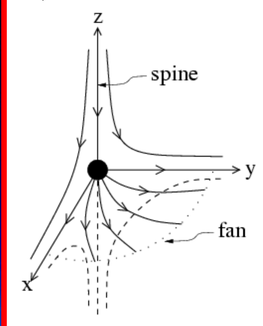
potential magnetic field extrapolation with arbitrarily chosen fieldlines



photospheric footprint of topological skeleton of the same magnetic configuration

- example above shows how calculating magnetic topology captures only essential fieldlines which outline regions of different connectivity
- useful structural information is highlighted

3) Overview of Magnetic Topology



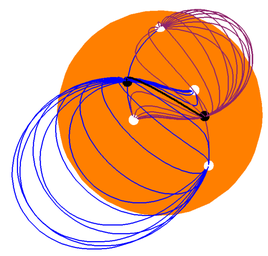
structure of a generic first-order potential magnetic null point

Sequence of steps to determine magnetic topology:

- locate magnetic null points (**B** = 0)
- find starting points for *spine* and *fan* fieldlines by considering eigenvectors of **B** linearised close to null
- extrapolate those fieldlines fully
- fan extends out to form *separatrix surface*: boundary between two domains of distinct magnetic connectivity

- separatrix surfaces can intersect each other in fieldline called *separator*
- separators join two null points and bound four domains of magnetic connectivity
  ⇒ prime locations for magnetic reconnection and heating

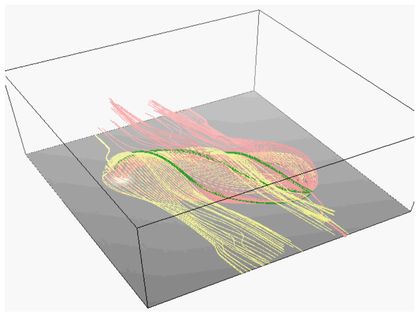
Example on right shows separator fieldline in black.



one possible topology resulting from four magnetic sources on the sphere

4) The New Magnetic Topology Code: Capabilities and Potential

- current magnetic topology analysis mostly accomplished by reducing line-of-sight magnetogram data to a finite set of point magnetic sources, analytically calculating the potential field they produce, and analysing it as explained in panel 3
- similar techniques could usefully be applied to much wider range of magnetic field data
  - e.g. could relax point source assumption and use finite sources
  - e.g. could use linear or nonlinear force-free magnetic fields instead of potential
  - e.g. could apply to data from numerical simulations – any case where **B** is known on a 3D grid

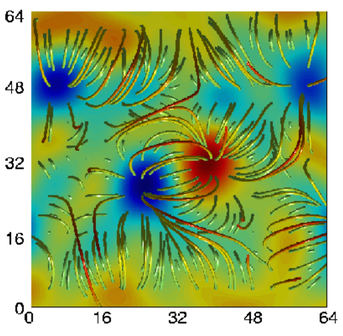


B from 3D MHD simulation with 2 finite sources creating 2 separatrices (red and yellow) and 3 separators (green)

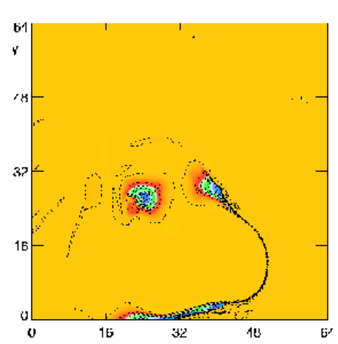
- code being developed at St Andrews to achieve these goals
- approach is the same for all cases:
  - locate nulls on photospheric boundary
  - calculate photospheric footprint (spine and separatrix fieldlines)
  - locate nulls in corona
  - calculate coronal separatrix surfaces and spines
  - find separators
- example on left from results of 3D MHD simulation shows how complex magnetic configurations with multiple separators can be clearly visualised with the new code

5) Case Study: X-ray Bright Points

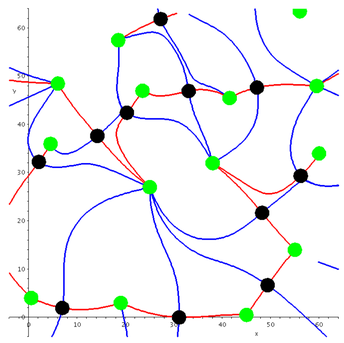
- central region of negative (blue) flux is rotated in numerical MHD experiment
- causes strong parallel electric field which indicates regions of magnetic reconnection and heating
- excellent correlation with location of (red) separatrix fieldline in topological reconstruction
- *shows that magnetic topology analysis is good predictor for heating locations in corona*



magnetogram with extrapolated fieldlines



contour plot of parallel electric field



photospheric footprint of topological reconstruction

6) Conclusions

- exciting opportunity approaching to use Solar-B vector magnetogram data
- will allow most comprehensive modelling of **B** in corona
- magnetic topology analysis is useful technique to analyse such data
- highlights essential structure and connectivity of field
- can help to predict locations of dynamical and energetic processes
- new code under development at St Andrews will enable this technique to work on observational and numerical data
- will improve understanding of structure of coronal magnetic field for both large- and small-scale solar features
- **for more information** please contact Rhona Maclean (rhonam@mcs.st-and.ac.uk) or Clare Parnell (clare@mcs.st-and.ac.uk)

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