CATEGORY: **ASTRONOMY & ASTROPHYSICS - AA03**

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GPU TECHNOLOGY CONFERENCE

Efficient Analysis of Simulations of the Sun's Magnetic Field

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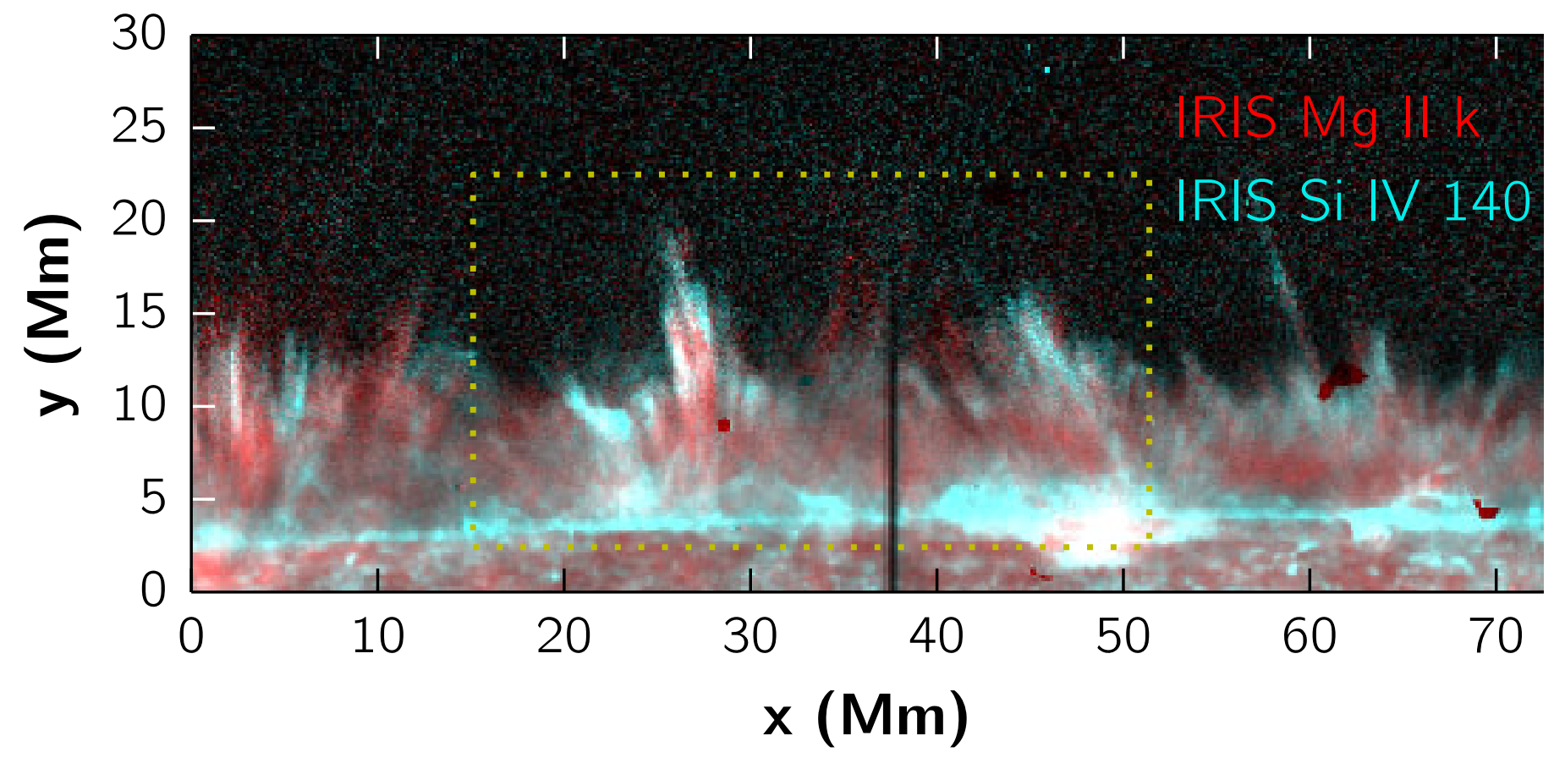
Abstract

Dynamics in the solar atmosphere (e.g. solar flares and coronal mass ejections) are powered by the evolution of the sun's magnetic field. Radiative Magnetohydrodnamic (MHD) computer simulations have furthered our understanding of the processes involved.

The reconnection of non-aligned magnetic field lines alters the topology of the field, converting magnetic energy into thermal and kinetic energy. Detailed analysis of the magnetic field topology entails tracing individual field lines, a slow operation on a single processor. By utilizing a graphics card, or GPU, to trace lines in parallel, conducting such analysis is made feasible.

We applied our GPU implementation to the most advanced 3D Radiative-MHD simulations (Bifrost, Gudicksen et al. 2011) of the solar atmosphere in order to better understand the evolution of the modeled field lines.

Introduction



Spicules in the chromosphere (Mg II) and the transition region (Si IV)
Captured by IRIS (Pereira et. al 2014)

Recent observations of the chromosphere have identified a new type of spicule, dubbed "type II's"

- NASA's *Interface Region Imaging Spectrograph* (IRIS) provided a new look at Type II spicules upon launch
    - They are short-lived; rising and fading away quickly
    - It is theorized that they are the site of vigorous heating
- It has proven challenging to model structures similar to these in 3D Magnetohydrodnamic (MHD) simulations

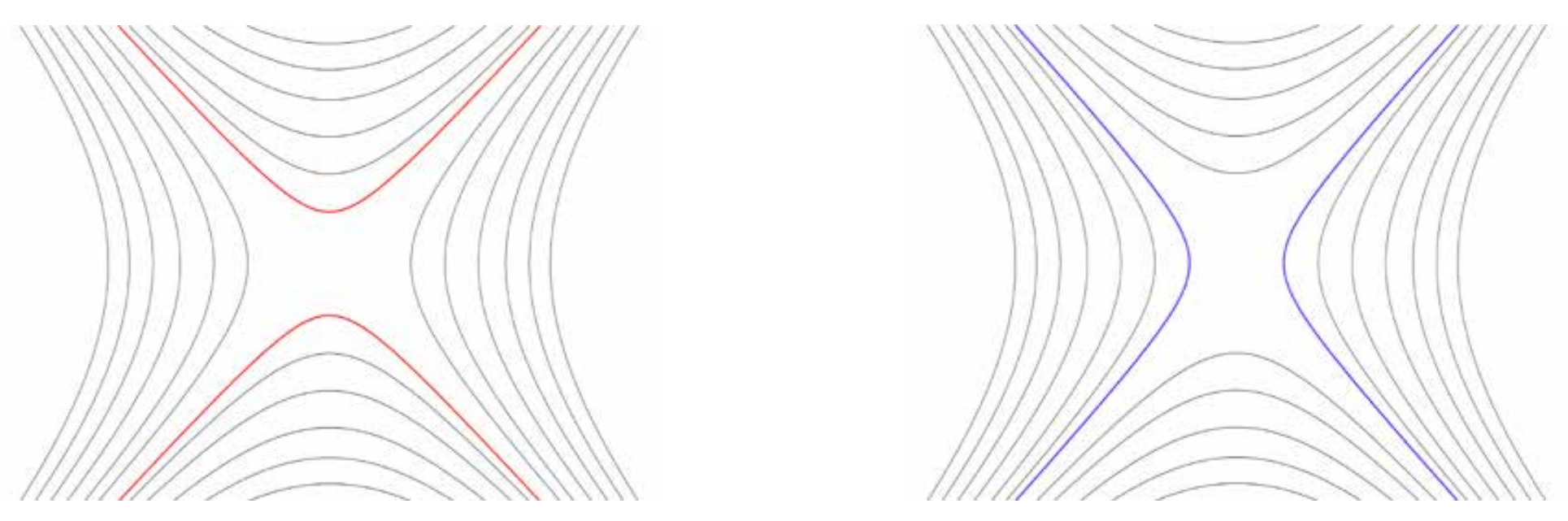
Radiative MHD Simulations

Bifrost code (Gudicksen et al 2011) solves MHD equations while including thermal conduction along the magnetic field, non-gray and non-LTE radiative transfer with scattering, and characteristic boundary conditions on the upper and lower boundaries, which allow waves to pass outside of the computational box and permit the specification of an input magnetic field at the lower boundary.

Radiative MHD Simulations (Cont.)

The simulation (Martinez-Sykora et al. 2011 & 2013) is evaluated on a grid of 256 × 128 × 160 points, expanding from the upper convection zone to the lower corona. The gird is non-uniform in the z-axis to ensure that the vertical resolution is sufficient to resolve the photosphere and the transition region with a grid spacing of 32.5 km. The Factor Q is calculated taking into account this non-uniform grid. (See below)

Magnetic Field Line Reconnection

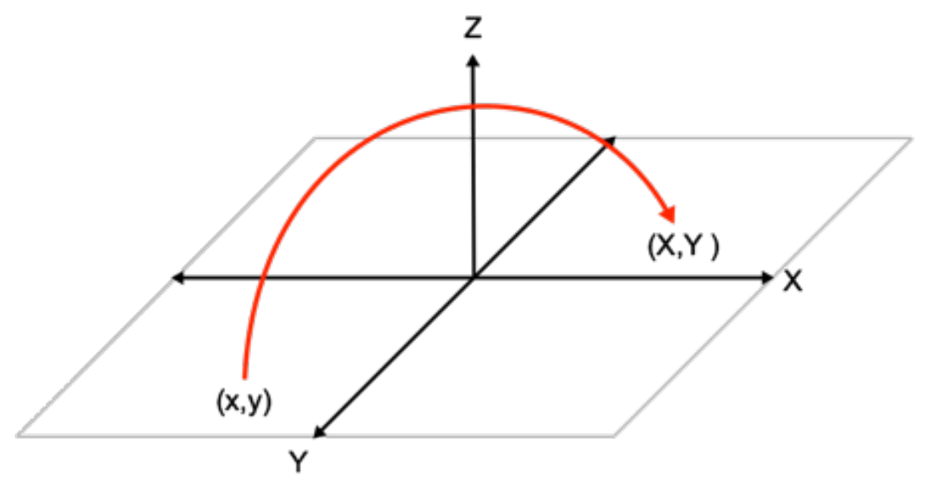


Field line maps depicting reconnection about a coronal null point

Magnetic reconnection occurs when neighboring field lines map to distant conjugate locations. The lines exchange endpoints, allowing the field to relax.

Field Line Connectivity Maps

We created field line connectivity map for planes by tracing the paths individual field lines took through the atmosphere.



By iteratively tracing a line that began in the plane until it again intersected the plane, we obtained the mapping (x, y) → (X, Y).

The Squashing Factor Q

The Jacobian matrix *J* can be derived from the mapping (x, y) → (X, Y):

$$J = \begin{bmatrix} a & b \\ c & d \end{bmatrix} = \begin{bmatrix} \frac{\partial X}{\partial x} & \frac{\partial X}{\partial y} \\ \frac{\partial Y}{\partial x} & \frac{\partial Y}{\partial y} \end{bmatrix}$$

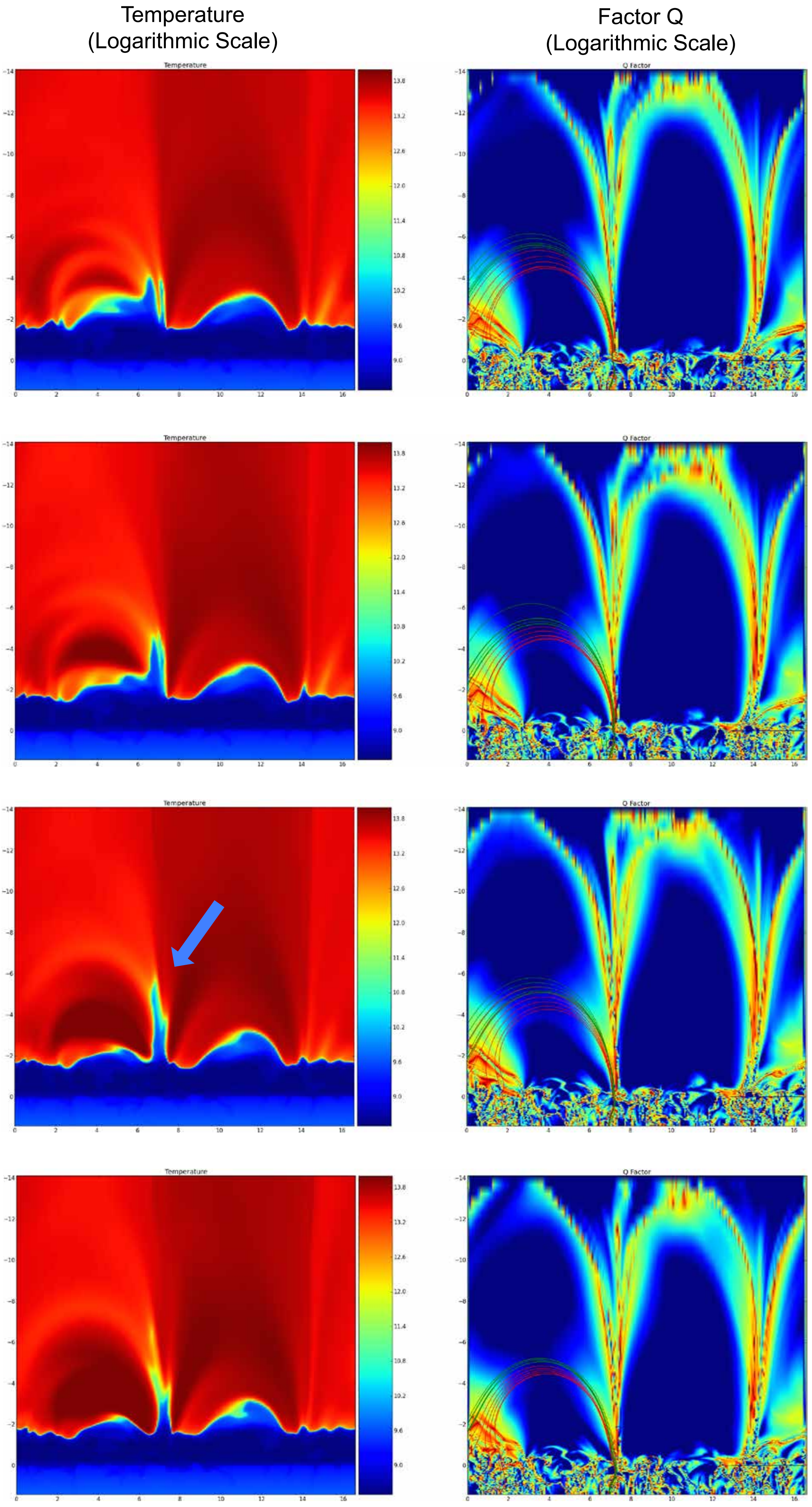
The Factor Q is defined as one of the following (Titov et. al 2009):

$$Q = \frac{a^2 + b^2 + c^2 + d^2}{|ad - bc|} \qquad Q = \frac{a^2 + b^2 + c^2 + d^2}{\left|\frac{B}{B'}\right|}$$

Large values of Q represent locations where neighboring field lines map to conjugate locations that are far apart. These lines are likely to reconnect.

Results

The following series of images follow the evolution of a structure that resembles a type II spicule, or the ejection of a cooler mass into the hot corona.



As the mass ascends, field lines on opposite sides of the spicule diverge, creating a shearing effect. Furthermore, the factor Q reveals a significant increase in the distance between the lines' endpoints.

Results (Cont.)

Such an increase suggests that reconnection is occurring more frequently. The resulting alteration of the magnetic field's topology releases magnetic energy, heating both the cool ejected plasma and the hot corona.

This correlation has led to the suggestion that spicules power – in part – coronal heating.

NVIDIA CUDA

CUDA is NVIDIA's parallel computing architecture. It enables dramatic increases in computing performance by harnessing the power of the GPU.

When compared to a single-core Python application, leveraging CUDA on a GTX 285 with 240 cores resulted in runtime falling from over an hour to under a second, an overall improvement of over 360,000%, and a per-thread improvement of 1,500%.

Python and PyCUDA

For ease of development, the application was written in Python. The PyCUDA framework was used to interface with the graphics card.

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Acknowledgements

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