Simulating nanoflares in the solar atmosphere

Analysis of synthetic observables

Helle Bakke[1,2], Lars Frogner[1,2], and Boris Vilhelm Gudiksen[1,2]

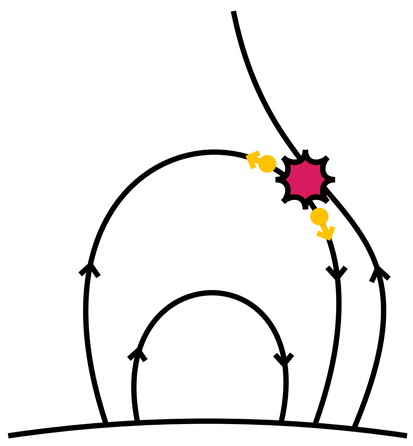
[1]Institute of Theoretical Astrophysics, University of Oslo, Norway
[2]Rosseland Centre for Solar Physics (RoCS), University of Oslo, Norway

Introduction

We present a model for energy transport by non-thermal electron beams in a radiative MHD simulation of the solar atmosphere. The model consists of the following steps:

- Identifying reconnection sites.
- Inferring the electron energy spectrum.
- Tracing the electrons along the magnetic field.

We make a direct comparison of two separate simulations made with the Bifrost code (Gudiksen et al. 2011), with and without non-thermal electrons. First results from this project were presented in Bakke et al. (2018).



Identification of reconnection sites

Magnetic reconnection involves a change in the field line topology. Identifying such effects in a 3D simulation requires tracking of the magnetic flux on a fine scale. A less numerically expensive method of identifying reconnection sites is found by considering the conservation of magnetic field line topology. The topology is conserved when

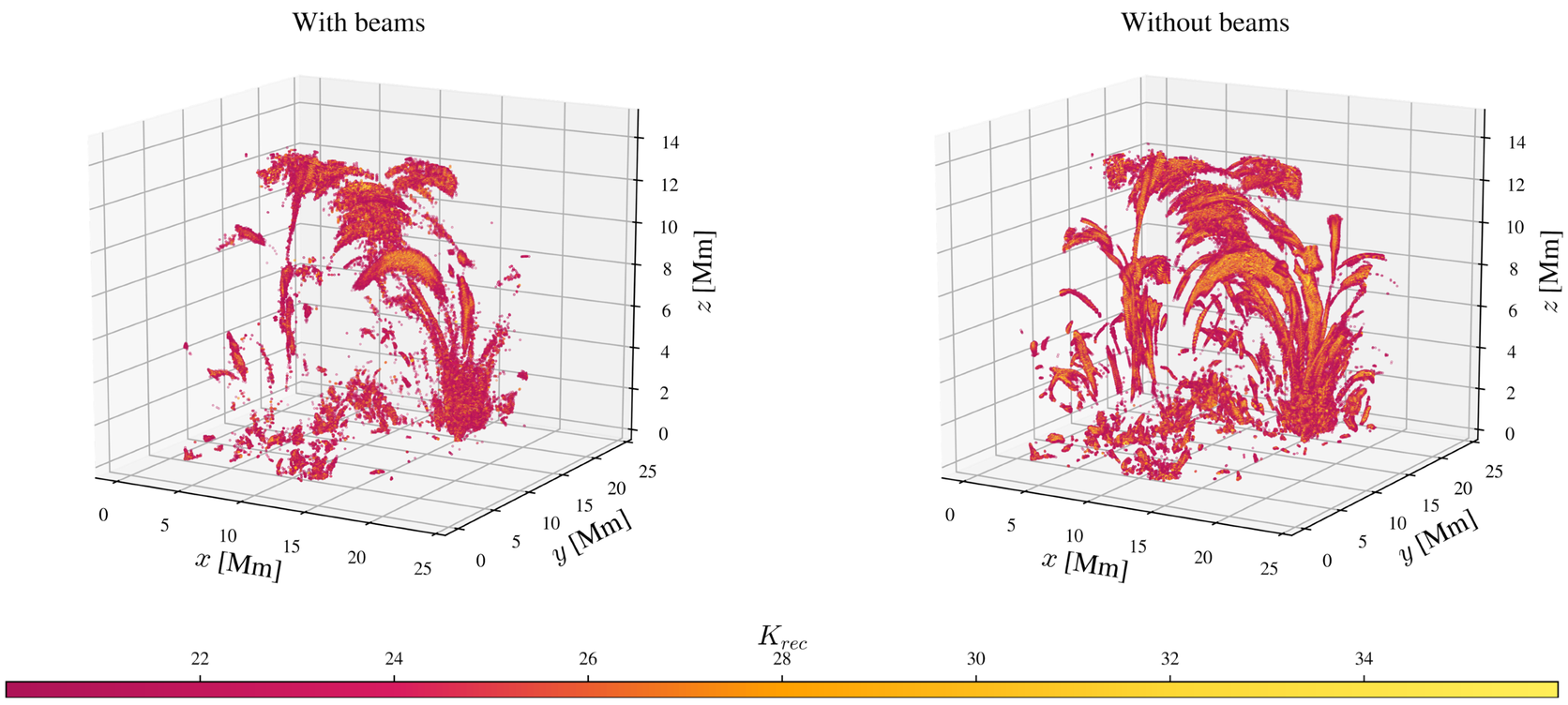
$$\mathbf{B} \times (\nabla \times \mathbf{S}) = 0$$

where $\mathbf{B}$ is the magnetic field vector and $\mathbf{S}$ is the component of the electric field aligned with the magnetic field (Biskamp 2005). Reconnection occurs when

$$\mathbf{K} = \mathbf{B} \times (\nabla \times \mathbf{S}) \neq 0$$

which can be calculated from pure MHD variables. Reconnection sites are located by defining the reconnection factor $K_{rec} = |\mathbf{K}| \neq 0$.

Reconnection sites



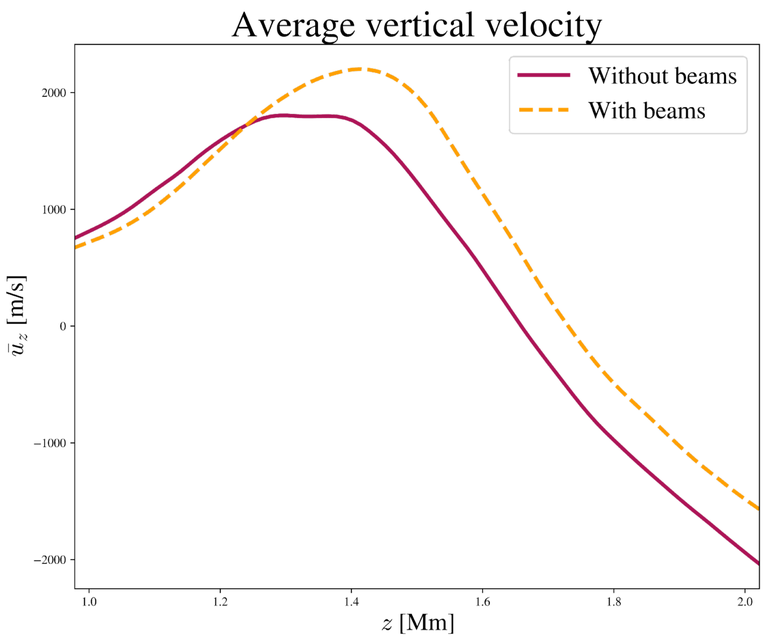
Effect on the corona

The distribution of reconnection sites suggests that the inclusion of non-thermal electrons alter the resulting atmosphere, in particular the corona. There is a decrease in the number of reconnection sites when non-thermal electrons are included in the simulation, which indicates a change in the long-term evolution of the corona.

Scan the QR code for a movie of the reconnection sites

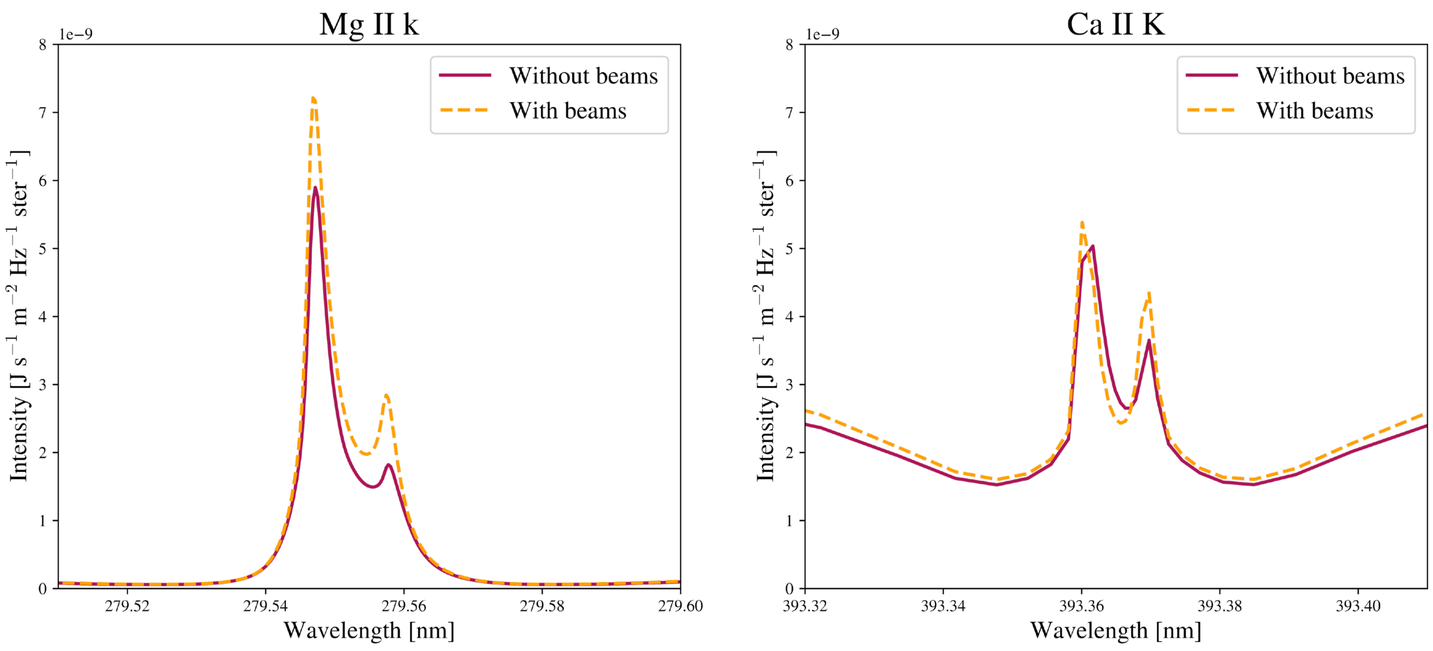
Effect on the lower atmosphere

Energy released from nanoflares is carried by non-thermal electrons to the lower atmospheric layers. The ambient plasma is heated, which in turn fills the flare loops. Negative vertical velocities imply motion upwards, and suggest *chromospheric evaporation* due to local heating of the chromosphere.



Synthetic observables

Synthetic Mg II k and Ca II K line profiles are calculated using the RH1.5D numerical code (Uitenbroek 2001; Pereira & Uitenbroek 2015). The figures show brightening intensities in both peaks, implying that the non-thermal electrons deposit their energies in the chromosphere. Other observable signatures include line broadening due to the vertical velocities.



Rosseland Centre for Solar Physics

UiO : Institute of Theoretical Astrophysics
University of Oslo

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