4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Realistic radiative MHD simulations of flux emergence from the convection zone to the corona

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Realistic magnetohydrodynamic simulations are a cutting-edge method for studying fine structures of sunspots[1], formation of active region[2], coronal heating[3] and recently for solar flares[4]. However, due to resource demanding nature of these simulations, no previous study can cope with the challenge of using a large spatial domain, high resolution, long evolution and strong magnetic field in a single simulation. Recent advances in the MURaM radiative MHD code[5] allow us to conduction an unprecedented simulation of the formation of flare productive active regions through emergence of magnetic flux generated a solar convective dynamo[6]. This simulation presents a whole picture of active regions from the interior to the corona.

This simulation accounts for radiative transfer for optically thick radiation, a realistic equation of state for the lower atmosphere, energy loss through optically thin radiation and anisotropic thermal conduction in the hot corona. With these treatments on energy transports, the model and synthetic observations have a sufficient degree of realism to be compared quantitatively with real observations. We present in Figure 1 an overview of the computational domain after 27 solar hours of evolution (c.f. 48 solar hours of total evolution). The horizonal extent of the domain is about 200 Mm and the vertical extent is about 120 Mm with the bottom boundary placed at 10 Mm below the solar surface. The magnetic flux generated in a solar convective dynamo (horizontal slice at the bottom) emerges through the convective layers and give rise to sunspots in the photosphere (horizontal cut in grayscale). The vertical slice in between shows the subsurface magnetic structure of the sunspots. Green-blue colored structures spreading in the box illustrate of 2 -- 3 million K hot plasma confined in coronal magnetic field, i.e., coronal loops as seen EUV images of the real solar corona.

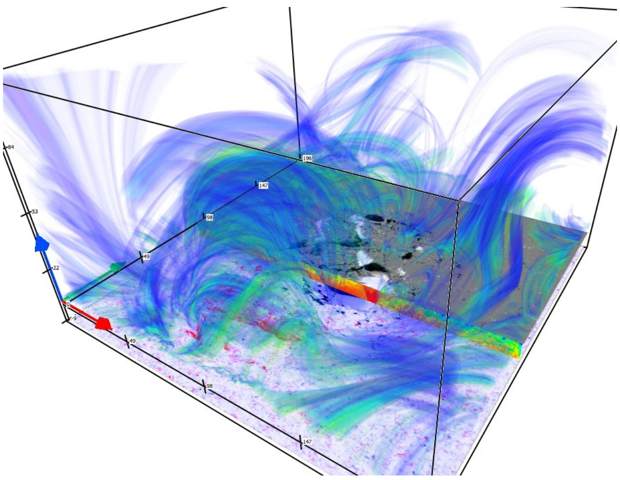

Fig. 1. Computational domain with slices showing the magnetic field in the convective zone and photosphere and volume rendering of hot plasma in the corona.

We report some first highlight results in this presentation. As demonstrated by synthetic EUV emission in passband that are widely used in real observations, the simulated active region corona reproduces many commonly observed structures and dynamics, such as coronal loops with various lengths and temperatures, and evaporation and drainage plasma in the solar atmosphere. A nice example of long coronal loops self-consistently formed in this simulation is shown in Figure 2.

More than 170 flares occur in 48 hours of evolution, with the largest flare reaching M class as revealed by its (synthetic) GOES flux. The statistical relation of the magnetic energy released by flares and the flare class successfully reproduces the relation deduced in observations. Moreover, we present an overview on the largest two flares, with highlights on the evolution of magnetic flux ropes, magnetic reconnections and large-scale coronal EUV waves driven by these eruptions.

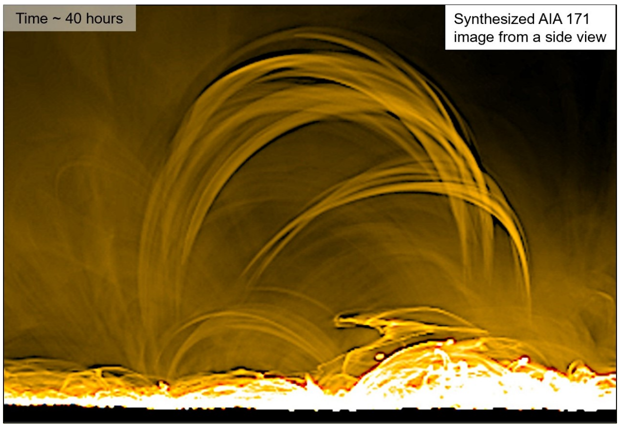

Fig. 2. Synthetic AIA 171 channel images showing a long EUV loop arching 70 Mm over the solar surface. The image is synthesized with the temperature response function of the instrument and plasma density and temperature in the simulation.

References

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