6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Radiative Magnetohydrodynamics Simulations of Solar Atmosphere and Eruptions

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The Sun is the most well-observed star, yet to be better understood. Detailed and ever-improving observations of the Sun provides accurate input parameters, as well as strict constraints on theoretical models. It is a challenge to reproduce a real-looking Sun and its key properties by numerical simulations—particularly in a self-consistent manner.

We will briefly review the development of the cutting-edge method of radiative magnetohydrodynamic simulations, which accounts for the radiative and conductive energy transport in the solar atmosphere (usually incorporated with a realistic equation of state). With these treatments in the energy equation, the model and synthetic observations have a sufficient degree of realism to be compared quantitatively with real observations and reveal physical processes that are not present in more idealized models. This method has been successfully used in modeling, for example, fine structures of sunspots[1], emergence of magnetic flux[2], heating of the solar corona[3][4][5], as well as in solar flares[6], respectively.

Recently, we conducted a comprehensive simulation that present a whole picture of flare productive active regions from the interior to the corona (as shown in Figure 1) and a wide activity spectrum from ubiquitous bright point in the quiet Sun to solar flares up to M class[7]. Figure 2 shows a few example events of the smallest bright points given rise by episode of magnetic energy release, which resemble campfires discovered by Solar Orbiter[7]. Figure 3 compares the source region of cool (< 1 MK) and hot (> 10 MK) plasma emission and shows how the emission features related to the magnetic field[8].

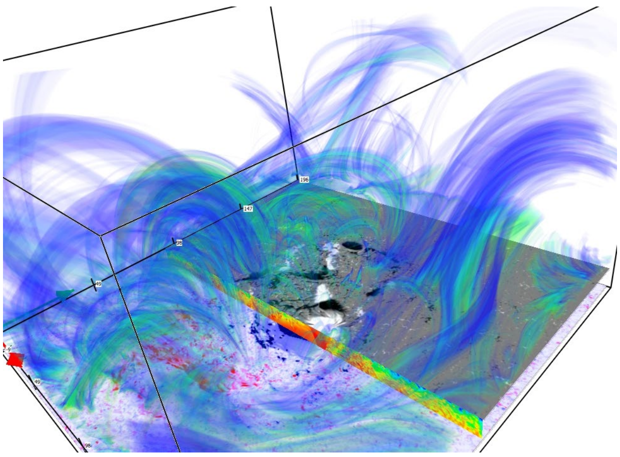

Figure 1: An overview of the simulation domain after 27 solar hours of evolution. Blue- and greenish structures outline hot plasma of 2-3 MK in the corona.

We will discuss how this simulation may help to shed new light on "active problems" in solar physics, such as the heating and plasma dynamics in the corona and the origin of solar eruptions.

We will also present our ongoing works on incorporating radiative MHD simulations with data-driven techniques, which paves the way for reproducing the thermodynamic and magnetic properties of a particular solar eruption.

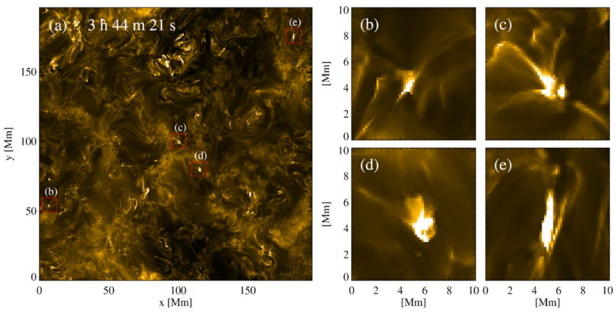

Figure 2: Synthetic AIA 171 channel observation of the whole horizontal domain (left panel). Right panels show ubiquitous small bright points in size of about 2000 km.

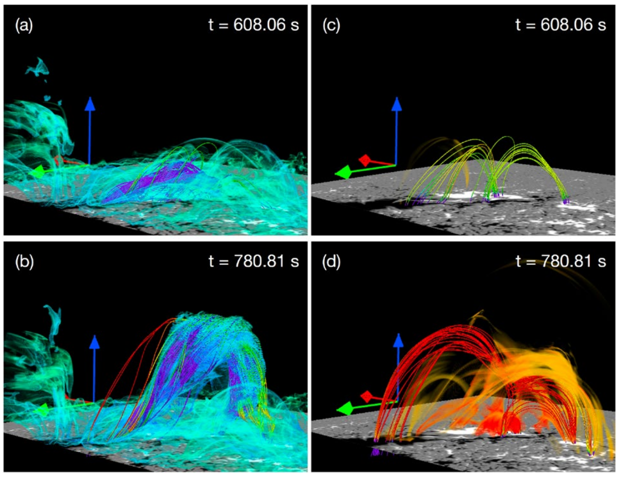

Figure 3: Distribution of cool (left) and hot (right) plasma before (upper) and during (lower) a magnetic flux rope eruption.

References

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