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Coronal dynamics driven by magnetic flux emergence

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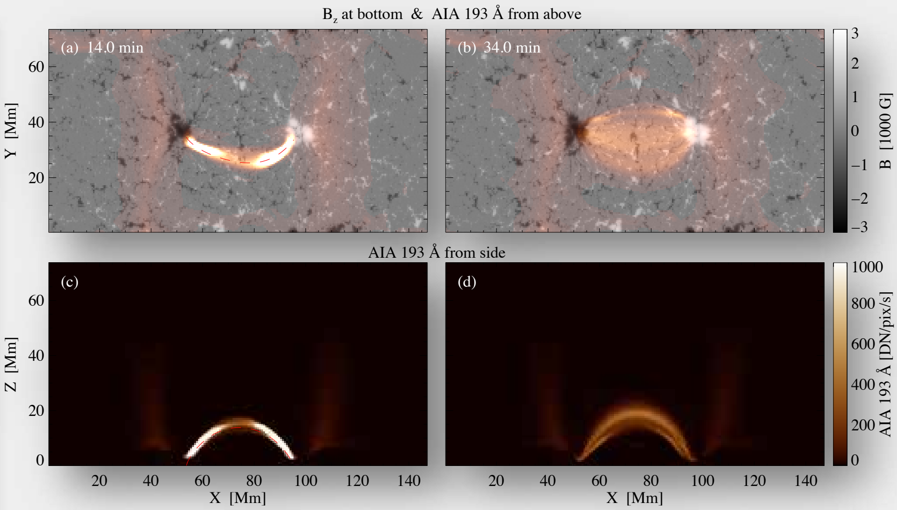
We present the first model that couples the formation of the corona of a solar active region to a simulation of the emergence of a sunspot pair. This allows us to study when, where, and why active region loops form, and how they evolve.

We use a 3D radiation MHD simulation of the emergence of an active region through the upper convection zone and the photosphere as a lower boundary for a 3D MHD coronal model. The latter accounts for the braiding of the magnetic fieldlines, which induces currents in the corona heating up the plasma. We synthesize the coronal emission for a direct comparison to observations. Starting with a basically field-free atmosphere we follow the filling of the corona with magnetic field and plasma

Numerous individually identifiable hot coronal loops form, and reach temperatures well above 1 MK with densities comparable to observations. The footpoints of these loops are found where small patches of magnetic flux concentrations move into the sunspots. The loop formation is triggered by an increase of upwards-directed Poynting flux at their footpoints in the photosphere. In the synthesized EUV emission these loops develop within a few minutes. The first EUV loop appears as a thin tube, then rises and expands significantly in the horizontal direction. Later, it seems to fragment and develops into a system of multiple loops or strands.



Appearance of a coronal loop in the 3D simulation

Evolution of synthesized coronal emission and magnetic field. The top panels show the photospheric magnetogram (vertical component), overlaid with the synthesized coronal emission as it would be seen in the AIA 193 Å channel. The bottom panels show synthesized AIA 193 Å images as seen from the side. The synthetic emission is integrated along the line of sight, comparable to what would be seen at disk center (top) or the limb (bottom).

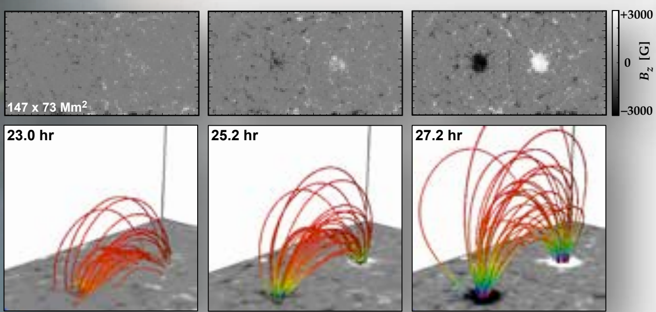
As in observations, the coronal loop is rooted in the periphery of the sunspots.

While the EUV loop evolves, it changes its appearance significantly in response to the heat input, forming a multitude of new strands, so that the process looks like fragmentation.

3D MHD coronal model

We solve the time-dependent 3D MHD problem, i.e. the induction equation along with the mass conservation, momentum, and energy balance from the cool solar surface into the hot corona above an active region. The energy equation includes Spitzer heat conduction along the magnetic field, optically thin radiative losses and Ohmic heating. Only this ensures a proper description of the coronal pressure, which is prerequisite to synthesizing EUV emission as would be expected for AIA observations.

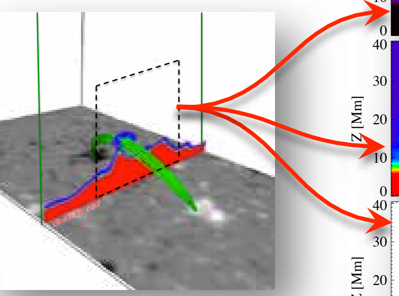
The model is driven by a 3D MHD flux-emergence model by Cheung et al. (2010, ApJ 720, 233). We use the properties of that model in the photosphere (T,ρ,u,B) to prescribe a time-dependent lower boundary condition in our coronal model. The computational domain encompasses 147 Mm x 73 Mm x 73 Mm.

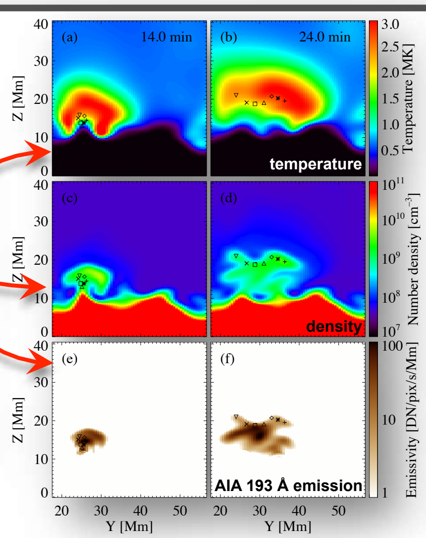


This sequence shows how the magnetic field expands into the coronal while the active region flux emerges in the photosphere.

3D structure of the coronal loop

We investigate a vertical cut in the midplane between the sunspots:





– density and temperature structure is relatively smooth

– AIA emission is convolution of density and temperature (→ n^2 * temperature-response-function)

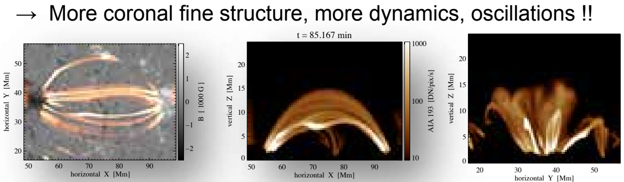
– heat input changes in time and causes different parts of the magnetic tube to have right temperature and high enough density to be seen in AIA 193 Å

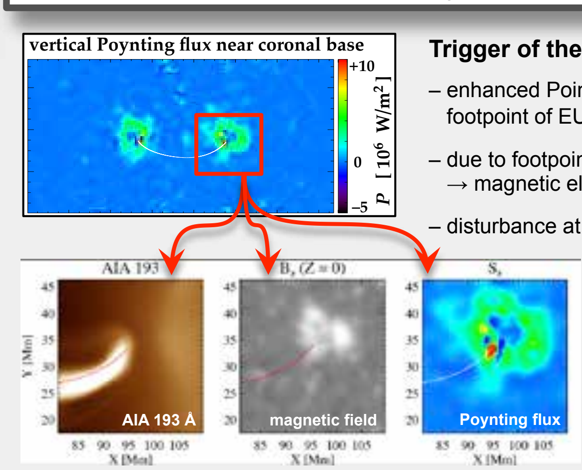
→ this appears as if the EUV loop would fragment in time.

Outlook

We conducted a new numerical experiment with high-resolution: now 1024 x 515 x 256 grip points.
This allows to resolve inter-granular lanes in photosphere

→ More coronal fine structure, more dynamics, oscillations !!





Trigger of the loop formation

– enhanced Pointing flux at the footpoint of EUV loop

– due to footpoint motion in photosphere → magnetic element moving into spot

– disturbance at one footpoint propagates to the other side

– then also increase of Poynting flux there

→ increased Poynting flux at both footpoints

→ loop heats and fills !