Numerical study on the formation of solar active regions

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One of the important problems in plasma physics of the Sun is the formation process of the active regions including sunspots. Active regions are the regions where magnetic flux is strongly concentrated, and may cause catastrophic eruptions such as solar flares and affect the interplanetary space. Theoretically, active regions are created by the magnetic flux transported from the deep convection zone, which is produced through a global dynamo action [1]. However, we cannot investigate the physical state of the subsurface magnetic flux from direct optical observations. Therefore, numerical simulations on the rising magnetic flux can be a powerful tool to understand the formation process of an active region. Here we show magnetohydrodynamic simulations of the rising magnetic flux in a large scale from $-20,000$ km of the solar convection zone due to its magnetic buoyancy (see Figure 1). We found that, as the magnetic flux approaches the surface layer (photosphere), the flux slows down its ascent because of the isothermally-stratified (i.e., convectively-stable) photosphere in front. Thus, the flux extends horizontally to create a sheet-like structure just beneath the photosphere. As the field strength increases, the subsurface flux penetrates the photosphere and bursts into the rarefied upper atmosphere [2]. By conducting parametric survey, we found that the magnetic flux that yields an actual solar active region is expected to have a field strength of $10^4$ G, total flux of $10^{21}$–$10^{22}$ Mx, and a sufficient twist $>2.5 \times 10^{-4}$ km$^{-1}$ at $-20,000$ km in the convection zone. In the presentation we will show and discuss the simulation results in connection with recent observations of the birth of active regions.

Figure 1: Temporal evolution of the magnetic flux. The color indicates the field strength, $B_0 = 300$ G, and $\tau_0 = 25$ s. (a) The initial condition of the flux embedded at $-20,000$ km of the solar convection zone. (b) The final state at $t = 800\tau_0 = 5.5$ hr.