Solar coronal loops as nonaxisymmetric toroidal plasmas*

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Coronal loops on the surface of the sun appear to be magnetic flux ropes containing plasma, driven by hidden processes in the solar interior. Unstable loops can lead to large impulsive events such as coronal mass ejections (CMEs) of energetic particles and solar flares that contribute to the earth's space weather and can affect man-made communications, satellites, and electrical power grids. The first consistent steady state loop model[1], for a section of a nonaxisymmetric toroidal plasma with its ends tied in the photosphere, is based on 3D analytic solution of the MHD momentum equation in a small inverse aspect ratio expansion, using ideas from toroidal fusion plasmas. The solar gravity, previously neglected, determines the degree of nonaxisymmetry of the density, through a competition between the MHD gravity parameter $\hat{G} = ga/v_A^2$ and the plasma beta β_o, where g is the acceleration due to gravity, a the loop minor radius, and v_A the shear Alfvén velocity. Gravity pulls the plasma down along the magnetic field lines towards the sun, while temperature buoys it up. Curved current-carrying plasmas are unstable to expansion in major radius. The opposing gravitational force density, at the loop-top, is $-\rho_o \hat{G} \hat{\mathbf{h}}$, where ρ_o is the mass density and $\hat{\mathbf{h}}$ the solar vertical direction. The maximum gravity scaling $\hat{G}/\beta_o \simeq \epsilon^1$ determines the largest steady state loop height. Powers ϵ^2 and higher correspond to increasingly axisymmetric loops that resemble partial tokamaks. Due to the fixed loop ends, the radial force balance can differ from fusion plasmas. The solutions fit the observed range of thin coronal loops ($\epsilon \simeq 0.02$) that commonly appear in solar active regions. They are also consistent with properties of the fatter, more rarely observed loops ($\epsilon \simeq 0.1$–0.2) that can generate solar flares and CMEs.

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