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Solar Coronal Loops as Magnetically Confined Tori with Gravity

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A large amount of evidence suggests that the bright loops that are regularly observed in the sun's corona are magnetic flux ropes that confine plasma, tied at both ends to structures in the photosphere.

Due to the difficulties of observation, their steady states have never been explained.

Coronal loops resemble partial magnetic tori and ideas from the equilibrium and stability of toroidal magnetic fusion plasmas lead, for the first time, to 3D ideal MHD solutions for coronal loop steady states that take into account the complete force balance and geometry. The apparently weak solar gravity, previously ignored, is found to be the crucial factor that allows a loop steady state and provides a unified observational picture.

Gravity, combined with magnetic line-tying at the loop footpoints, stabilizes the intrinsic radial (major radius) expansion instability of a curved current-carrying loop, replacing the external fields used in laboratory plasmas.

Normalized to the loop MHD parameters, the gravitational force parameter is $\hat{G} = G a / v_A^2$, in terms of the acceleration due to gravity $G=274.9 \text{ m/s}^2$, the loop minor radius a , and the shear Alfvén speed v_A .

Analytical steady states exist at two orders in the loop inverse aspect ratio $\epsilon = a/R_o$, $\hat{G} = \epsilon^2$ and ϵ^3 .

Comparison to observations shows good agreement. Short hot coronal loops and the shorter warm loops fit the ϵ^3 ordering, while long, lower density loops better fit ϵ^2 .

Intermediate length loops fall in between.

Small \hat{G} loops have an axisymmetric tokamak-like core, while large \hat{G} loops are strongly nonaxisymmetric and more closely related to high beta stellarators, modified by gravity.

Sufficiently long loops will be metastable, since the gravitational force begins to decrease with height as $(R_o + R_s)^{-2}$, and may provide the seed state for large Coronal Mass Ejections.

The constraints imposed by the gravitational $N=1$ nonaxisymmetry are related to fusion questions on the effects of small magnetic nonaxisymmetries on tokamaks, such as error fields and the density pump-out by RMPs.

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