A review on the Kippenhahn-Schlüter prominence model

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HELLENIC ASTRONOMICAL SOCIETY

Solar Prominences

What are solar prominences?

Large, bright plasma structures with small width compared to their length that extend high into the solar corona. Observed in the solar limb.

Other physical properties

- Denser and colder than surrounding hot and diffuse coronal plasma.
- They can live for a long time and present modest flow velocities $\rightarrow$ close to energy balance equilibrium.

What about their types?

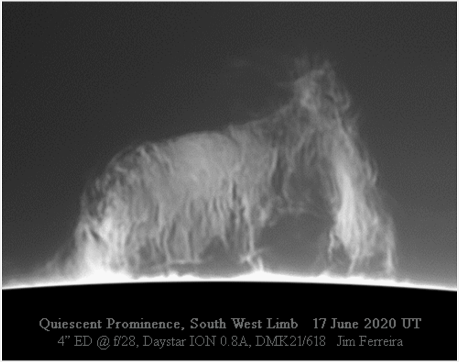
Quiescent and Eruptive SP.

Motivation

The Enigmatic Nature of Solar Structures

1. What supports prominences against gravity?
2. How can prominences be so cool in the corona?

Quiscent Prominence



K-S Model

The prominence is modelled as a thin vertical sheet of magnetized plasma in magneto-hydrostatic equilibrium.

- Assumptions:
  $P = P(x), \rho = \rho(x), T = const., B_x, B_y = const., B_z = B_z(x), \frac{\partial}{\partial t} = 0$

Theoretical framework

$$\nabla P = \frac{1}{4\pi}(\nabla \times \mathbf{B}) \times \mathbf{B} + \rho \mathbf{g} \quad \nabla \times \mathbf{B} = \frac{4\pi}{c}\mathbf{J} \quad \nabla \cdot \mathbf{B} = 0$$

$$P = 2n_e kT \quad \lambda_p = \frac{2kT}{\mu m_H g}$$

Solutions

Equations

$$\hat{x}: -\frac{\partial}{\partial x}\left(P + \frac{B^2}{8\pi}\right) = 0,$$
$$\hat{z}: -\rho g + \frac{B_x}{4\pi}\frac{\partial B_z}{\partial x} = 0$$

B.C. $P(x \to \pm\infty) = 0$ and $B_z(x \to \pm\infty) = \pm B_{z\infty}$ and by using the E.O.S. for ideal gases:

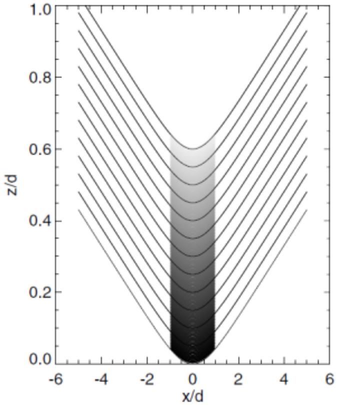
$$B_z(x) = B_{z\infty} \tanh\left(\frac{B_{z\infty}}{B_x}\frac{x}{2\lambda_p}\right),$$
$$P(x) = \frac{B_{z\infty}^2}{8\pi}\left[\cosh\left(\frac{B_{z\infty}}{B_x}\frac{x}{2\lambda_p}\right)\right]^{-2}$$

Stability

Comments

- Both magnetic pressure and magnetic tension oppose gravity!
- It is a static equilibrium.
- Any perturbation of the magnetic field results in a change in the magnetic tension, which acts as a restoring force.

Computed magnetic field lines



Applications of K-S Model

Forecasting Space Weather

By understanding the mechanisms that stabilize or destabilize solar prominences.

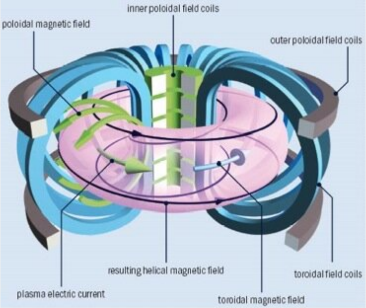
Developing Advanced Magnetic Confinement Models

Such as complex 3D models that can be used in plasma confinement technologies.

Designing Fusion Reactors

Ability to preserve hot plasma using magnetic fields and therefore produce huge amounts of energy.

Magnetic field

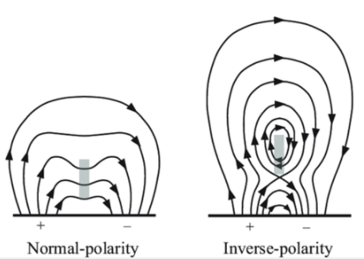


Extensions of the Model

Key Extensions

- The magnetic field lines aren't necessarily simple loops (Kuperus and Raadu 1974)
- Higher dimension models (Heasley and Mihalas 1976)
- Additional processes (e.g. thermal equilibrium, Anzer and Heinzel 1999)

Tandberg-Hanssen 1995



Dynamic Models

- Dynamics of Prominences (Low 1982)
- Thermal Nonequilibrium (Antiochos and Klimchuk 1991)
- Non force-free models (Xia and Keppens 2016)

Conclusions

Applications

- Despite its simplicity, the KS model is crucial in understanding the main mechanism of prominence stability.
- However, it can't accurately predict the complexities of solar prominences.

Complexity

- To model the diverse conditions under which solar prominences form, all mentioned processes should be taken into account and in detail (e.g. detailed structure and evolution of the magnetic field).
- Robust models are too complicated for analytic solutions and instead require detailed numerical simulations, relying on data from observations.

References

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thank
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