

Global 2D Axisymmetric MHD Simulations of Coronal Streamers

Graham Kerr,¹ Yuhong Fan², B.C Low²



¹SUPA, School of Physics and Astronomy, University of Glasgow, Scotland, UK

²High Altitude Observatory, NCAR, Boulder, Colorado



Summary

Coronal streamers are long-lived regions of closed magnetic fields in the solar corona which can erupt into CMEs.

In order to better understand the properties of these streamers, and their interaction with the solar wind we construct 2D axisymmetric global MHD solutions of global streamers and the solar wind, assuming an ideal polytropic gas with $\gamma = 1.1$.

Presented here are the preliminary results of this model.

Qualitatively the model reproduces the morphology and properties of the coronal streamer and solar wind.

Quantitatively, modelling with a uniform base density and pressure fails to achieve the observed density contrasts between streamer and coronal hole, or the wind speed in the open-field region.

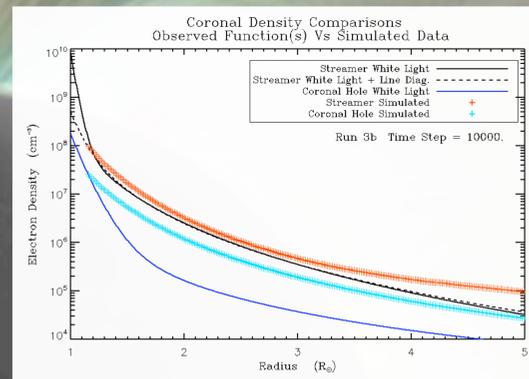
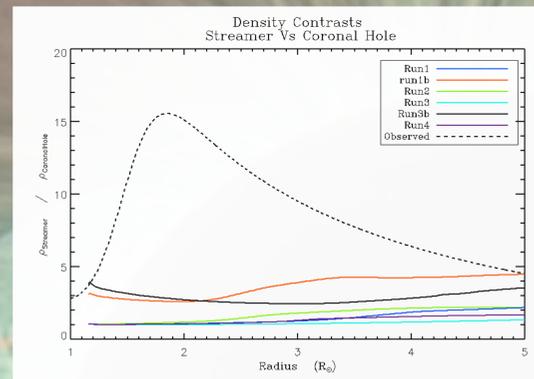
By dynamically adjusting the base density, with a lower base value in open-field regions, we obtain better density contrasts. They do not match the levels observed, but this limitation is known and understood.

The reason is that the polytropic model is unable to reproduce the fast-wind flows in open-field regions, the latter requiring additional energy deposition via Alfvén or magneto-acoustic waves.

Despite these limitations, this model is well placed to move onto studying the eruption of CMEs via the introduction of a twisted flux tube into the closed-field region, and successfully illustrated the interaction of streamers with the solar wind. Steps to improve the model are to include thermal conduction or non-adiabatic heating (among others) to move beyond the polytrope.

Density Contrasts

Comparing the density contrast between the streamer belt and coronal holes, to observations, and the density profiles in each region, it is clear that we are unable to match the density gradient in the coronal holes, but are successful in closely reproducing the streamer density profile (note that the boundary conditions here are a temperature of 1.5MK, which matches the temperature Gibson et al measured).

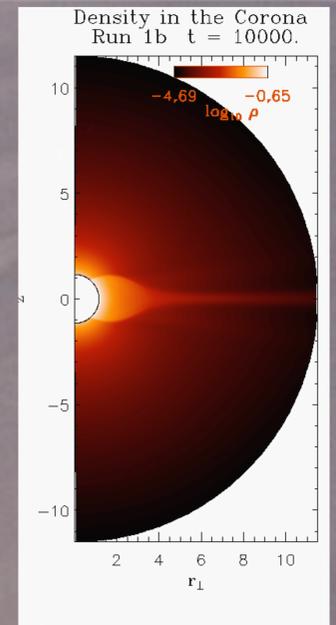
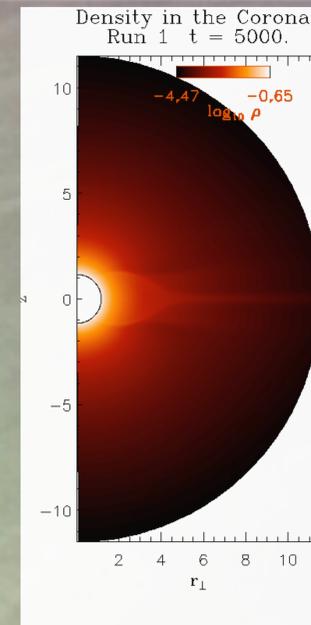


Dynamically Adjusted Results

By dynamically adjusting the base density we are able to achieve a much better contrast between streamer & coronal hole density, though not at the level of observations.

Normal Solution

Dynamically Adjusted Solution

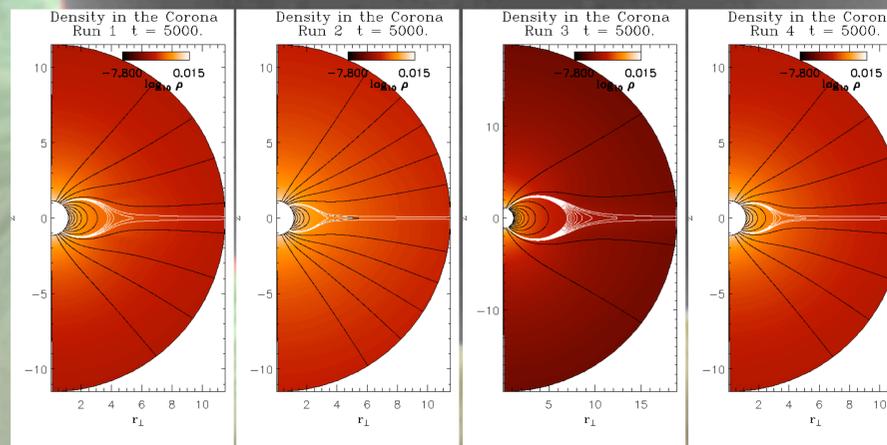
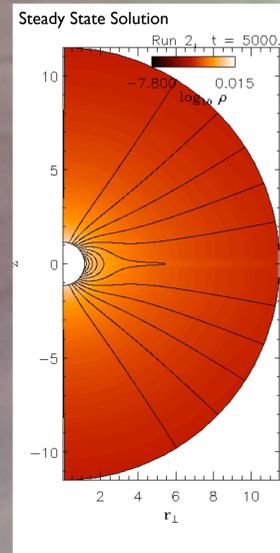
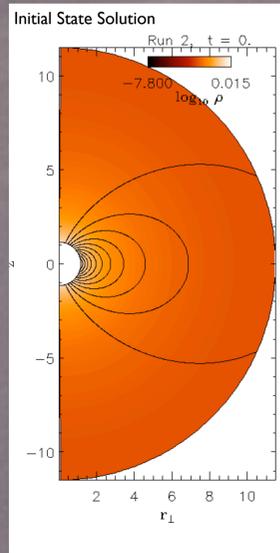


Streamer Morphology

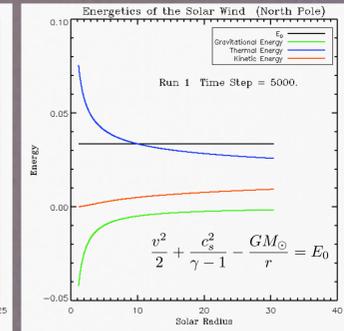
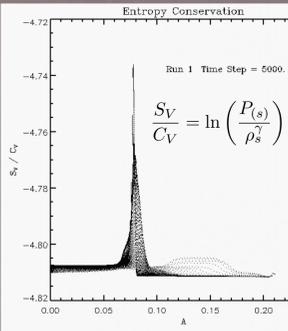
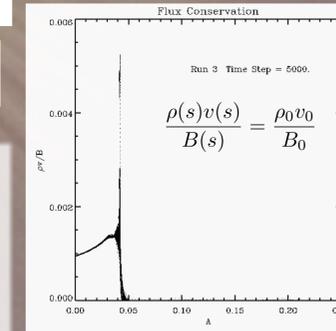
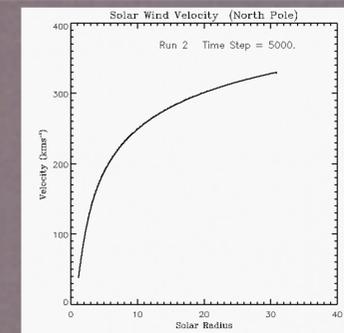
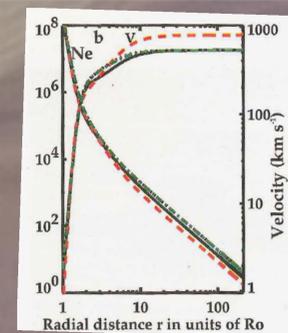
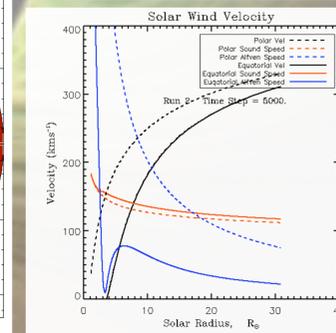
We successfully model a streamer with closed field lines, sandwiched between coronal holes in the polar regions. The streamer shape and surrounding field lines are as expected, but the length of the streamer is larger than expected in some instances.

Solar Wind Velocity

Good Qualitative picture of solar wind velocity. But, coronal hole wind speed is significantly lower than observations (Guhathakurta et al, 1999).



T: 1.75 MK, B: 10 G, Streamer Size ~3.44 R_⊙
 T: 2 MK, B: 10 G, Streamer Size ~2.39 R_⊙
 T: 1.5MK, B: 10 G, Streamer Size ~6.53 R_⊙
 T: 1.75 MK, B: 5 G, Streamer Size ~ 2.30 R_⊙



Numerical Simulation

Solve the MHD equations for a polytropic gas ($\gamma = 1.1$) in an axisymmetric spherical geometry, $r \in [1.15R_{\odot}, 30R_{\odot}]$, $\theta \in [0, \pi]$

Simulate 8 dependent variables $v_r, v_{\theta}, v_{\phi}, B_r, B_{\theta}, B_{\phi}, \rho, \epsilon$
 Initial State:

- Static atmosphere in hydrostatic equilibrium.
- Dipolar potential magnetic field (solar min. conditions).
- Drop pressure at outer boundary

Equations are solved using different boundary conditions (temperature and polar magnetic field strength) and the solutions evolve towards a steady state.

References

Cottar, M., & Fan, Y., 2009. 'A model of coronal streamers with underlying flux ropes.' *Astrophysical Journal* **704**, pp. 576-590
 Gibson, S.E., et al., 1999. 'Solar minimum streamer densities and temperatures using Whole Sun Month coordinated data sets.' *Journal of Geophysical Research* **104(A5)**, pp. 9691-9699
 Guhathakurta, M., et al., 1999. 'Physical properties of a coronal hole from a coronal diagnostic spectrometer, Mauna Loa Coronagraph, and LASCO observations during the Whole Sun Month.' *Journal of Geophysical Research* **104(A5)**, pp. 9801-9801

Parker, E.N., 1958. 'Dynamics of the interplanetary gas and magnetic field.' *Astrophysical Journal* **128**, pp. 664-675

Acknowledgements

Special thanks are due to Yuhong Fan and B.C. Low for their excellent guidance, support and patience.

Thanks are also due to the LASP REU Program, Martin Snow and Erin Wood.

This work is supported by NASA LWS TR&T grant NNX09AJ89G to NCAR.

Conservation Laws

The MHD solutions should conserve *Mass Flux*, *Magnetic Flux*, *Entropy* and *Energy* (via the Bernoulli Law).

The code successfully solves the MHD equations with a minimum of numerical dissipation - i.e. the above values are conserved.

Only in the streamer region are quantities not conserved - 'frozen in condition' is not satisfied here.