Global 2D Axisymmetric MHD Simulations of Coronal Streamers

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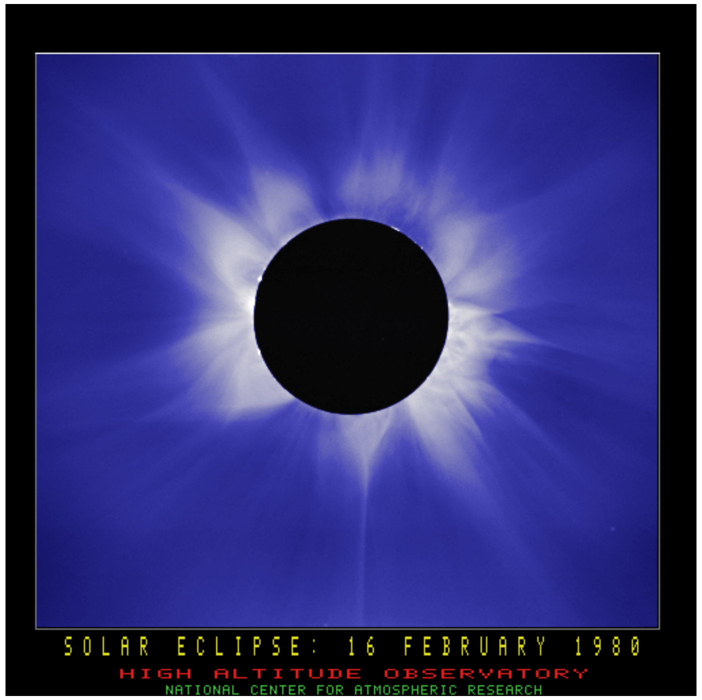
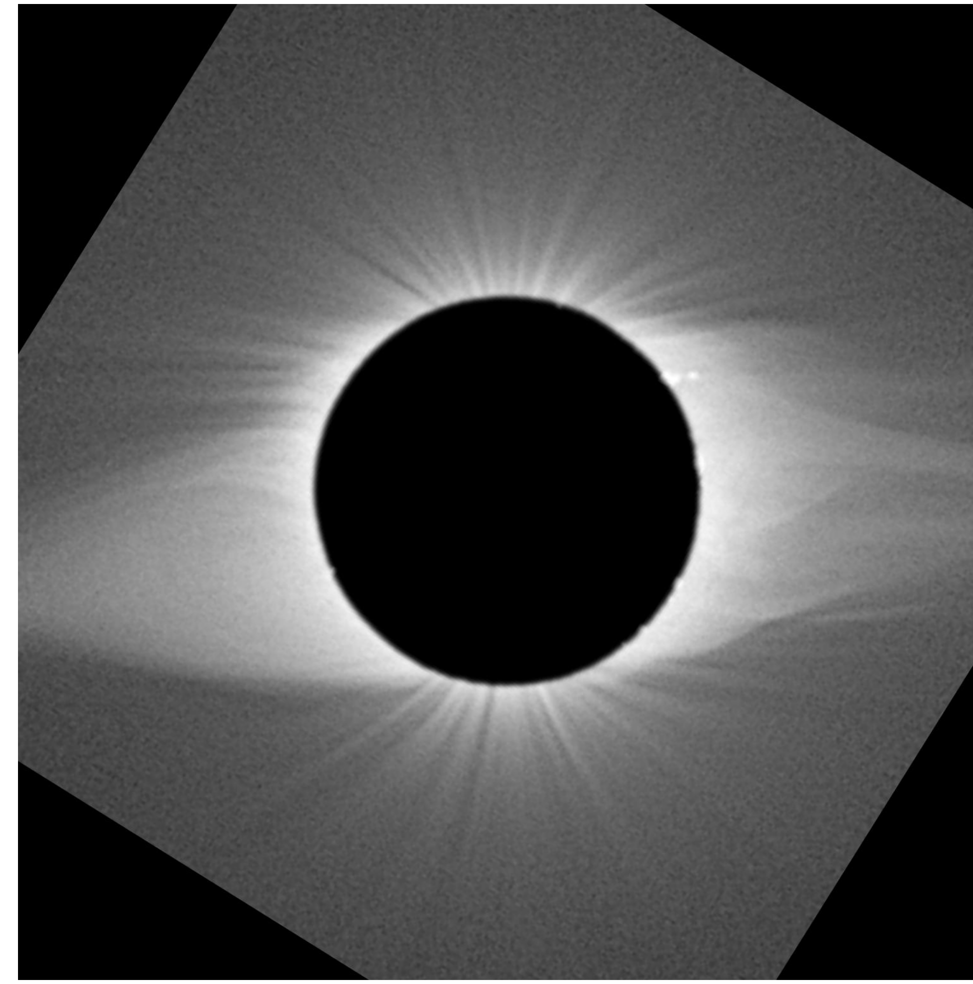
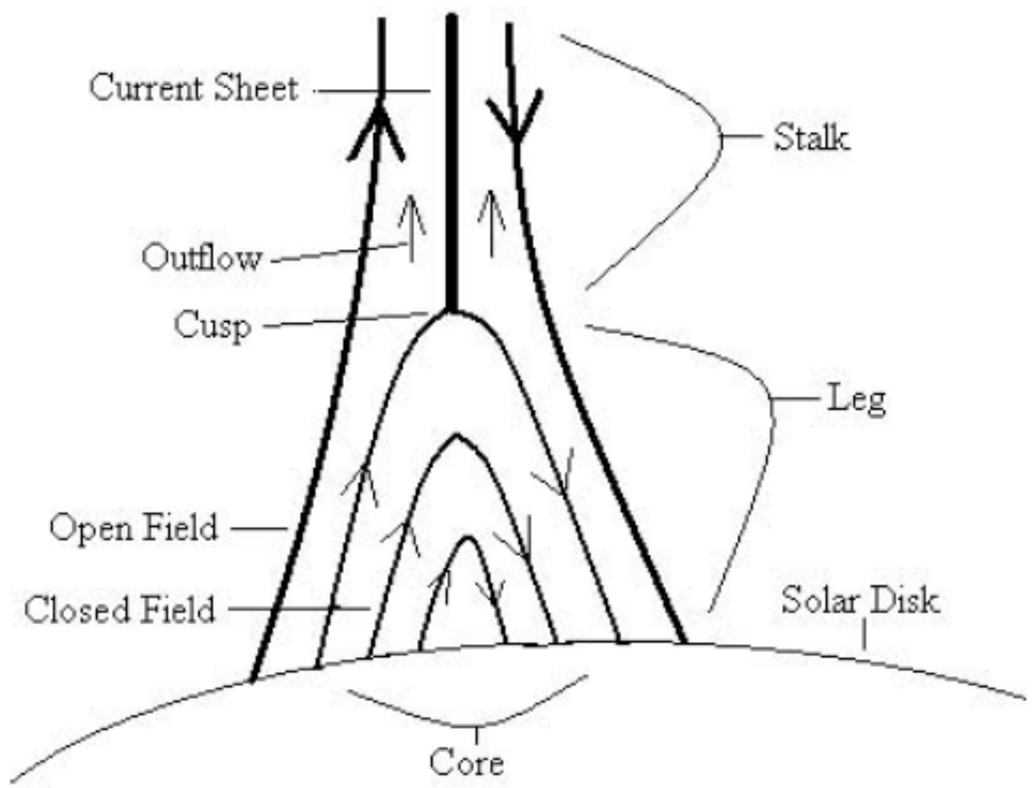
Solar Corona- Streamers and Coronal Holes





Solar Eclipse: India, 24-Oct-1995 04:33:30.000
HAO Eclipse Archive,
http://mlso.hao.ucar.edu/mlso_eclipse_archive.html



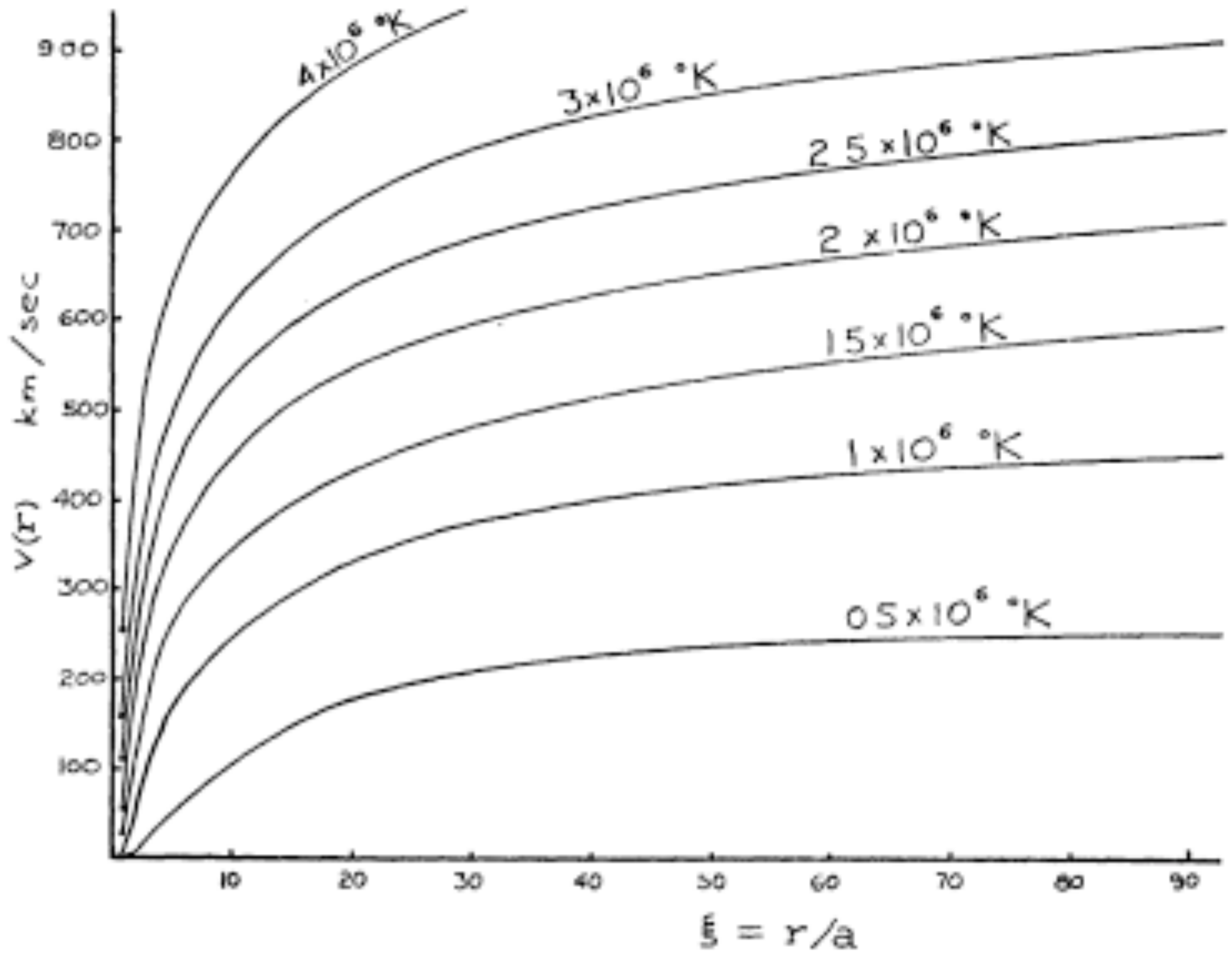
Airapetian, 2011 ; Cottar & Fan, 2009 ; Uzzo, 2006 ; Suess, 2006 ; Gibson, 1999(2) ; Miralles, 1999 ;

Solar Wind

Hydrostatic corona model leads to big overestimate in interplanetary medium properties.

Parker abandoned the static corona and modelled an isothermal expanding atmosphere

Thermally driven outflow
--Solar Wind



Parker, 1958 ; Parker 1965 ; Charbonneau, '*Large Scale Dynamics of the Solar Wind*'

Research Study

- Construct Streamer and Solar Wind solutions by solving the MHD equations numerically.

- We are interested in how Temperature and B-field strength affect:
    - Streamer size
    - Solar wind properties
    - Density contrast between streamers and coronal holes.

Methodology

Solve the MHD equations for a polytropic gas in an axisymmetric spherical geometry

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \mathbf{v}) = 0$$

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\nabla)\mathbf{v}\right) = -\nabla p - \rho\frac{GM_{\odot}}{r^2}\hat{r} + \frac{1}{4\pi}(\nabla \times \mathbf{B}) \times \mathbf{B}$$

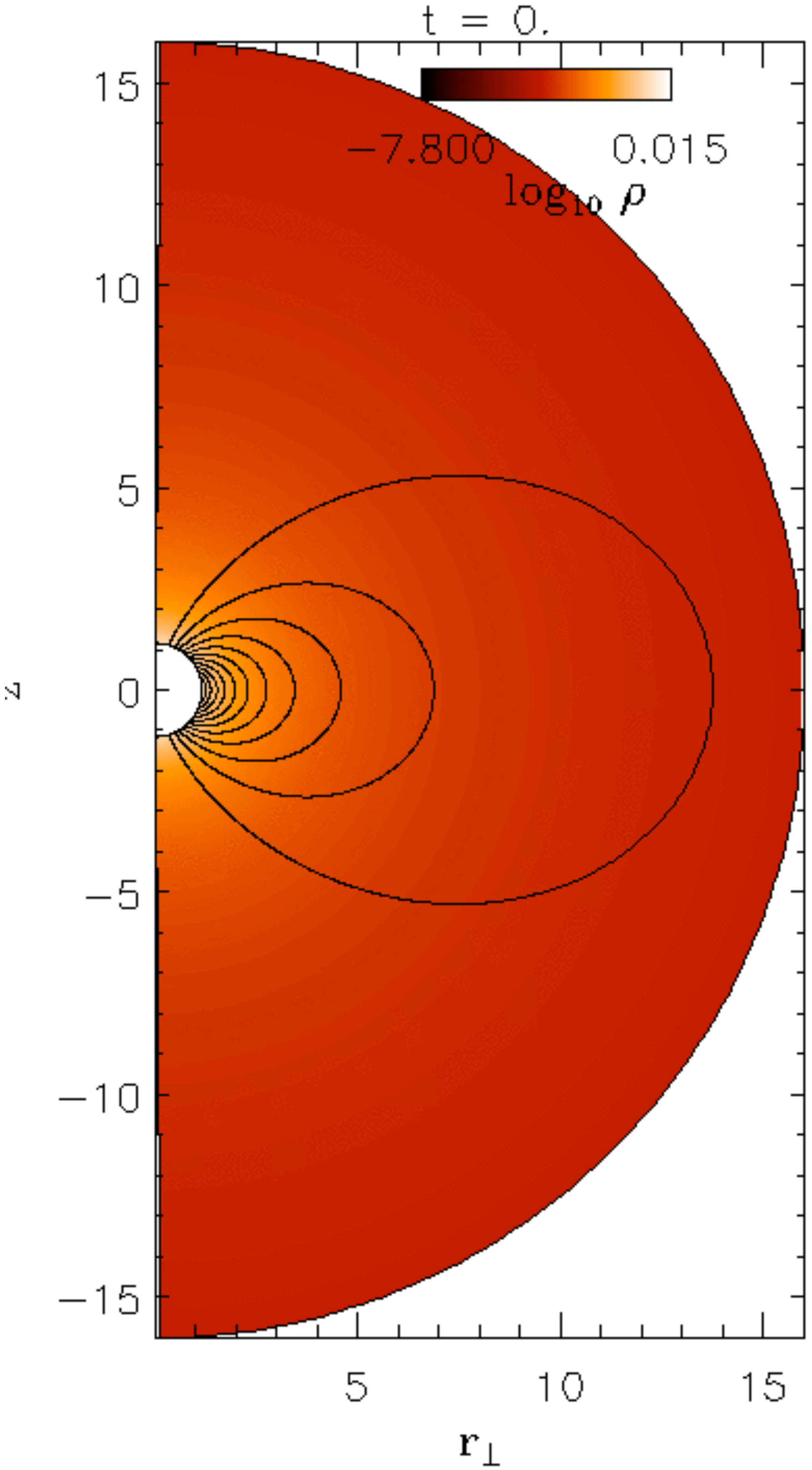
$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B})$$

$$\nabla.\mathbf{B} = 0$$

$$\frac{\partial e}{\partial t} = -\nabla.\left[\left(\epsilon + \rho\frac{v^2}{2} + p\right)\mathbf{v} - \frac{1}{4\pi}(\mathbf{v} \times \mathbf{B}) \times \mathbf{B}\right] - \rho\mathbf{v}.\frac{GM_{\odot}}{r^2}\hat{r}$$

$$p = \frac{\rho R T}{\mu} \qquad \epsilon = \frac{p}{\gamma - 1} \qquad e = \epsilon + \rho\frac{v^2}{2} + \frac{B^2}{8\pi} \qquad \gamma = 1.1$$

Numerical Simulation



Solved on an r, θ, Φ axisymmetric grid.

$r \in [1.15R_\odot, 30R_\odot]$

$\theta \in [0, \pi]$

$v_r, v_\theta, v_\Phi, B_r, B_\theta, B_\Phi, \rho, \epsilon$

Initial State:

Static atmosphere in hydrostatic equilibrium.

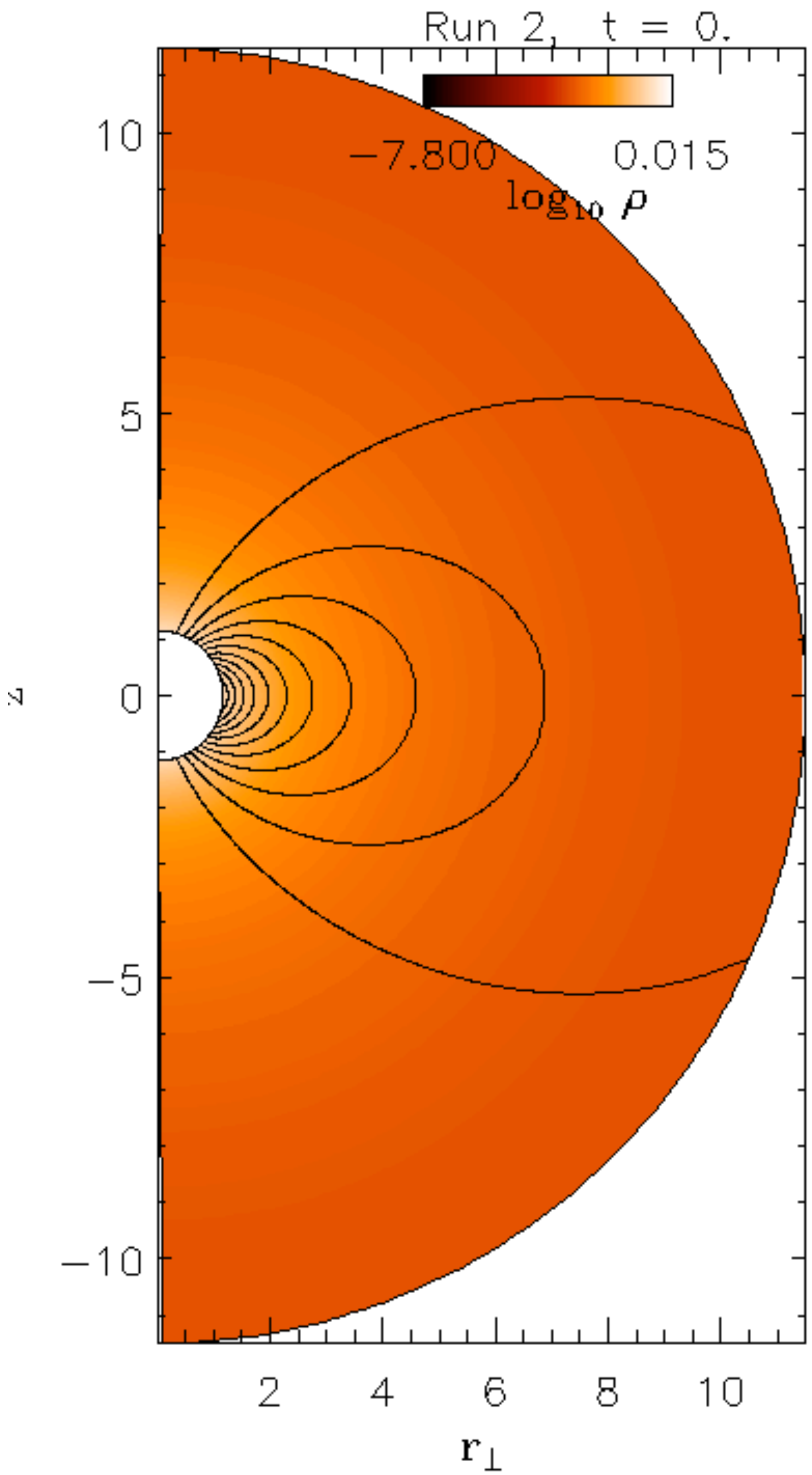
Dipolar potential magnetic field (solar min. conditions).

Drop pressure at outer boundary

Numerical Simulation

$$\mathbf{B} = \frac{1}{r sin\theta}\left[\frac{1}{r}\frac{\partial A}{\partial \theta}\hat{r} - \frac{\partial A}{\partial r}\hat{\theta}\right]$$

Numerical Simulation



$$\mathbf{B} = \frac{1}{r sin\theta}\left[\frac{1}{r}\frac{\partial A}{\partial \theta}\hat{r} - \frac{\partial A}{\partial r}\hat{\theta}\right]$$

What we are looking for

Is the code solving the equations correctly?
--Conservation Laws

What is the velocity of the solar wind?
--Compare the equatorial speed to the coronal hole speed

What is the size of the helmet streamer?
--Density plots ; equatorial velocity ; gas pressure vs magnetic pressure

Are the densities and density contrasts realistic?
--Create a white light coronagraph ; compare to observations

Conservation Laws - MASS & B FLUX

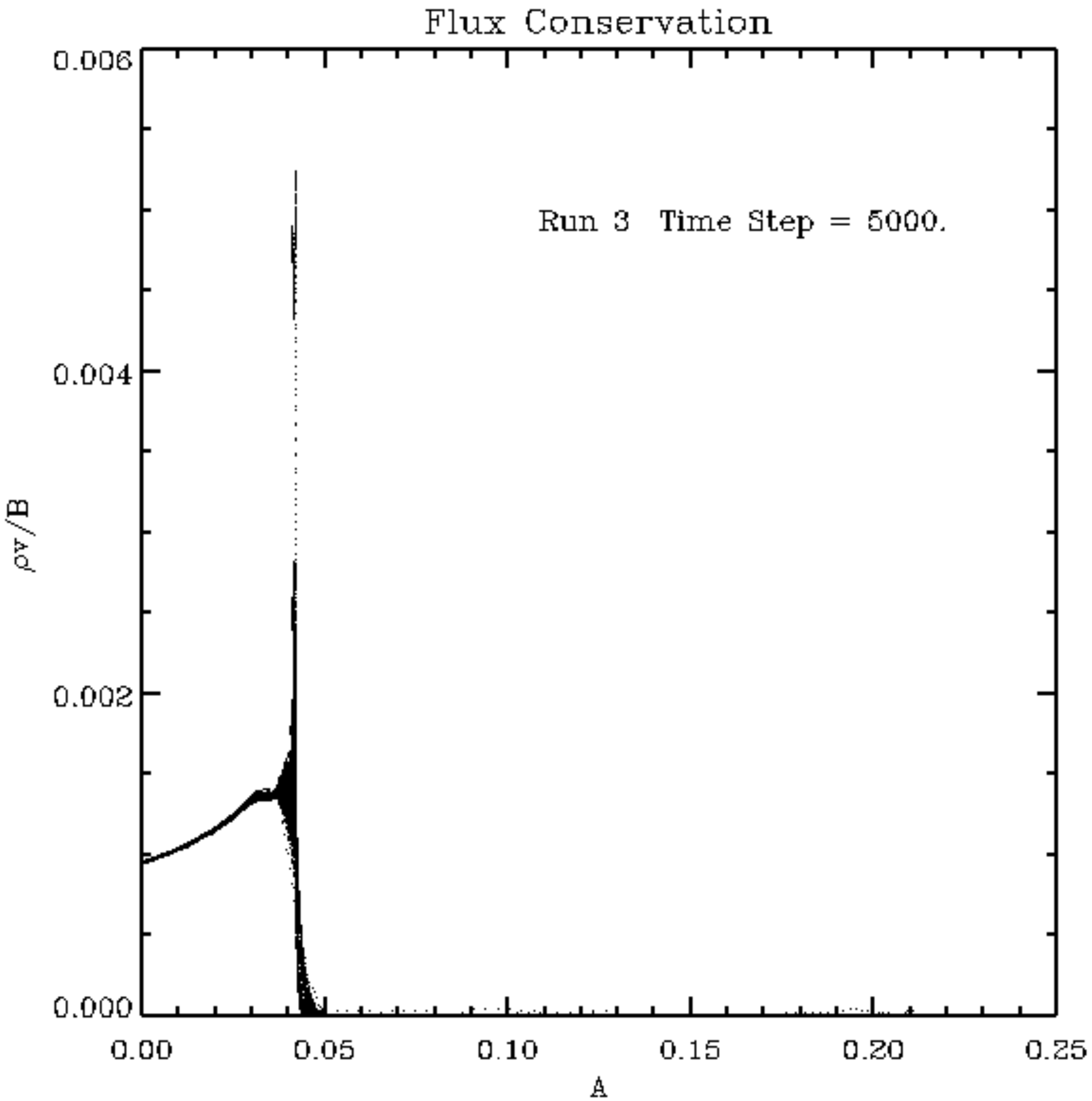
Magnetic flux and mass flux are conserved along flux tubes.

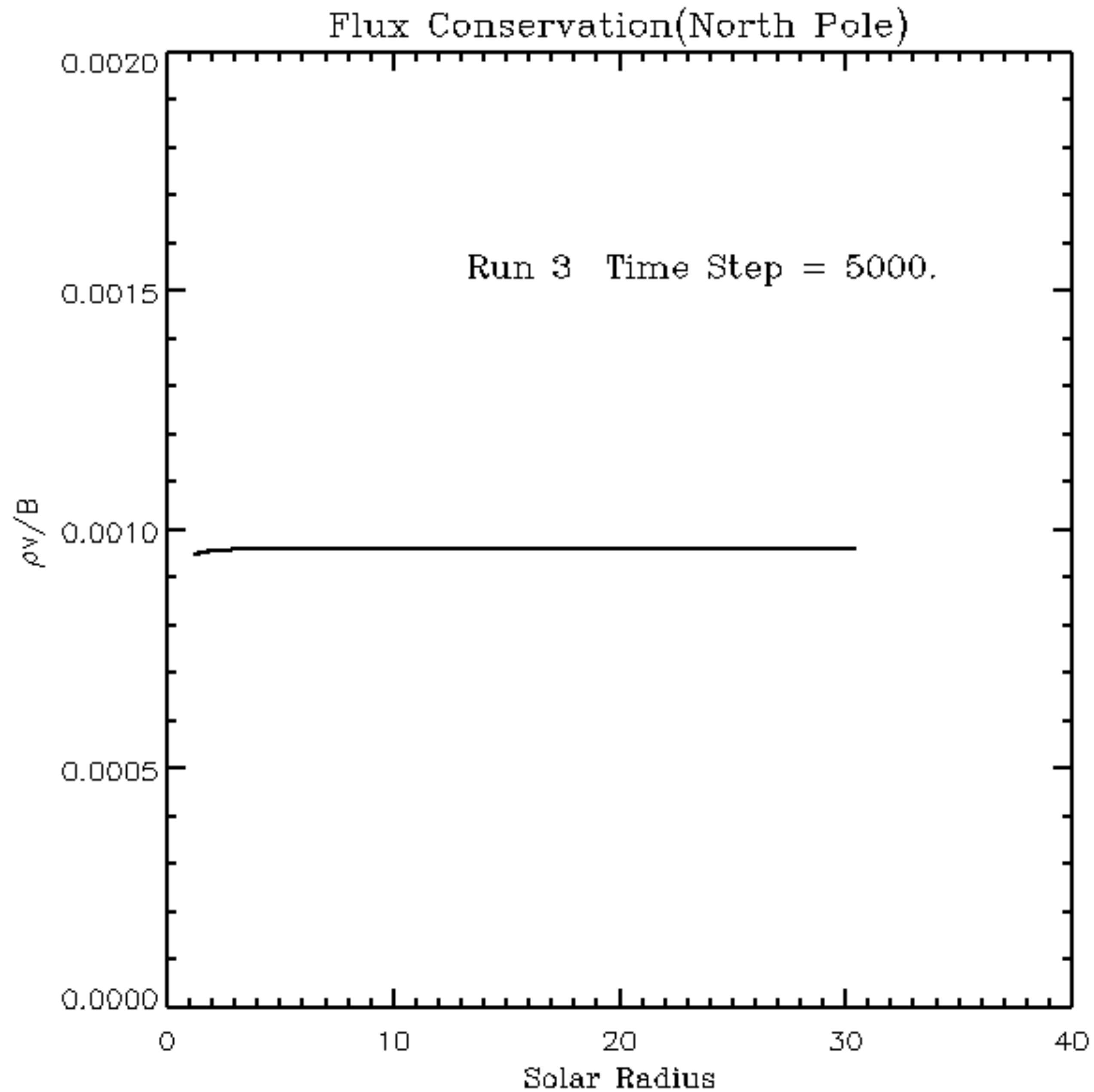
$$A(s)B(s) = A_0 B_0 = C_1$$

$$n(s)v(s)A(s) = n_0 v_0 A_0 = C_2$$

$$\frac{\rho(s)v(s)}{B(s)} = \frac{\rho_0 v_0}{B_0}$$

Conservation Laws - FLUX

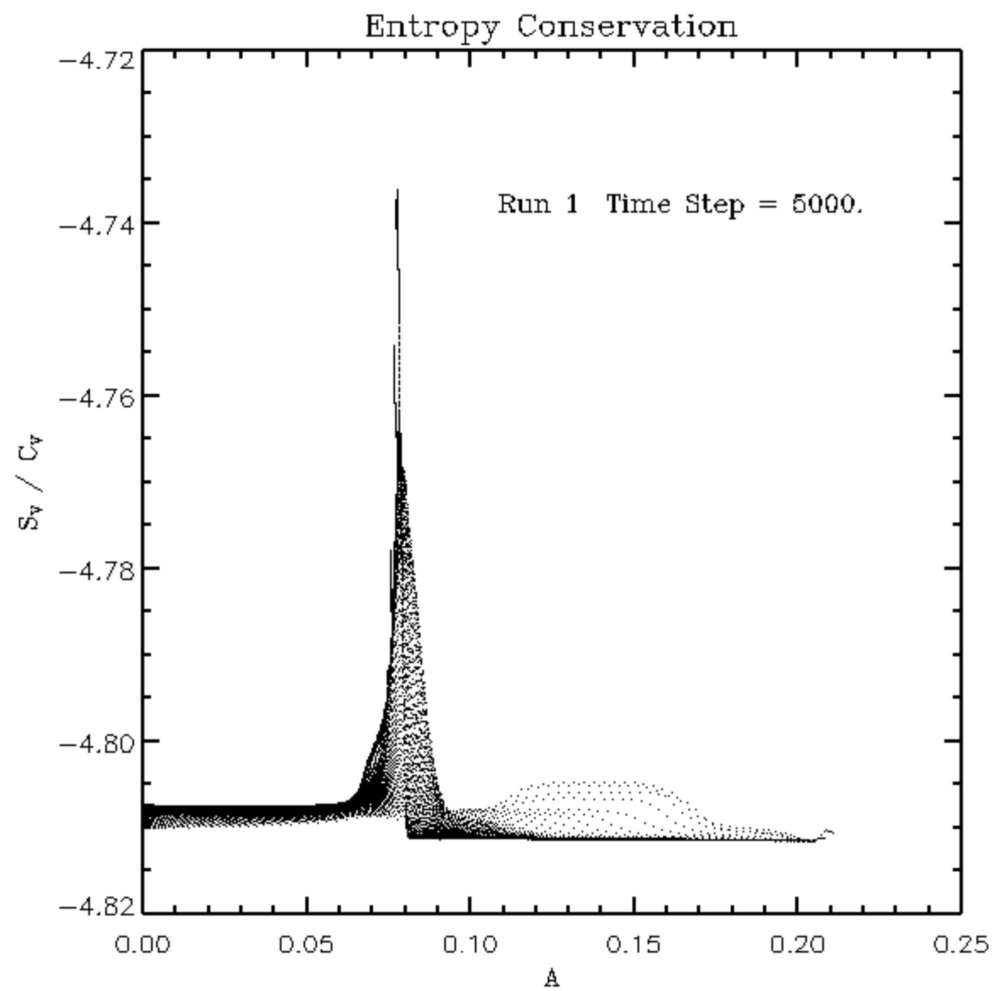


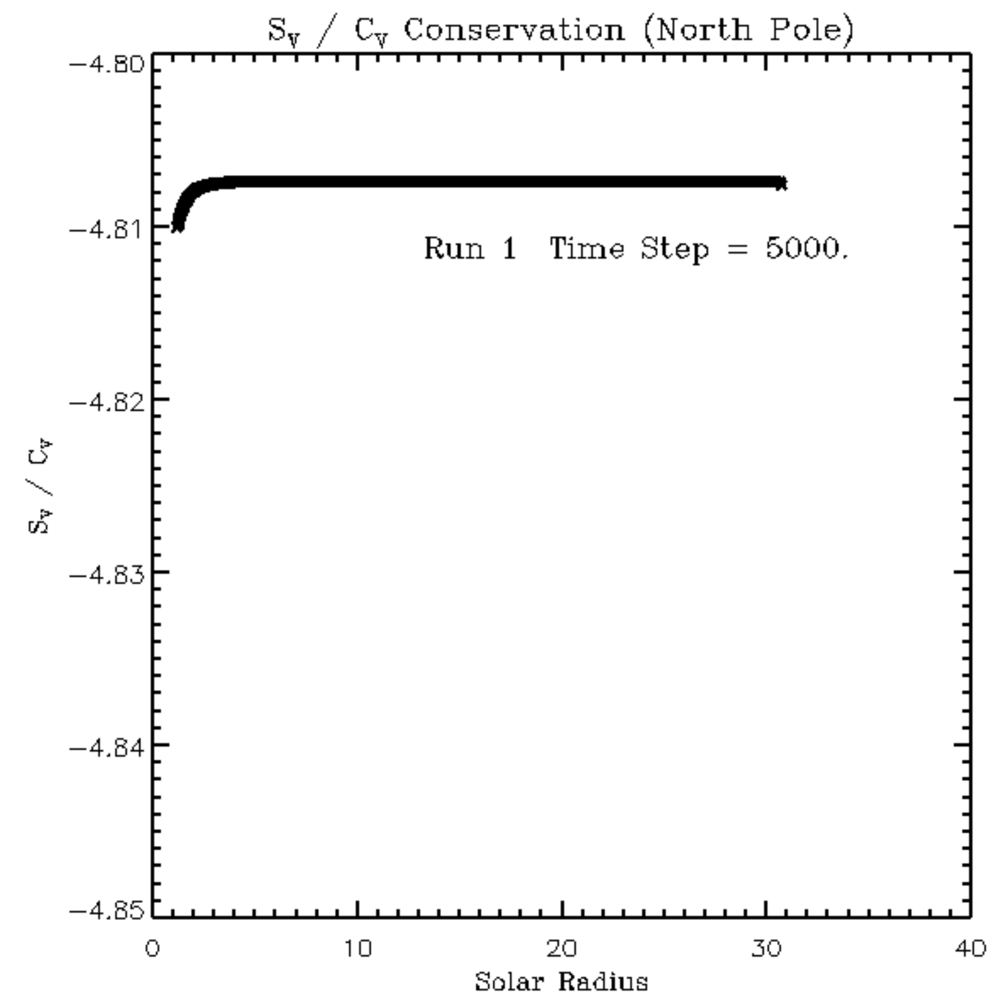


Conservation Laws - ENTROPY

Entropy is conserved along flux tubes

$$\frac{P(s)}{\rho(s)^{\gamma}} = \frac{P_0}{\rho_0^{\gamma}} \qquad \frac{S_V}{C_V} = \ln\left(\frac{P_{(s)}}{\rho_s^{\gamma}}\right)$$





Conservation Laws - BERNOULLI

$$\frac{\rho(s)v(s)}{B(s)} = \frac{\rho_0 v_0}{B_0} \qquad p(s) = \frac{p_0}{\rho_o^\gamma}\rho(s)\gamma$$

$$mnv(s)\frac{\partial v(s)}{\partial s} = -\frac{\partial p}{\partial s} - \frac{GM_\odot mn}{r^2}\hat{r}.\hat{s}$$

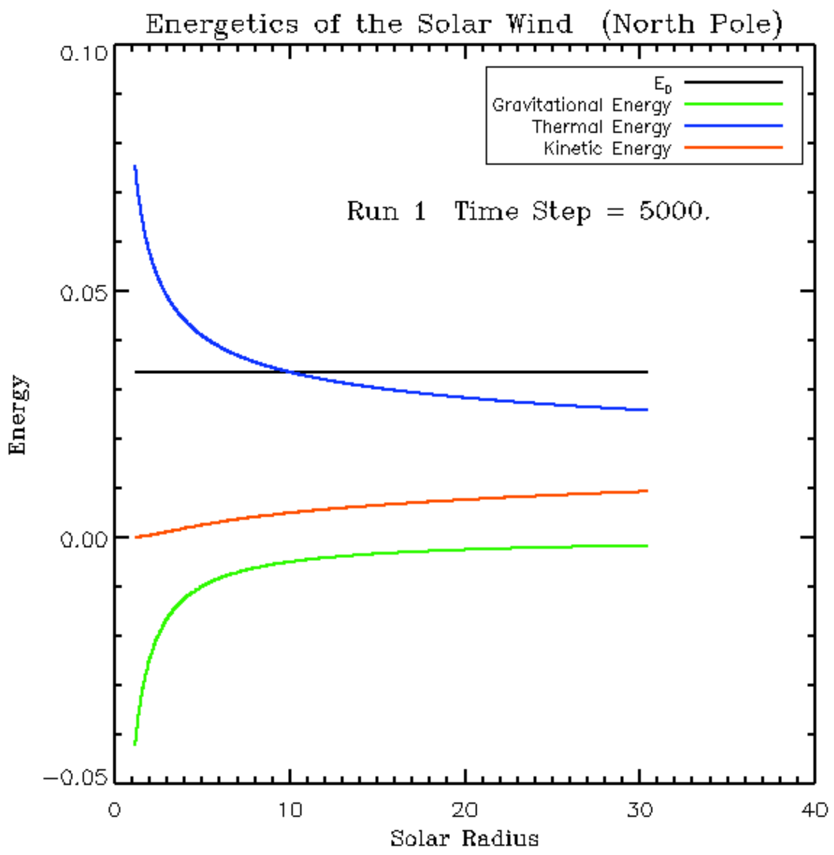
$$\frac{v^2}{2} + \frac{c_s^2}{\gamma - 1} - \frac{GM_\odot}{r} = \frac{v_0^2}{2} + \frac{c_{s_0}^2}{\gamma - 1} - \frac{GM_\odot}{R_\odot} = E_0$$

Kinetic Energy

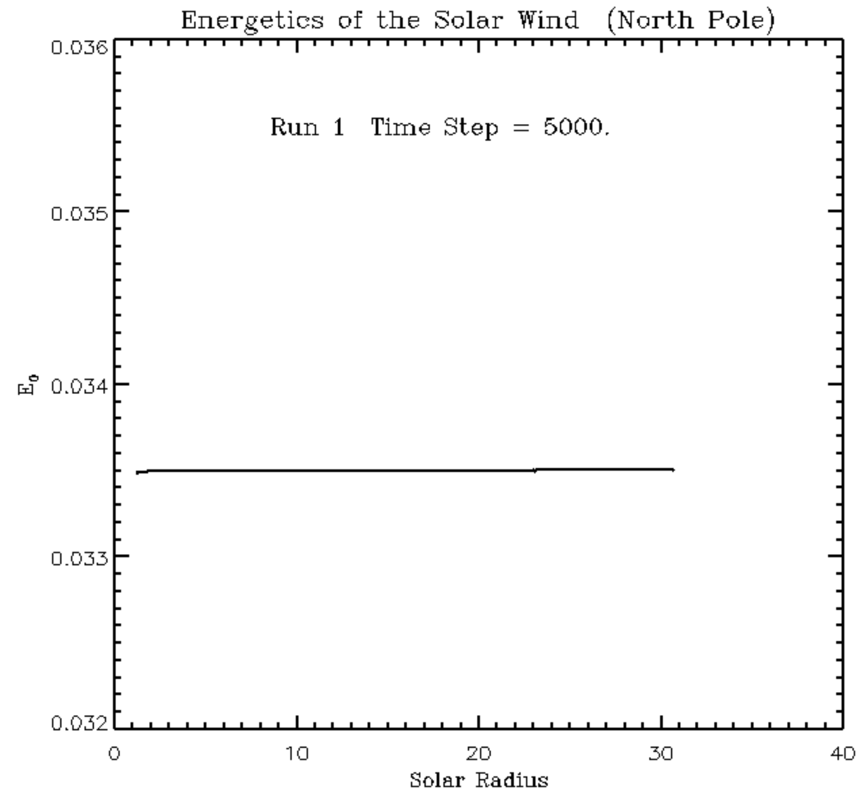
Thermal Energy

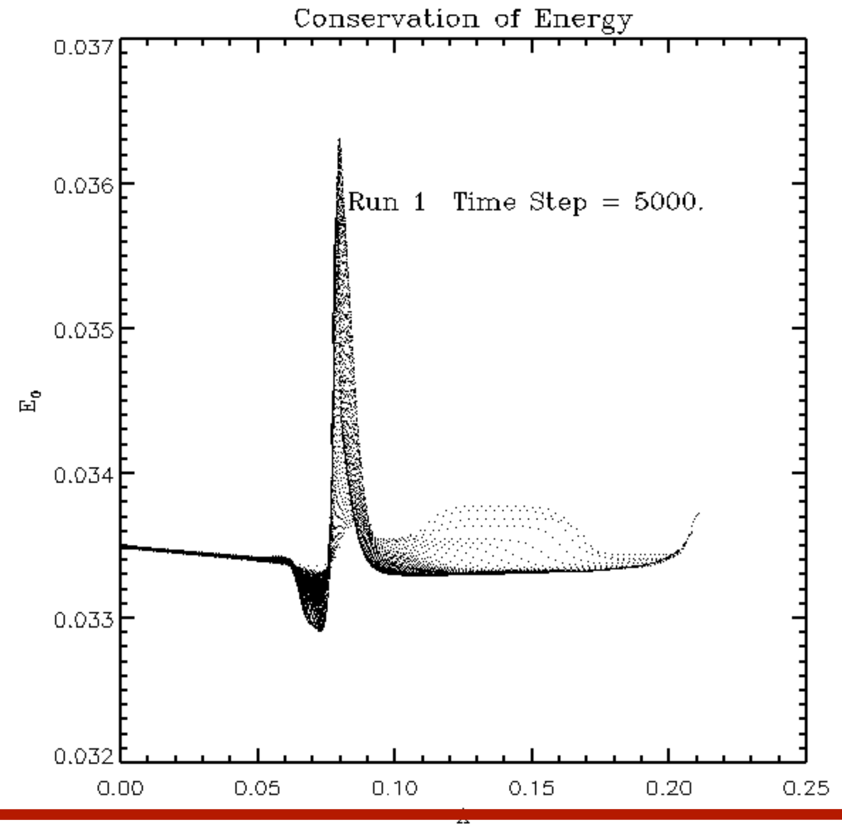
Gravitational Energy

Conservation Laws - ENERGY



$$\frac{v^2}{2} + \frac{c_s^2}{\gamma - 1} - \frac{GM_\odot}{r} = E_0$$





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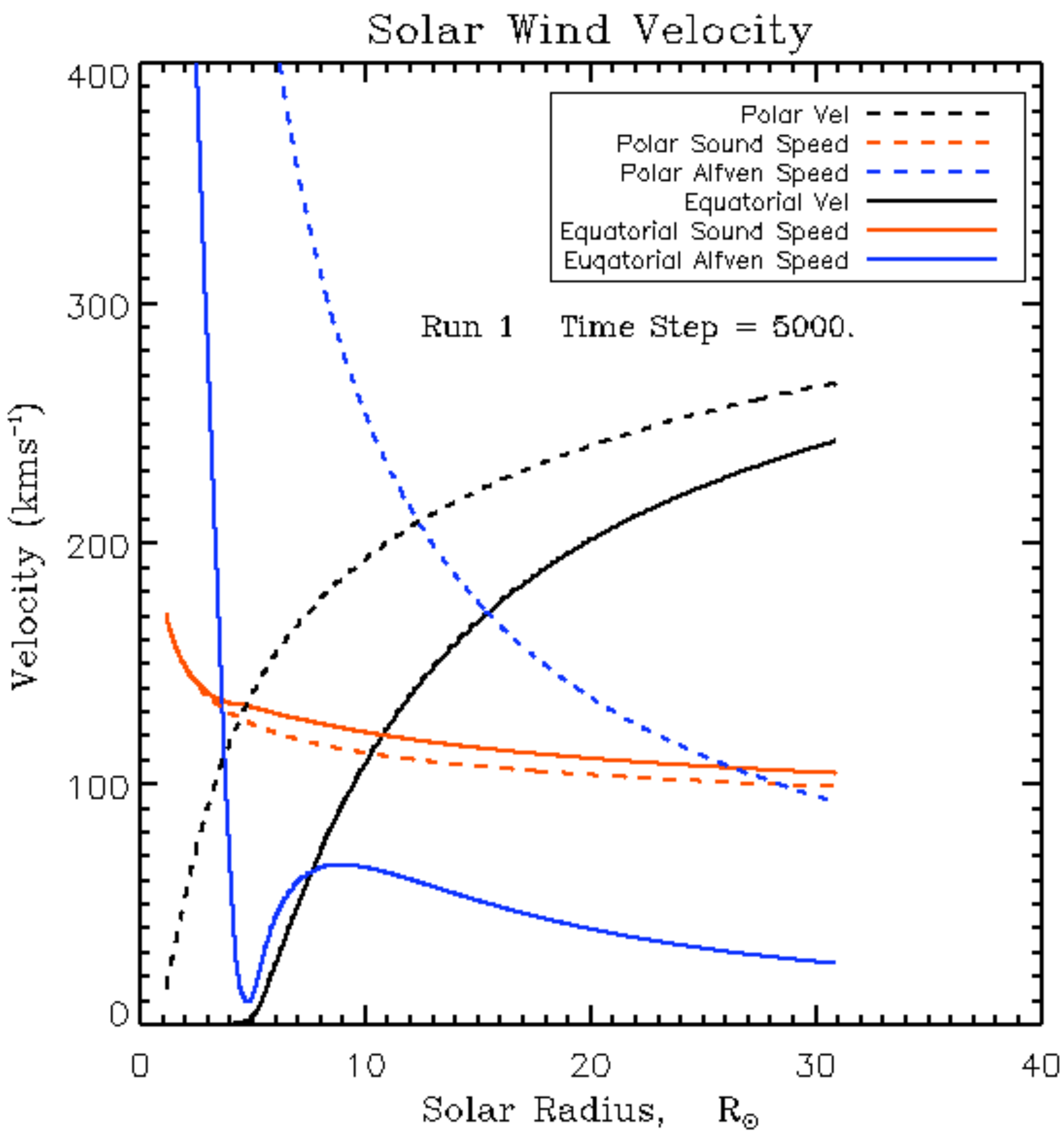
Velocity



Polar Vel

Polar Cs

Polar Valf

Equa Vel

Equa Cs

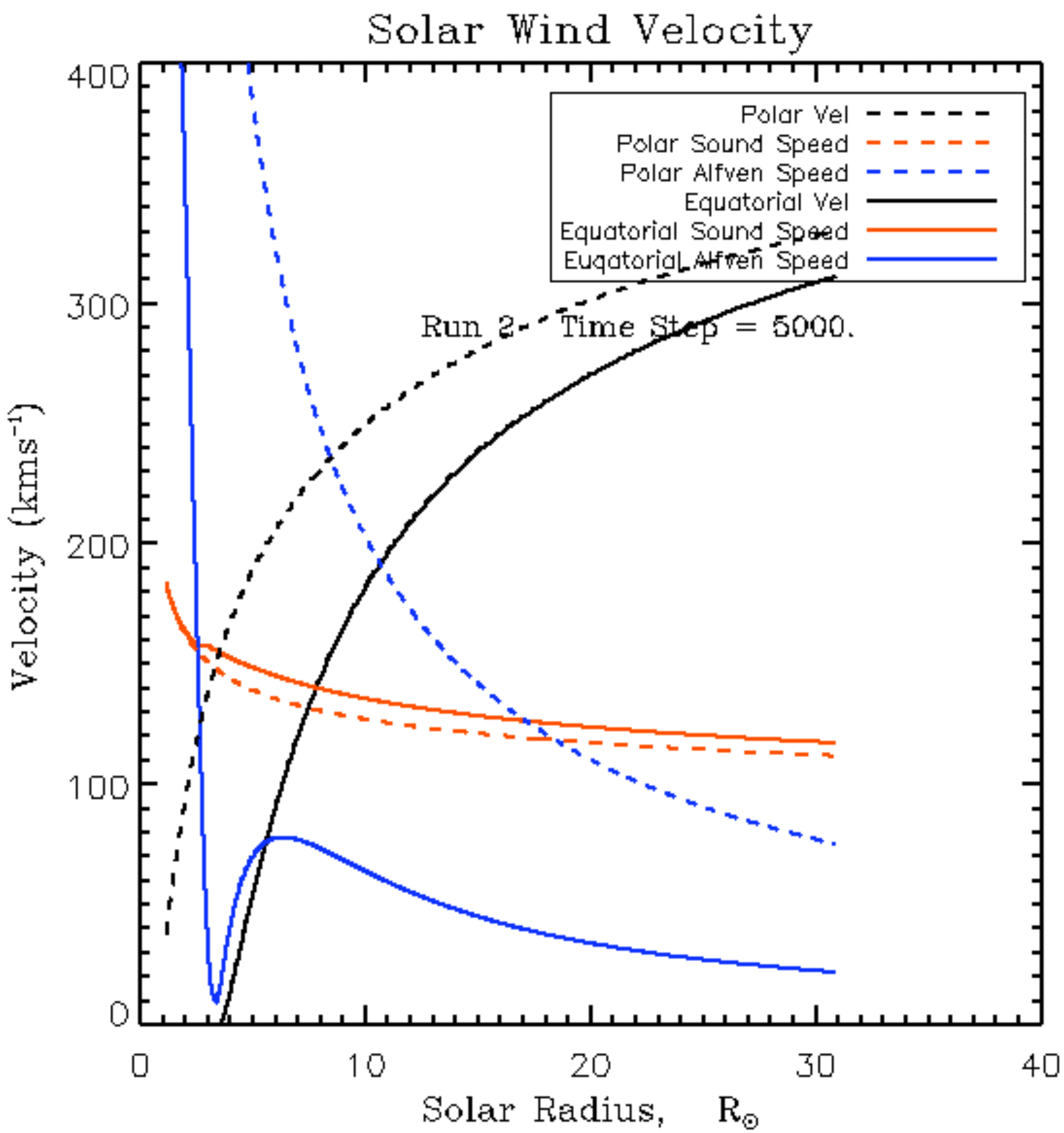
Equa Valf

Velocity

Polar Vel --------
Polar Cs --------
Polar Valf --------

Equa Vel ______
Equa Cs ______
Equa Valf ______

Velocity



Polar Vel

Polar Cs

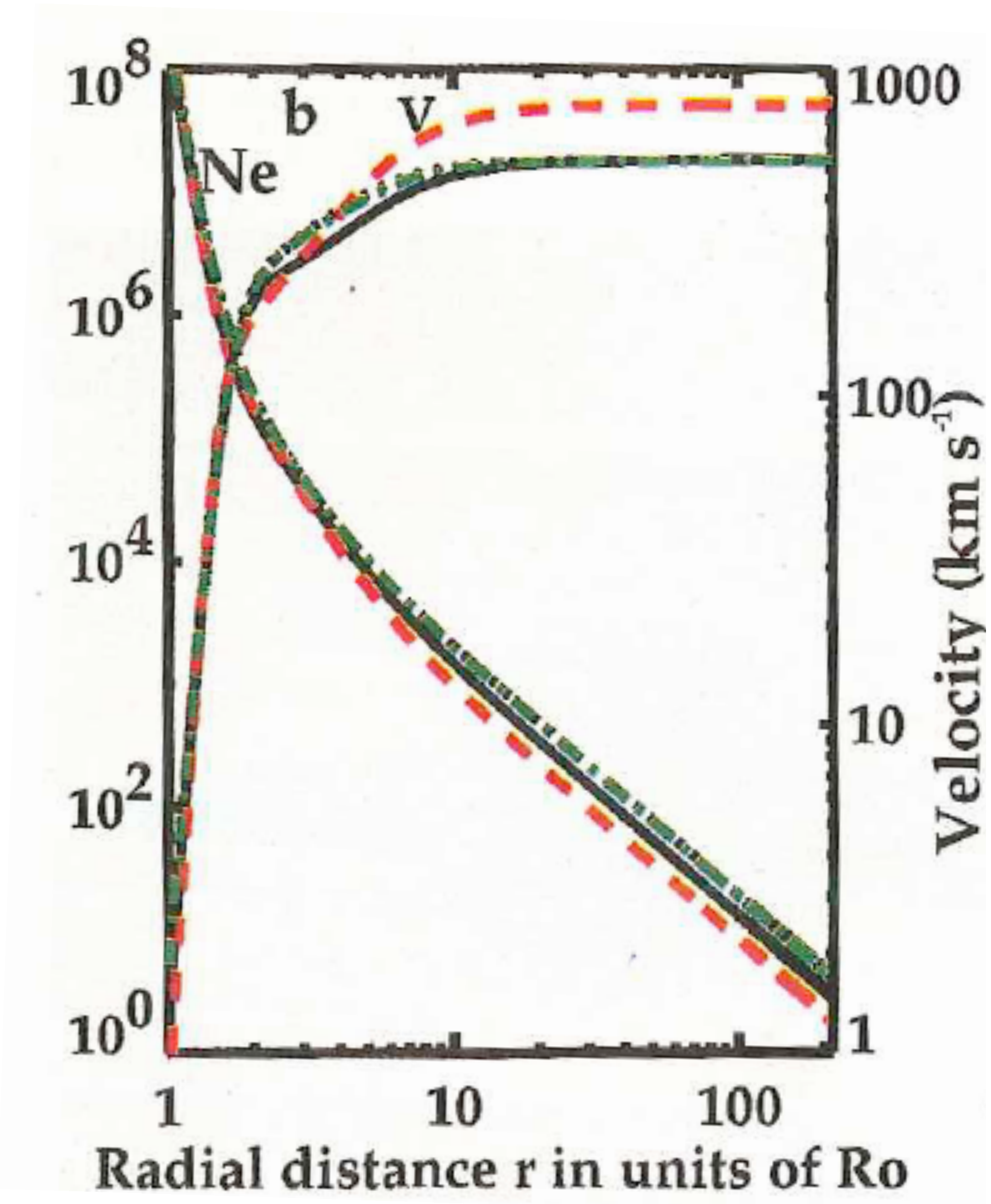
Polar Valf

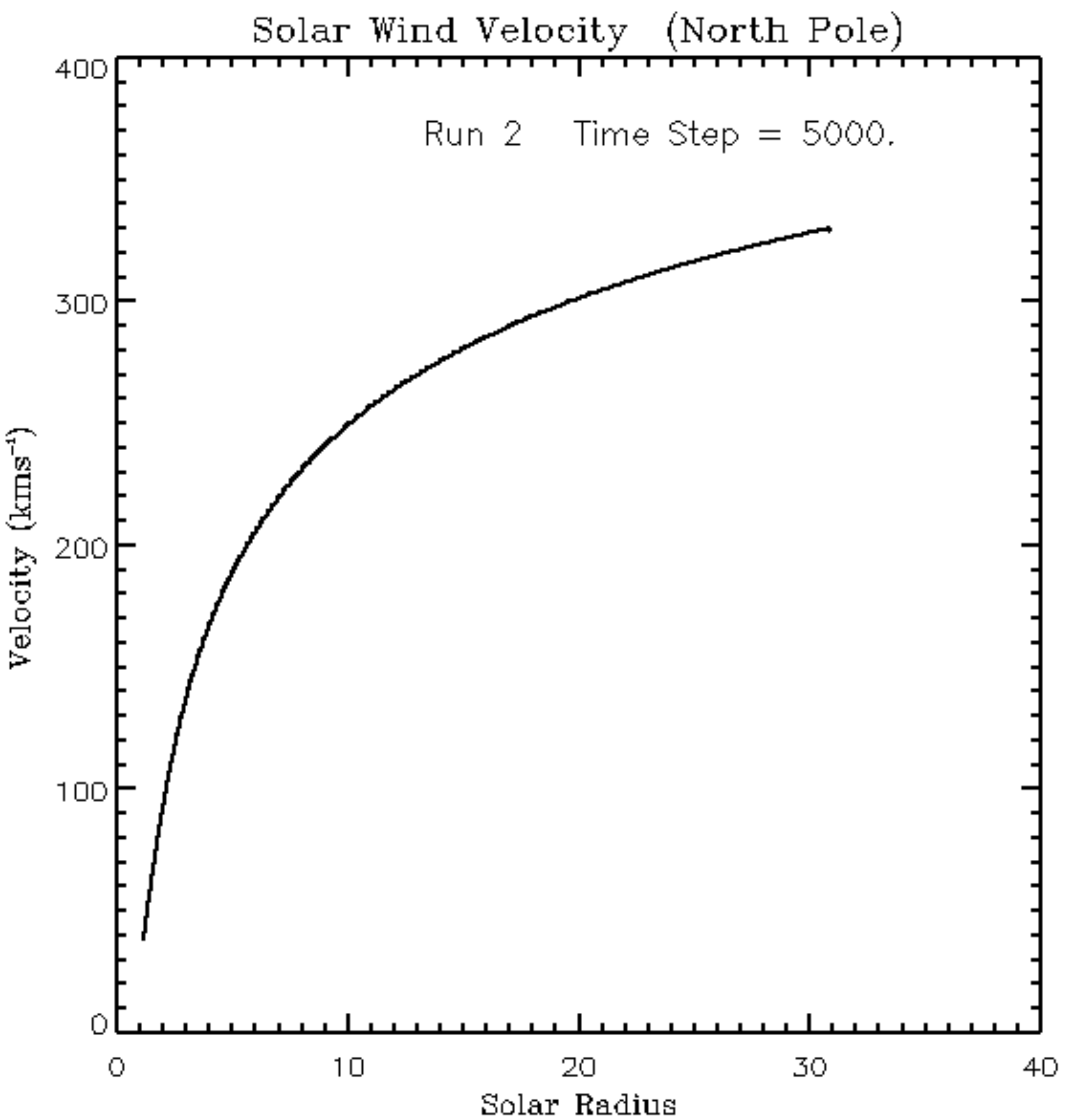
Equa Vel

Equa Cs

Equa Valf

Velocity





Guhathakurta et al, 1999

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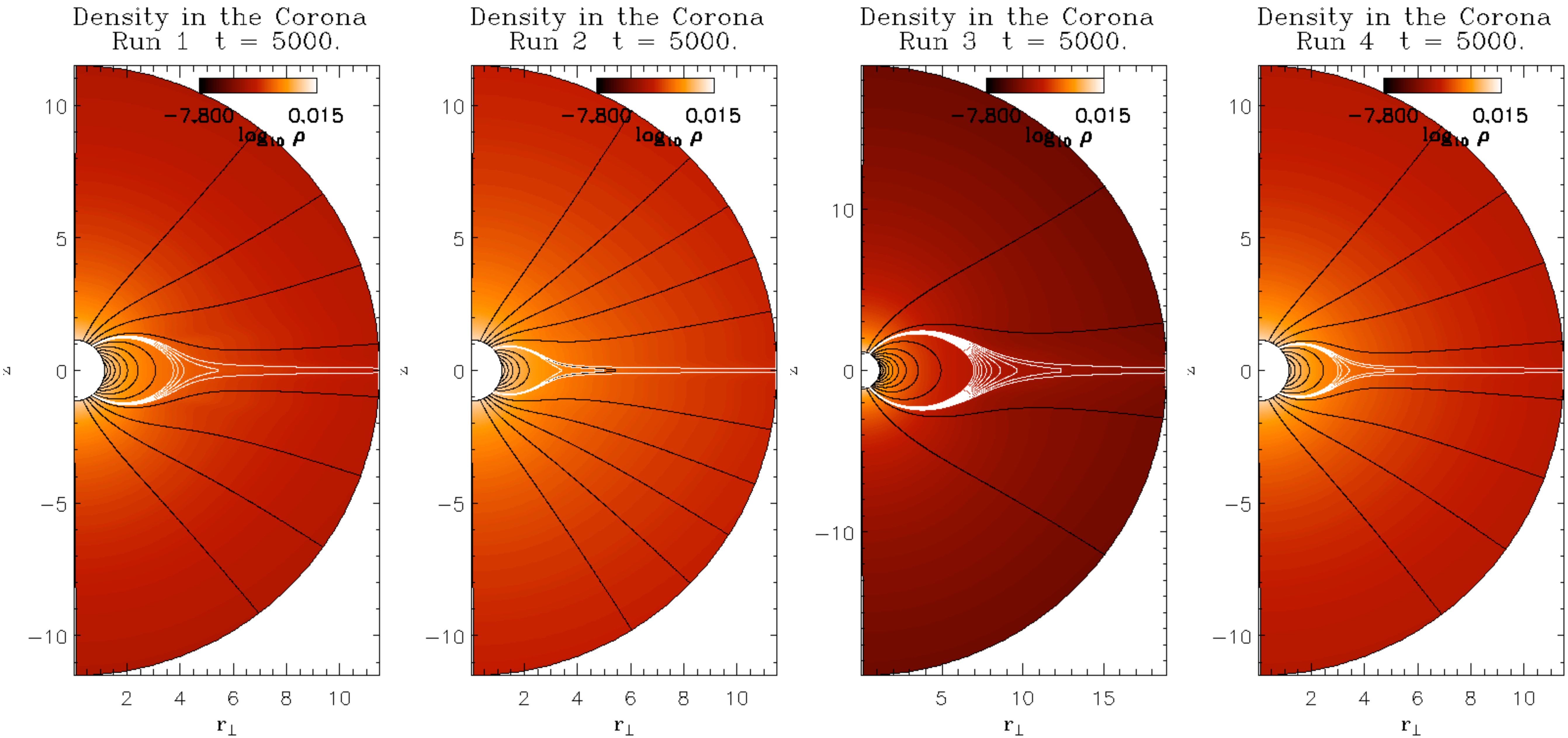
Helmet Streamer Size - Density Plots



Run 1	Run 2	Run 3	Run 4
T: 1.75 MK	T: 2 MK	T: 1.5MK	T: 1.75 MK
B: 10 G	B: 10 G	B: 10 G	B: 5 G
size: ~3.44 $R_\odot$	size: ~2.39 $R_\odot$	size: ~6.53 $R_\odot$	size: ~ 2.30 $R_\odot$

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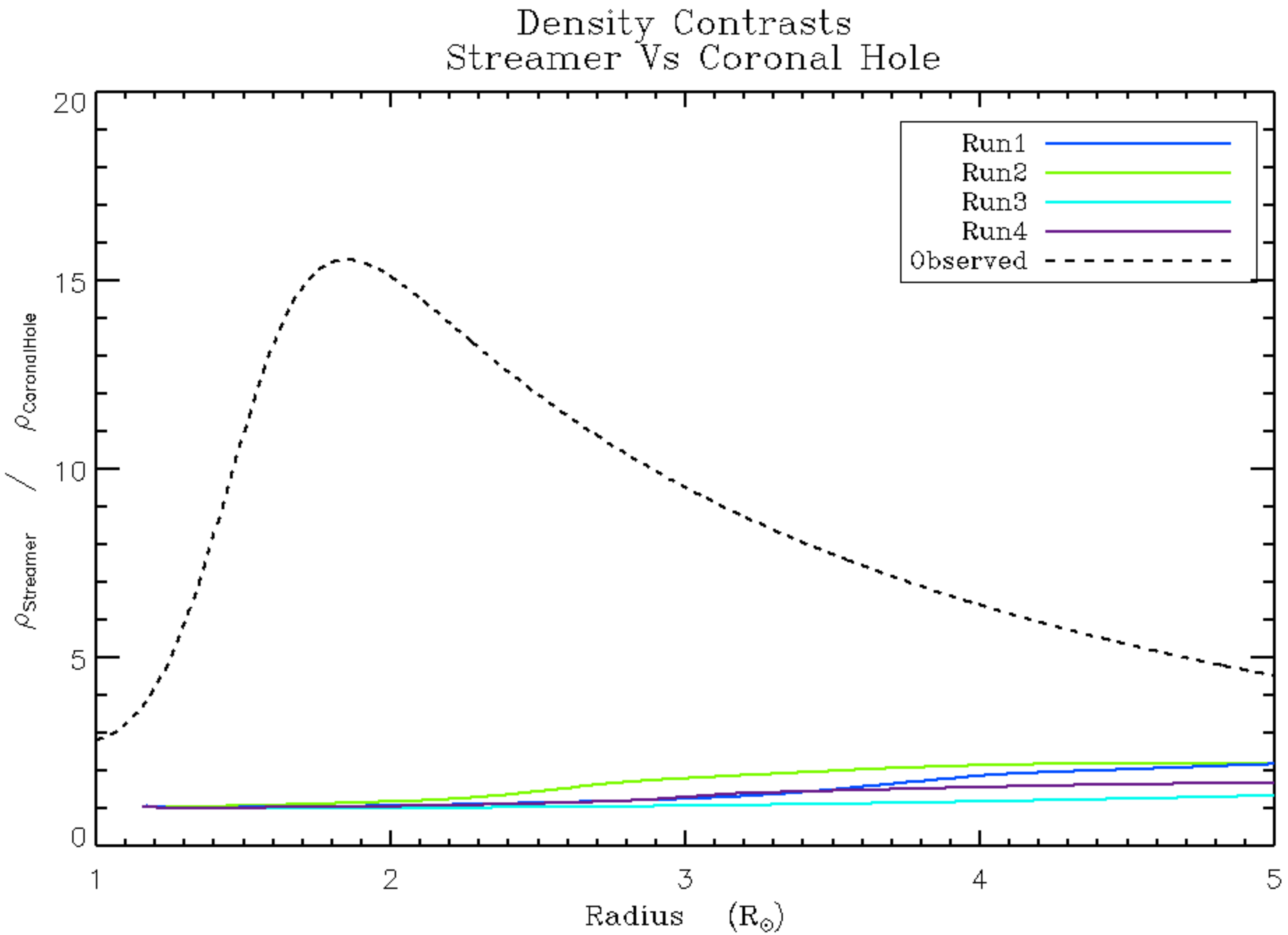
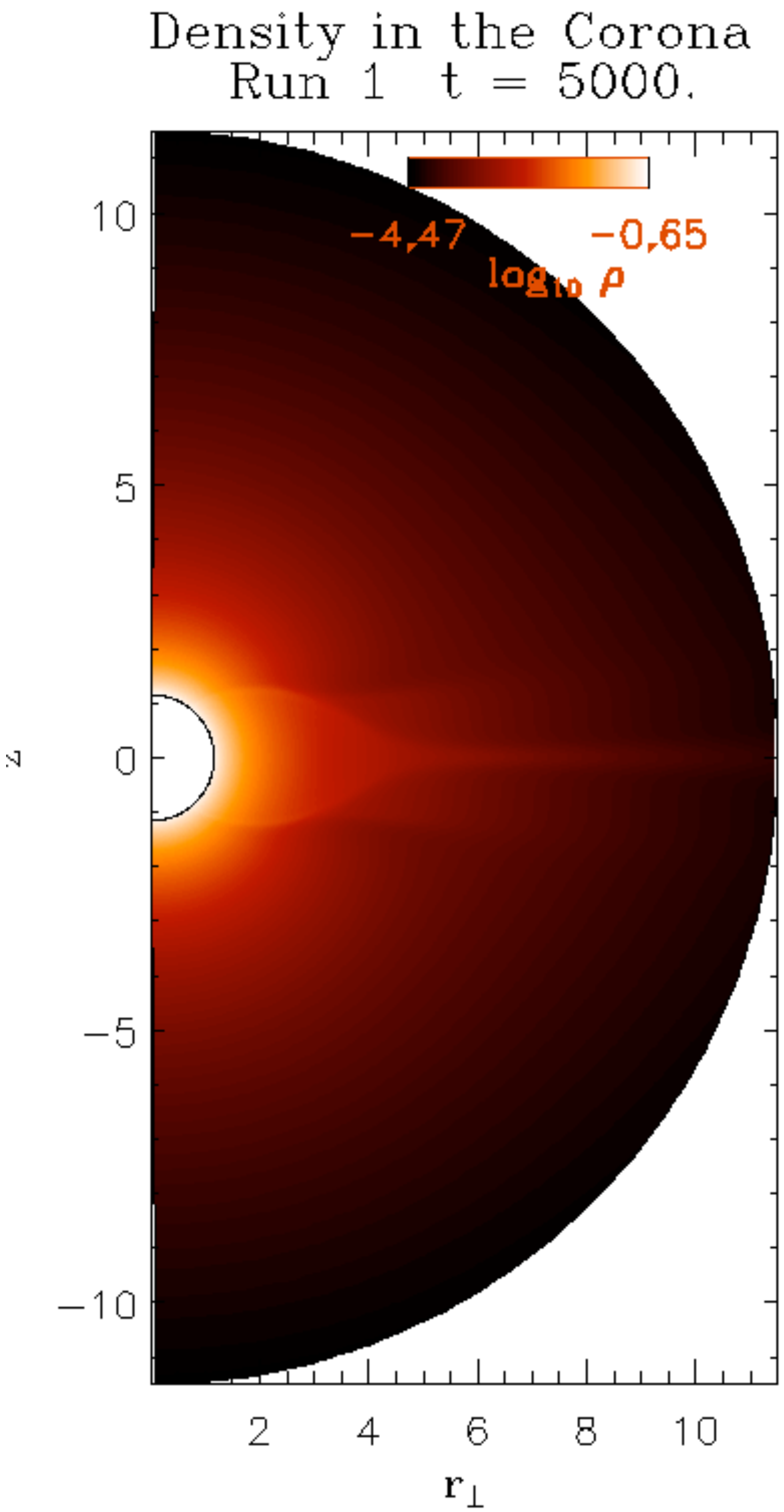
Density Contrasts



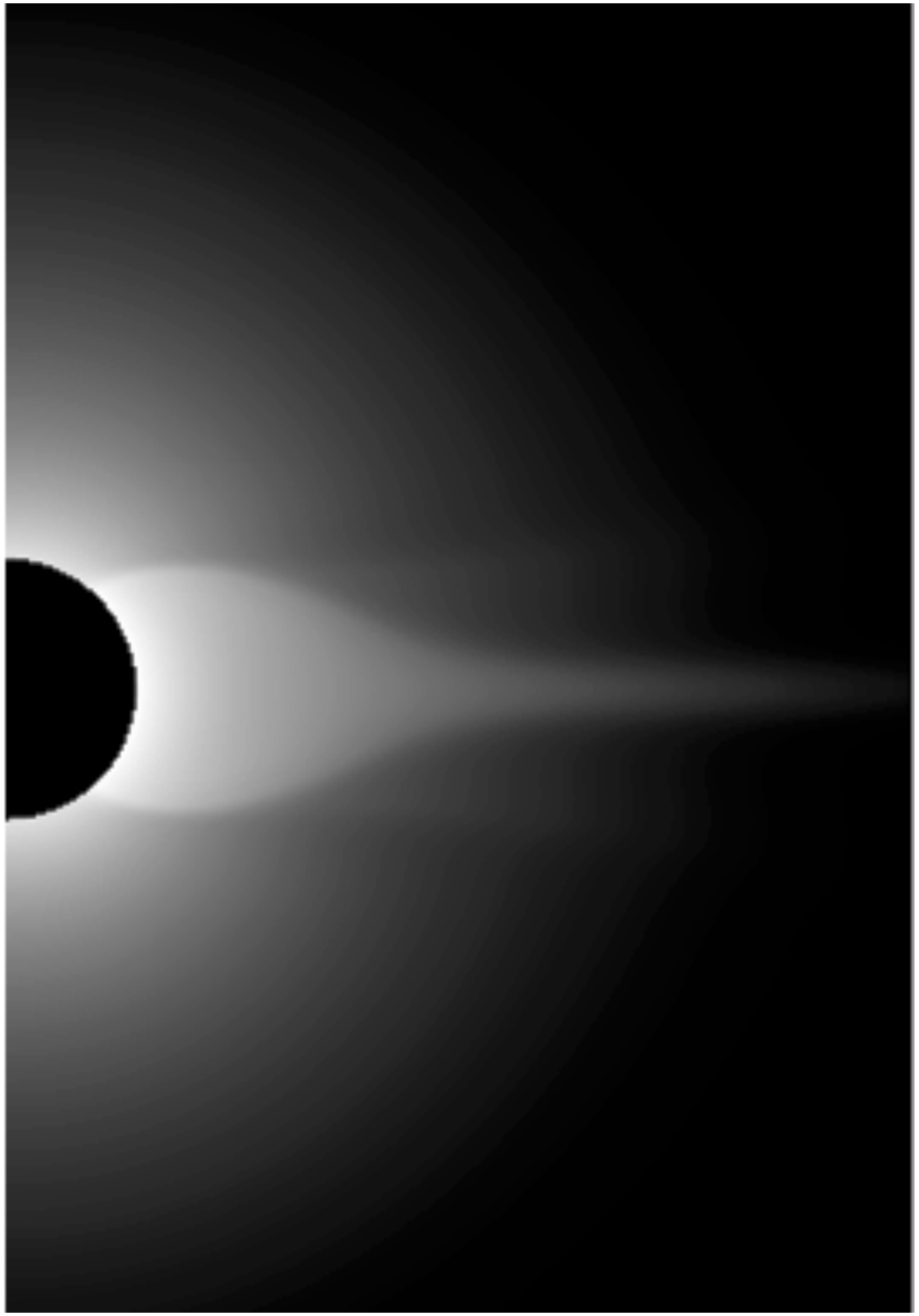
Guhathakurta, 1999 ; Gibson, 1999

Dynamical Adjustments



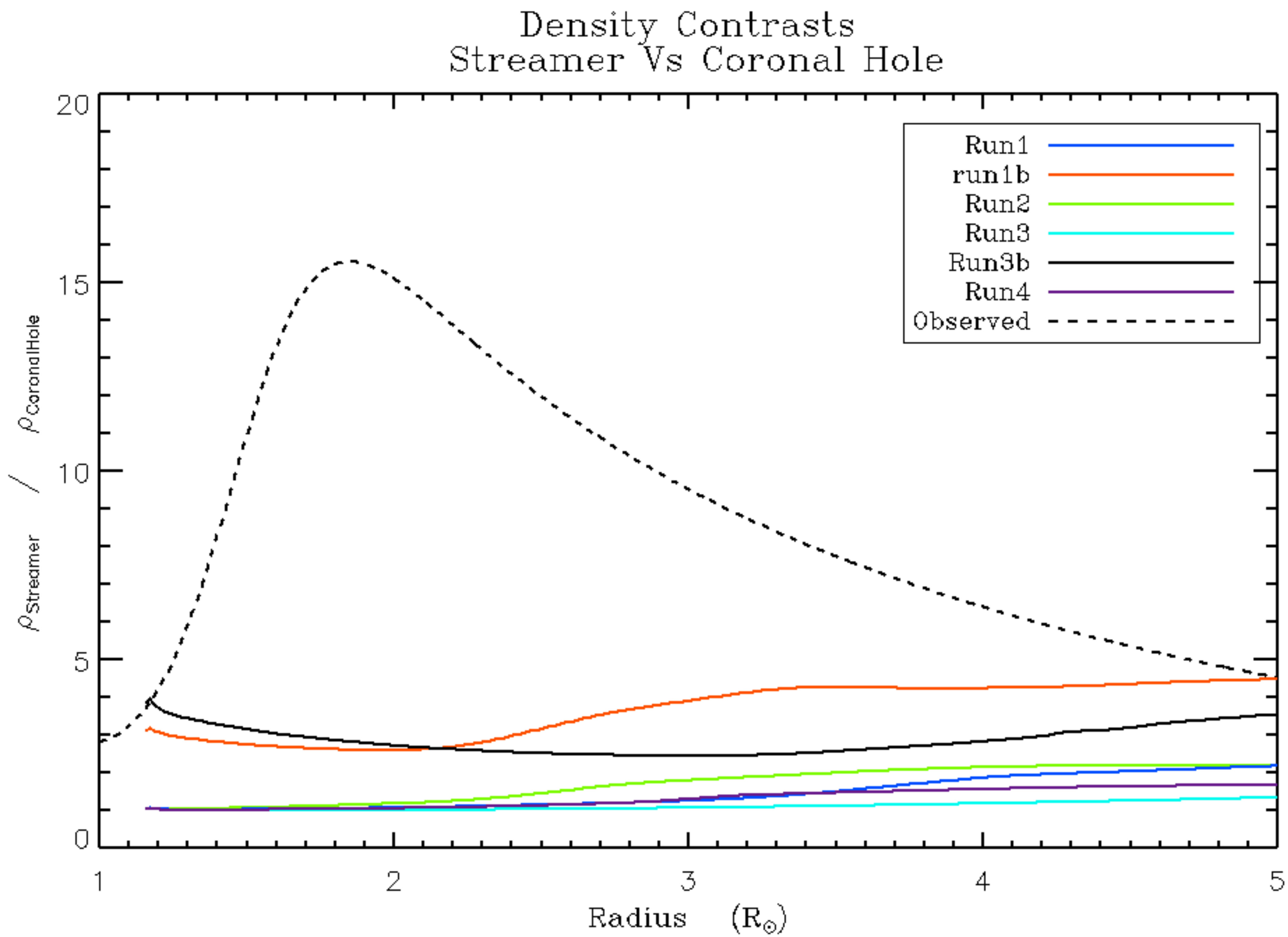
White Light Coronagraph

$$pB(x,y) = \int_{l.o.s.} C(r)n(r,\theta,\phi)ds$$



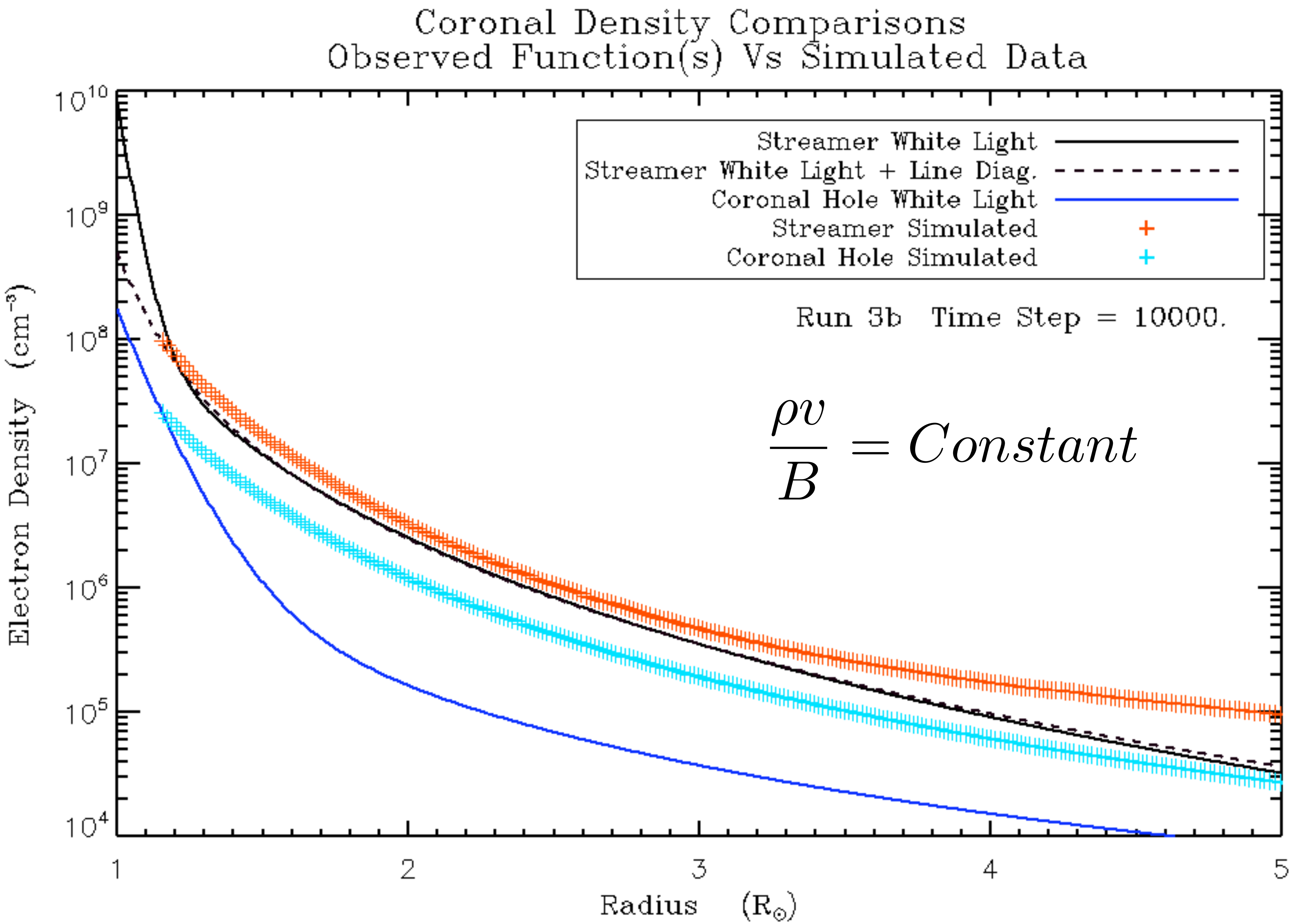
Van De Hulst, 1950 ; Billings, 1966

Density Contrasts Revisited



Guhathakurta, 1999 ; Gibson, 1999

Density - Comparing to observations



Guhathakurta, 1999 ; Gibson, 1999

Conclusions

- Code successfully solved the MHD equations for a polytropic gas.
- Although we could not match the density contrasts we understand why.
- Good position to start modelling CME release from streamers
- Beyond polytrope:

  Thermal conduction

  Non- adiabatic heating

  Additional energy deposition

  Relax single-fluid assumption

Acknowledgements

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Questions