The role of the bow shock in Solar wind-Magnetosphere coupling

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How do we think about the Solar wind-Magnetosphere interaction?

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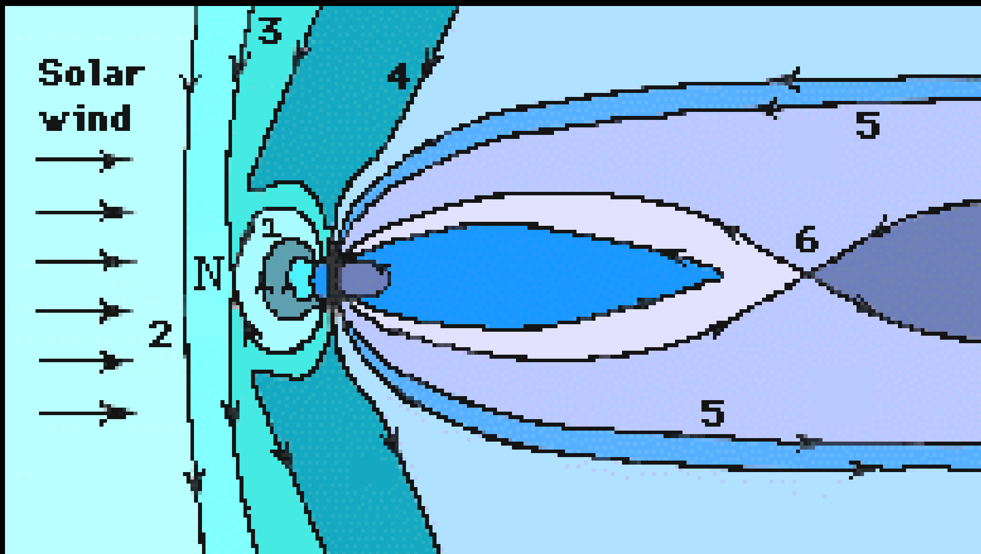

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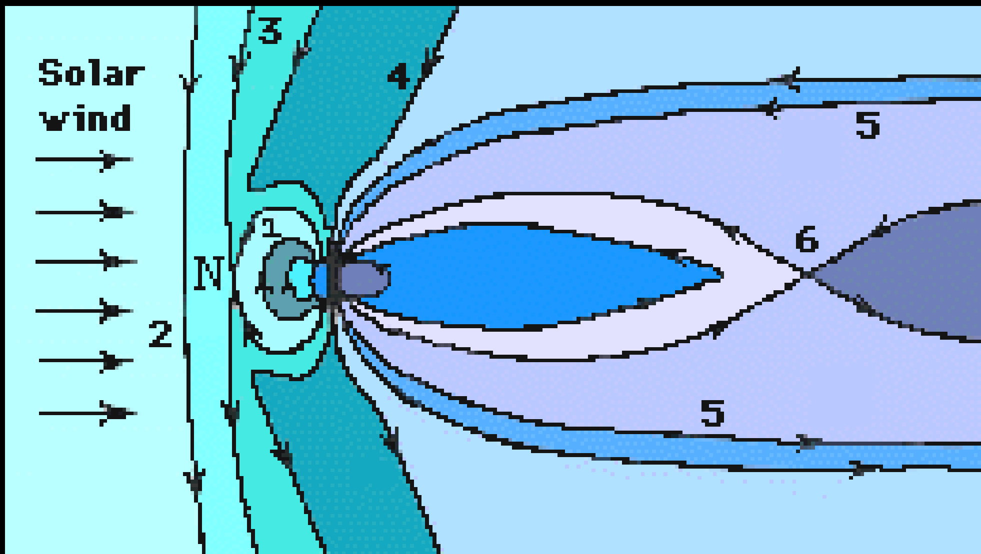

Dungey [1961]
Reconnection

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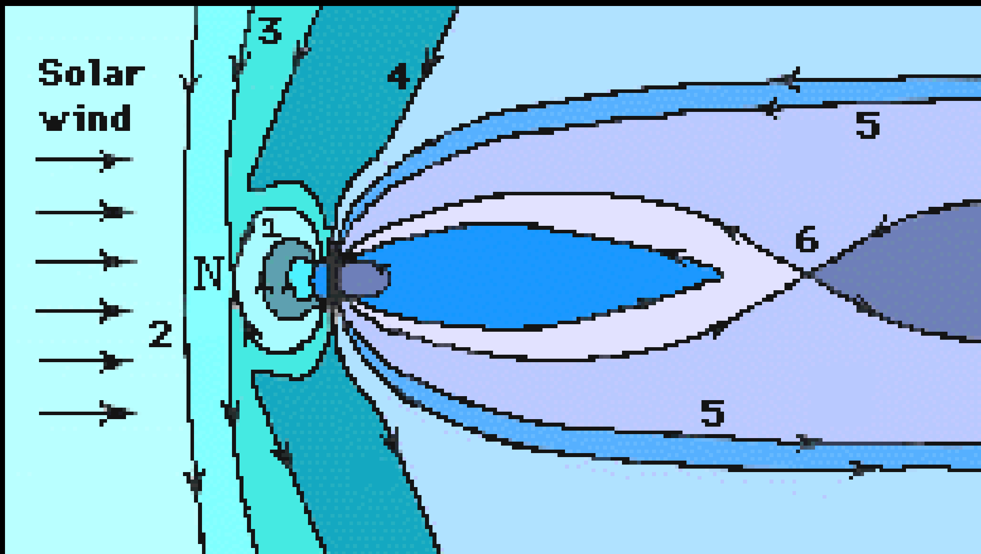

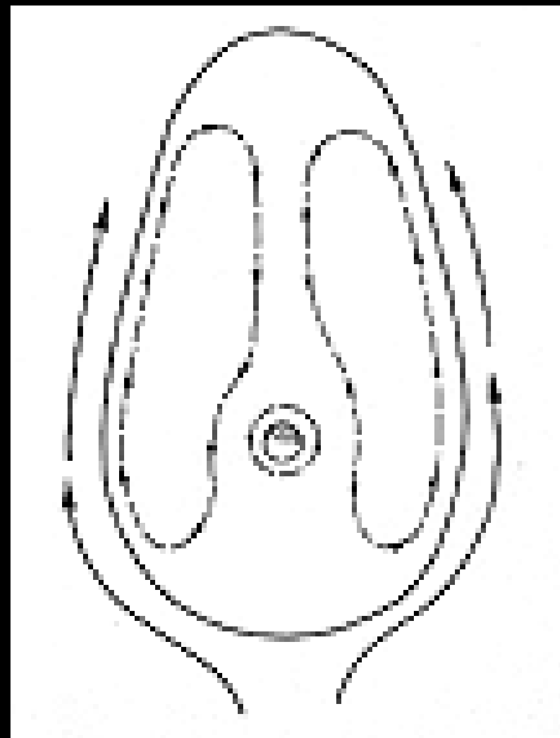

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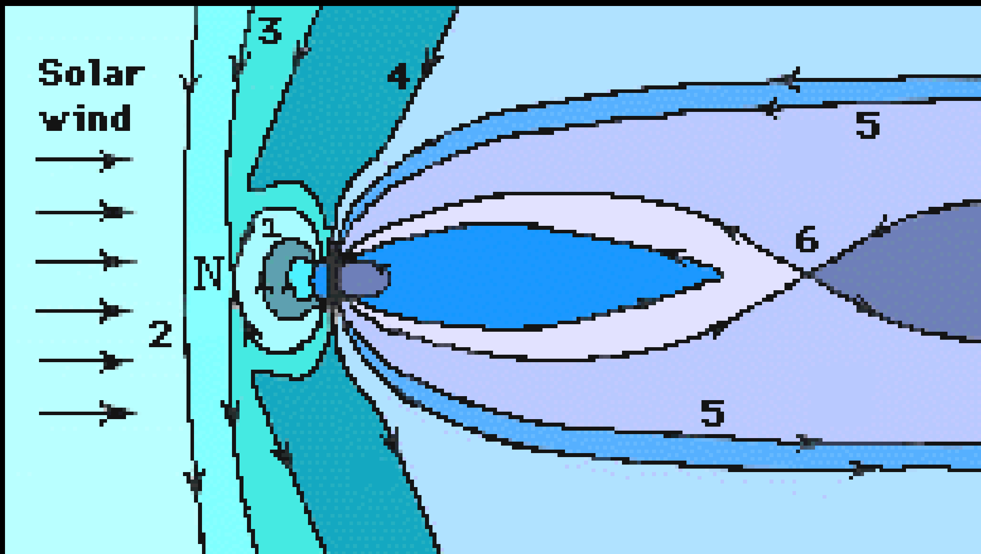

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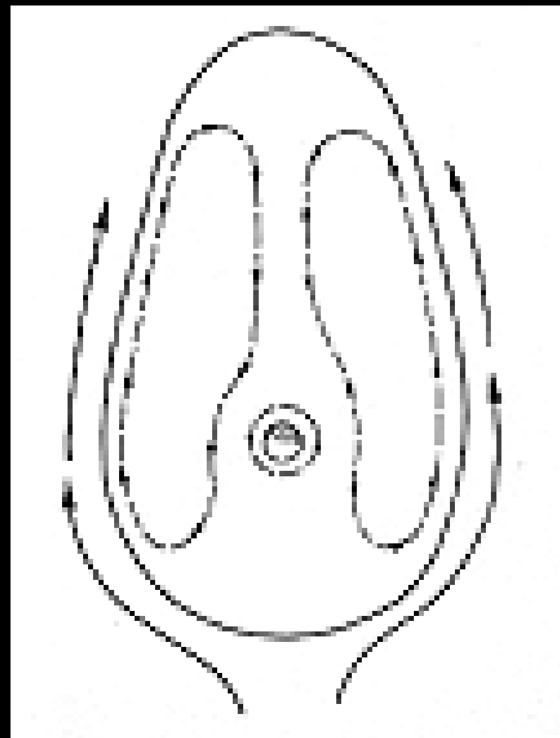


Axford and Hines (1961)
Viscous interaction

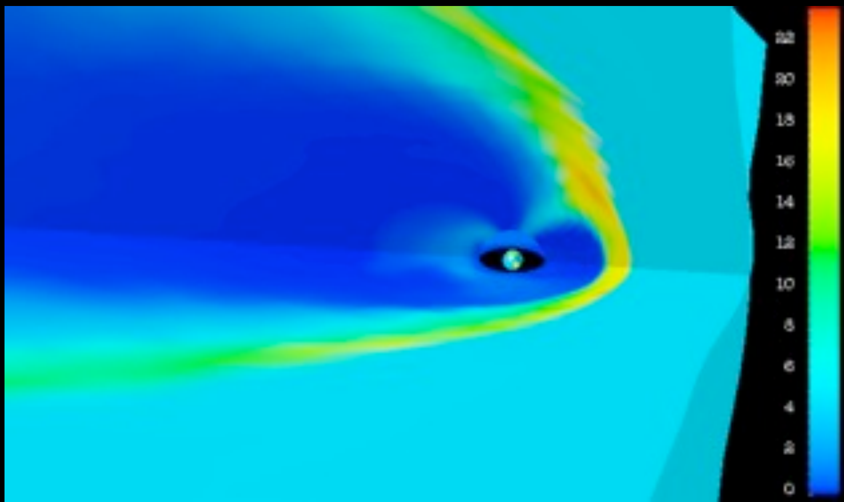
How is the energy to power convection extracted from the solar wind?

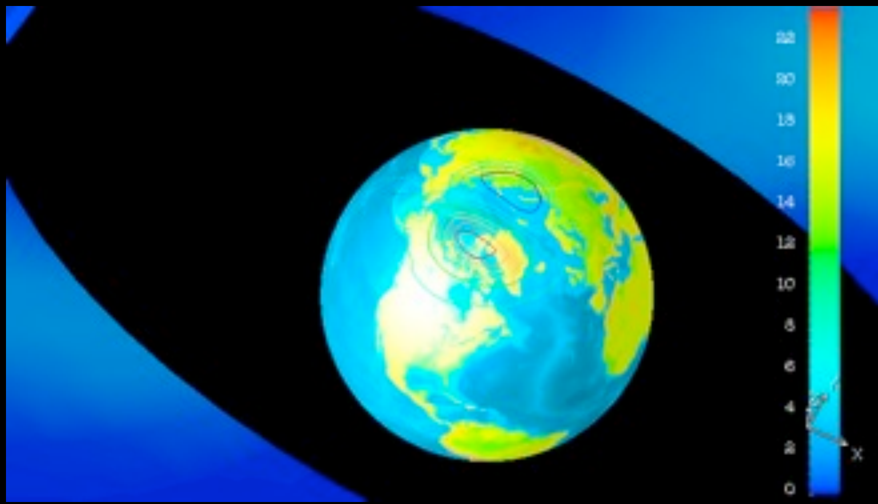
Where is work done against the solar wind and where are forces exerted in the system?

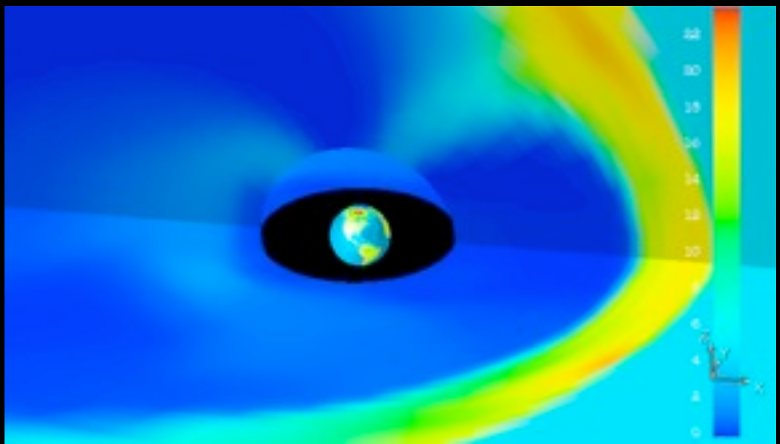
Magnetosphere simulation

- The Lyon-Fedder-Mobary (LFM) code is a fully 3-D MHD simulation that can be run with real solar wind input if desired
- Magnetosphere modeled via ideal MHD equations within 30 to −300R_E (x) and 100 R_E (y,z)
  - Upstream and side BCs -> Solar wind data
  - Downstream BC -> Supersonic outflow
  - Inner BC -> 2-D Ionospheric simulation
- Reconnection occurs due to numerical effects

V=400 km/s, n= 5/cc, Bz = -5 nT







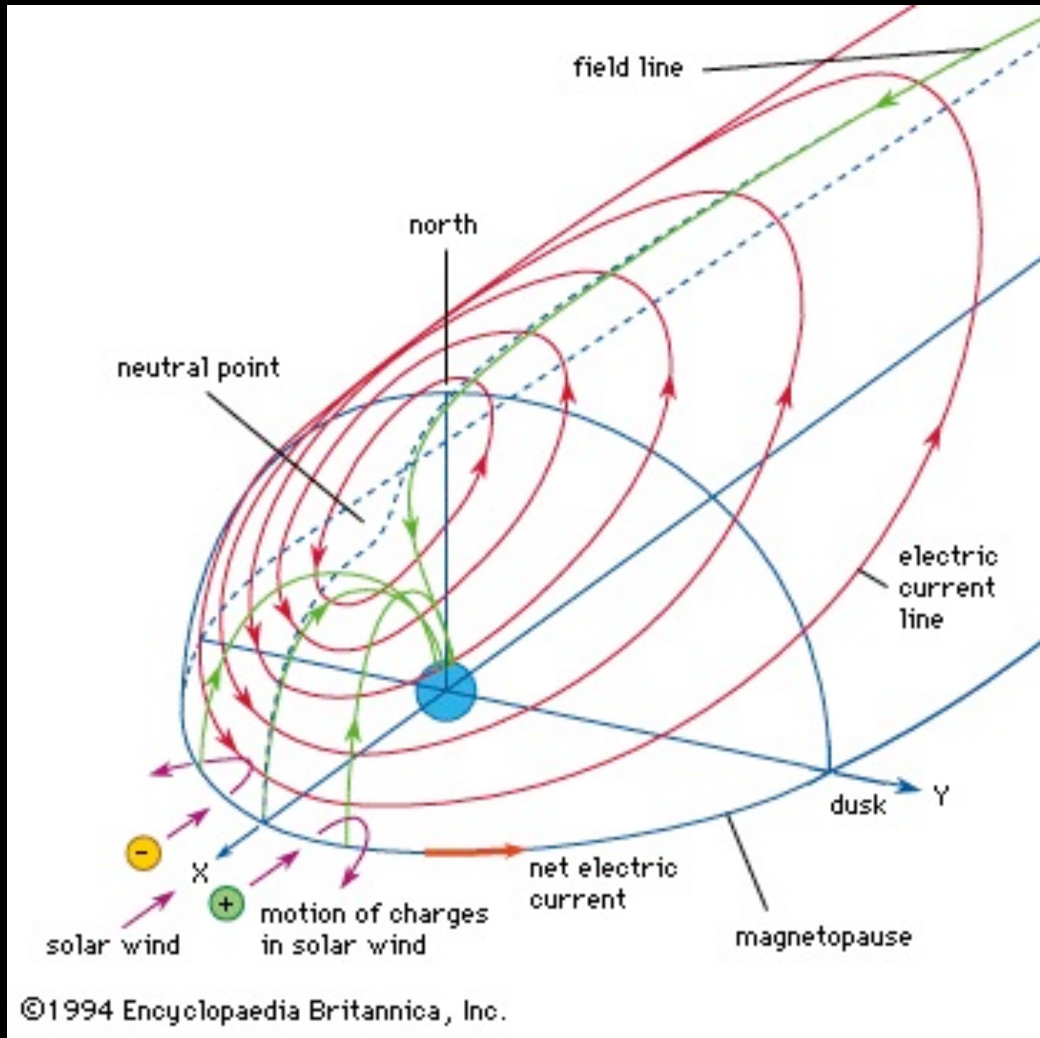
The Chapman-Ferraro current: Load and Generator

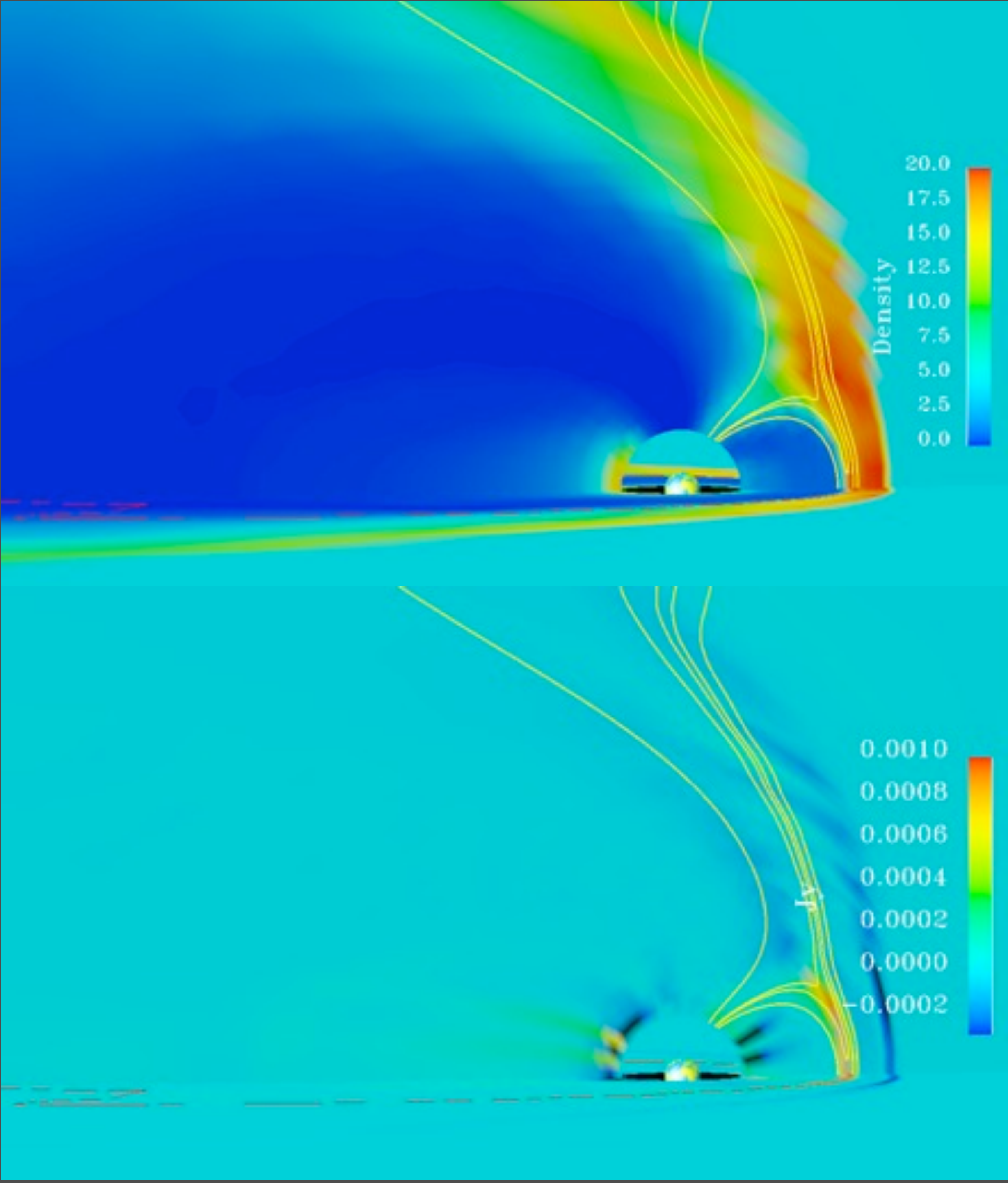
For southward IMF
E = VBz (dusk-direction)

J•E > 0 at low latitude

J•E < 0 at high latitude
(the mantle region)

C-F current exerts outward **JxB** force on solar wind





Simulations show the same thing -

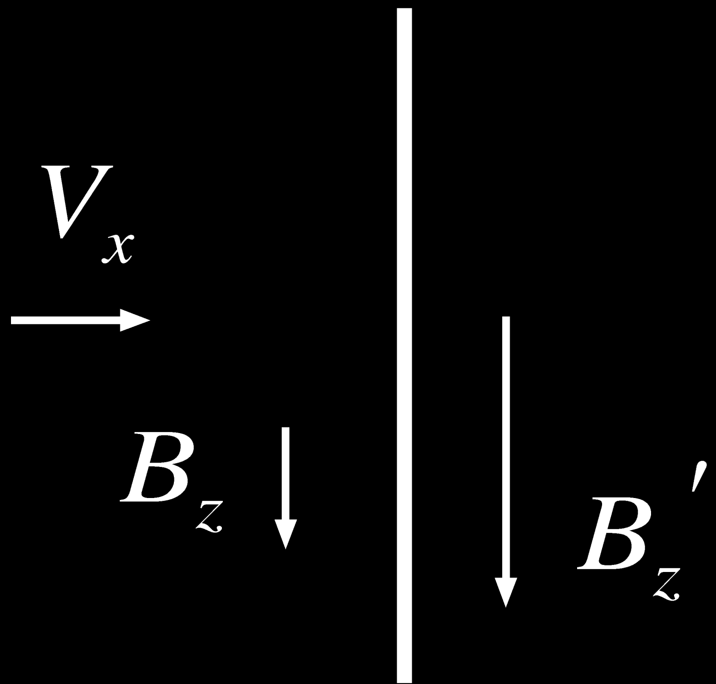
Bz = -5 nT

Ey > 0

so

Jy > 0 load
Jy < 0 generator

The bow shock and dynamics



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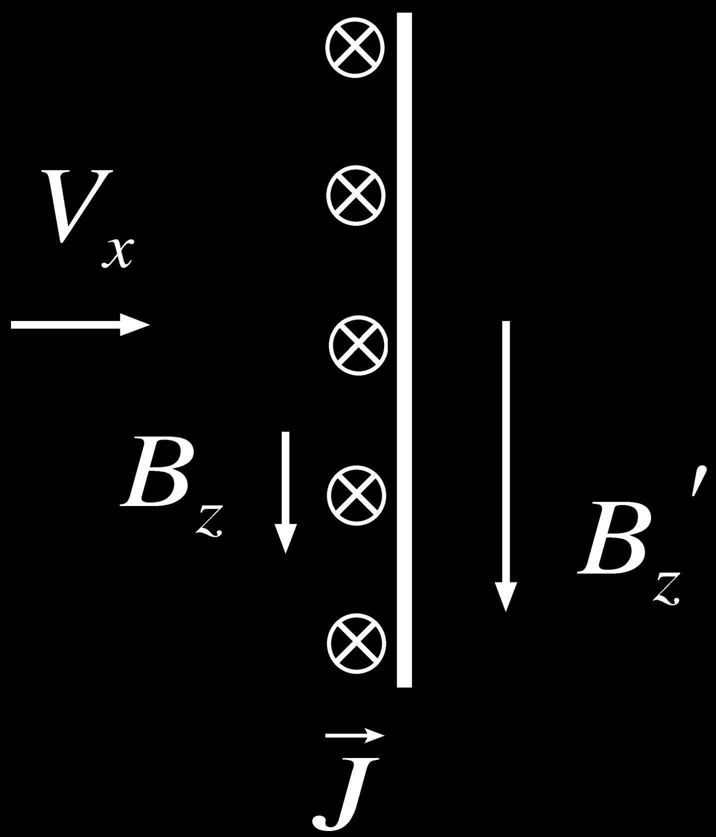
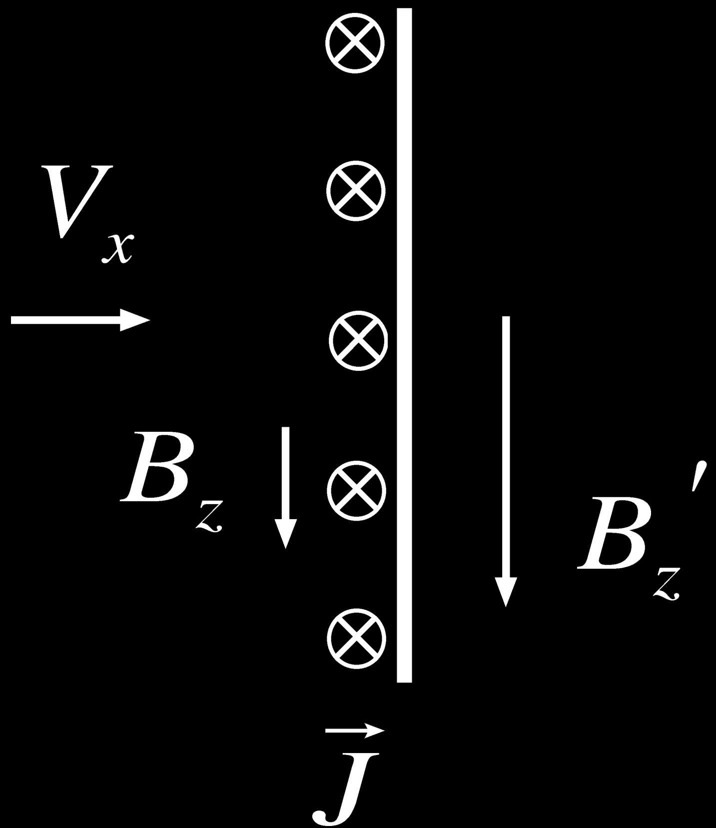


The bow shock and dynamics

$$J_y = \frac{\Delta B_z}{\mu_0} = \frac{B_z(r-1)}{\mu_0}$$



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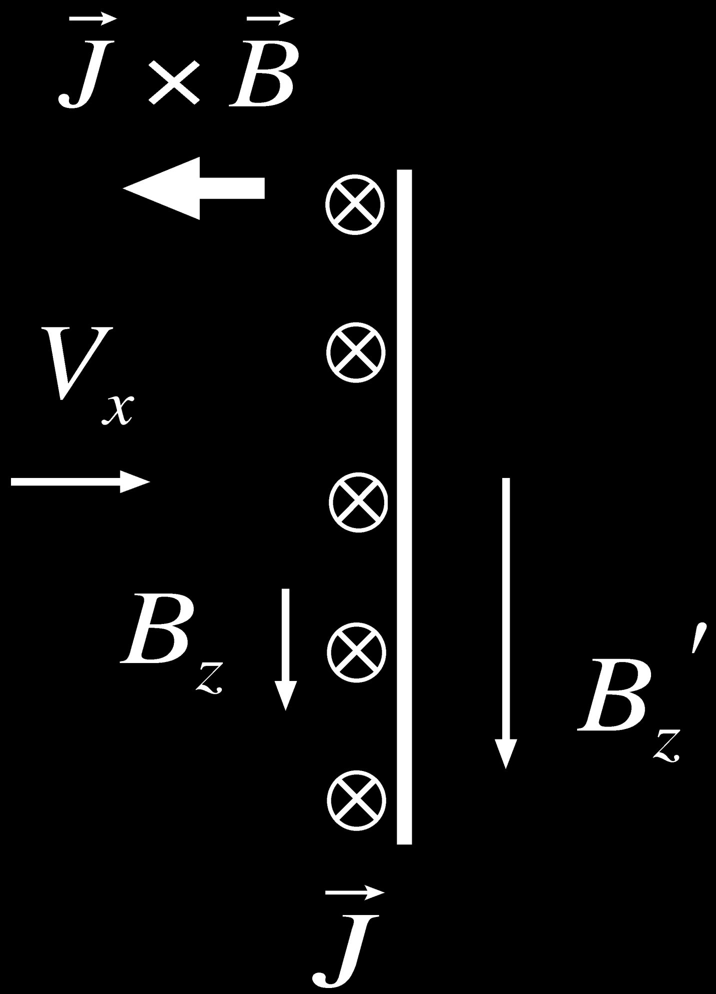

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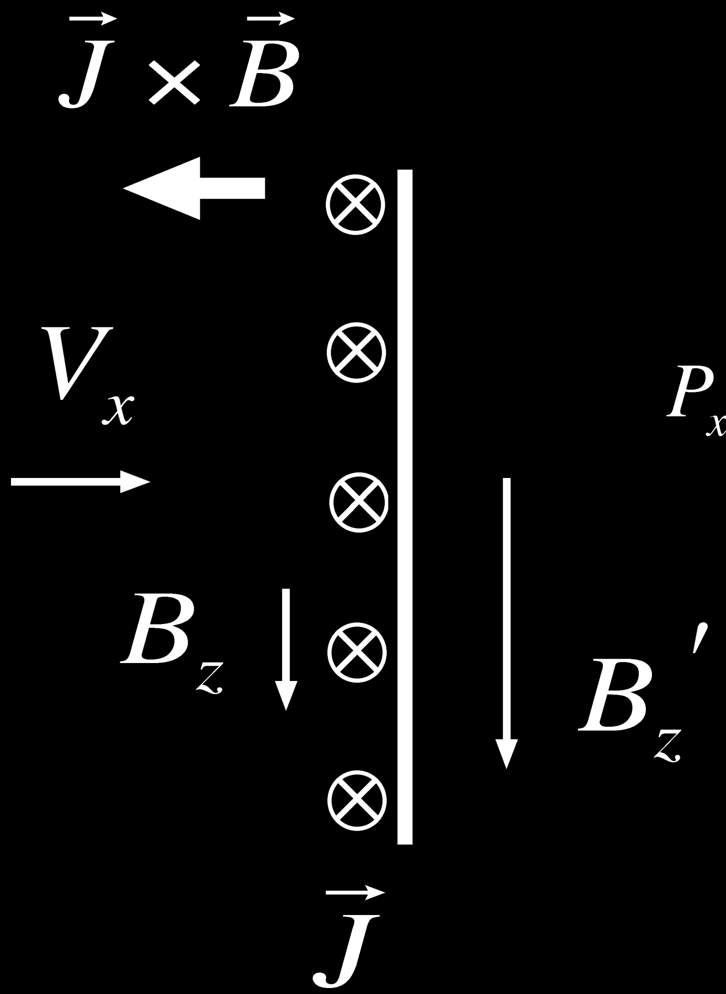

$$J_y = \frac{\Delta B_z}{\mu_0} = \frac{B_z\left(r-1\right)}{\mu_0}$$

$$P_x = J_y \overline{B}_z = J_y \frac{B_z + rB_z}{2} = \frac{B_z^{\,2}\left(r^2-1\right)}{2\mu_0}$$

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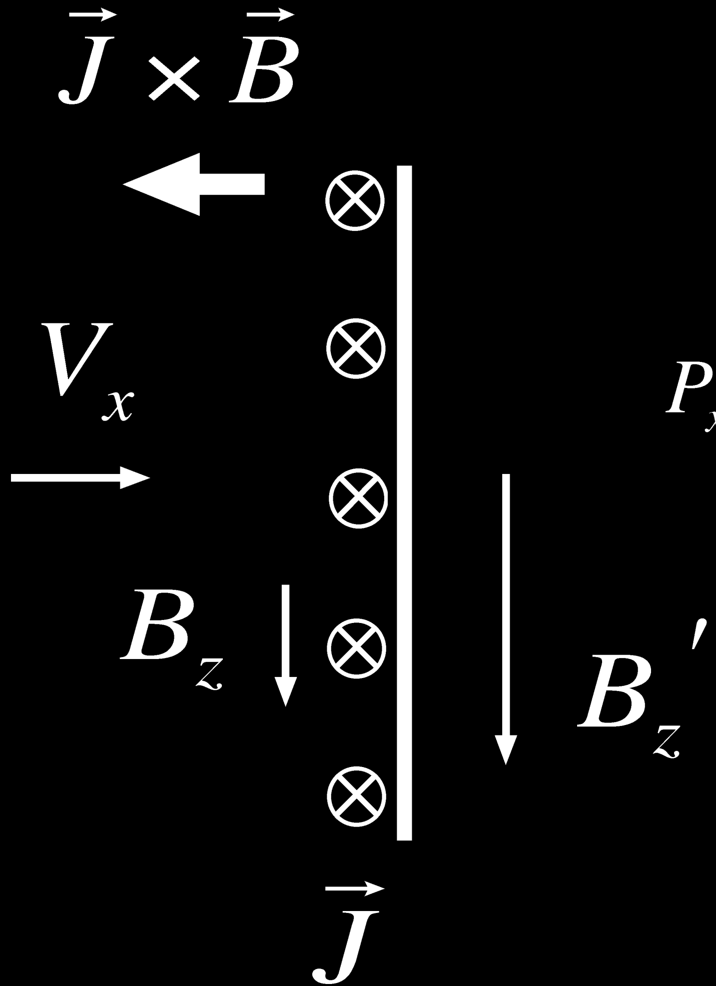

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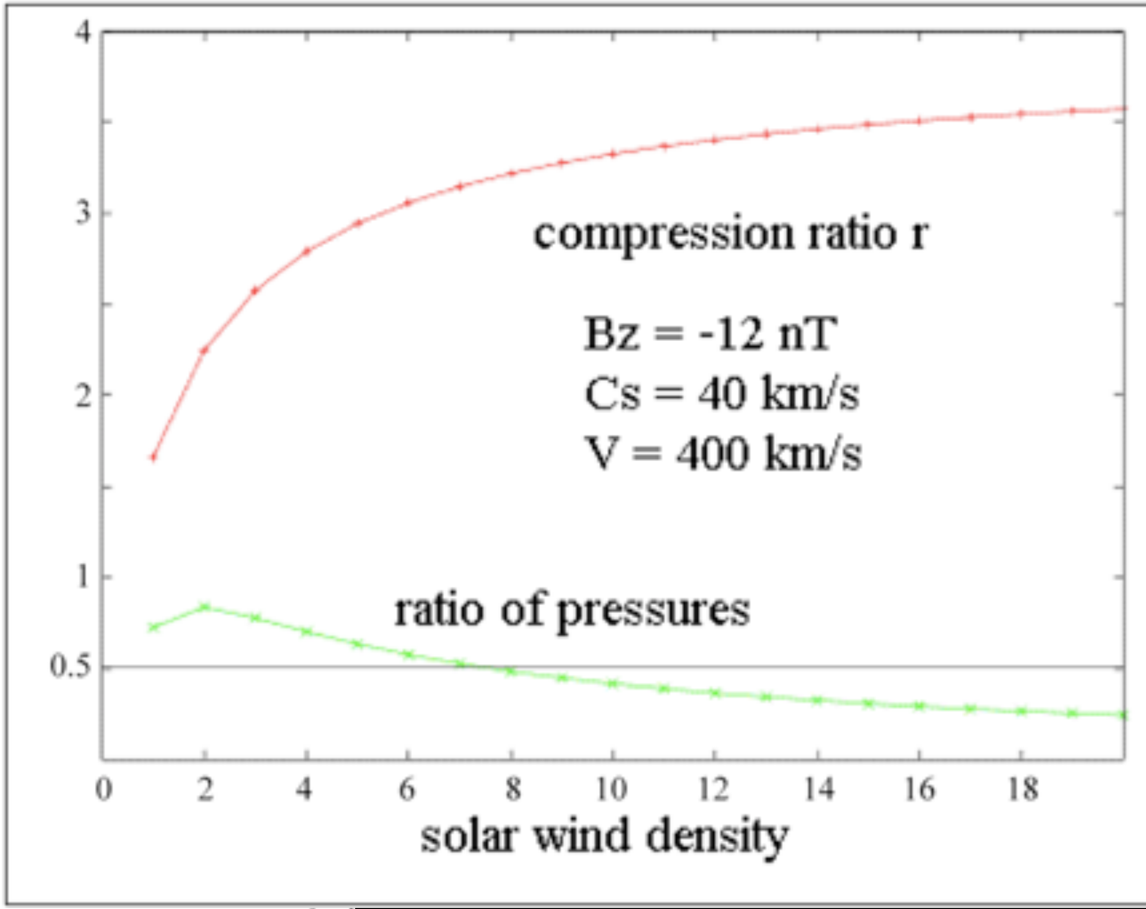
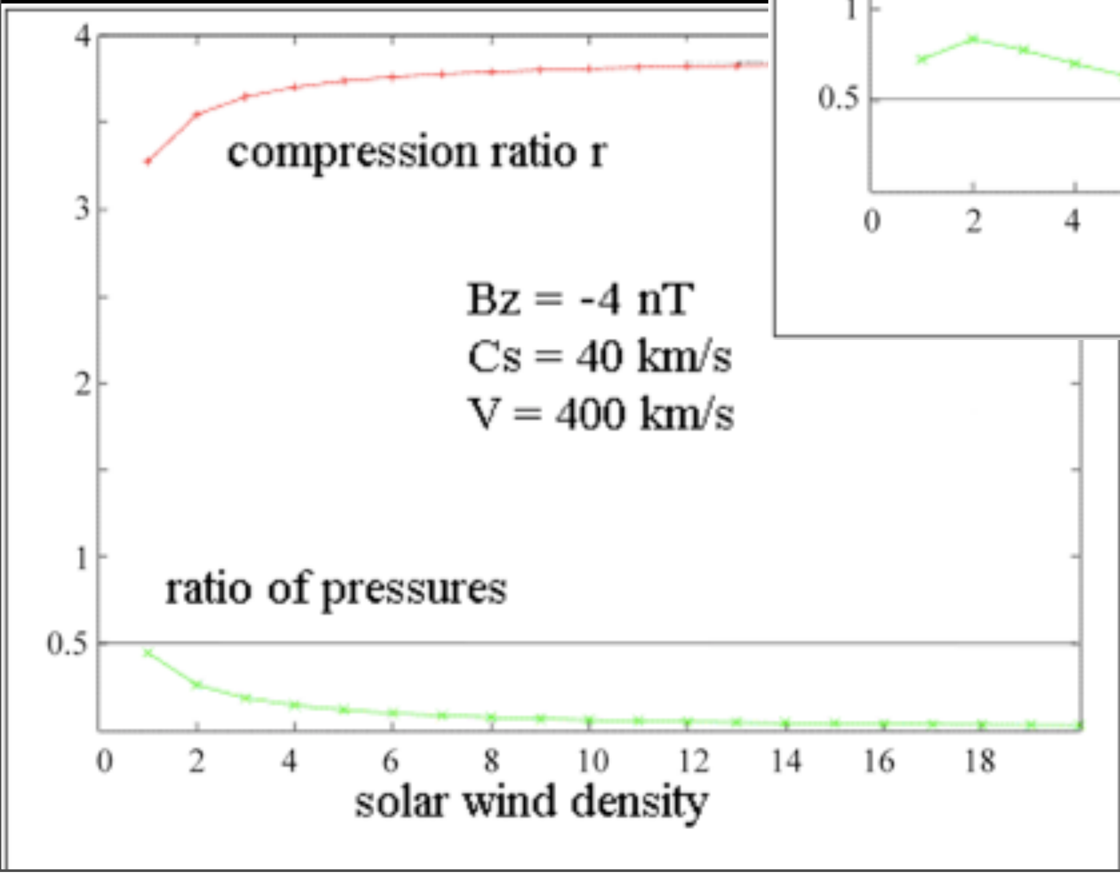
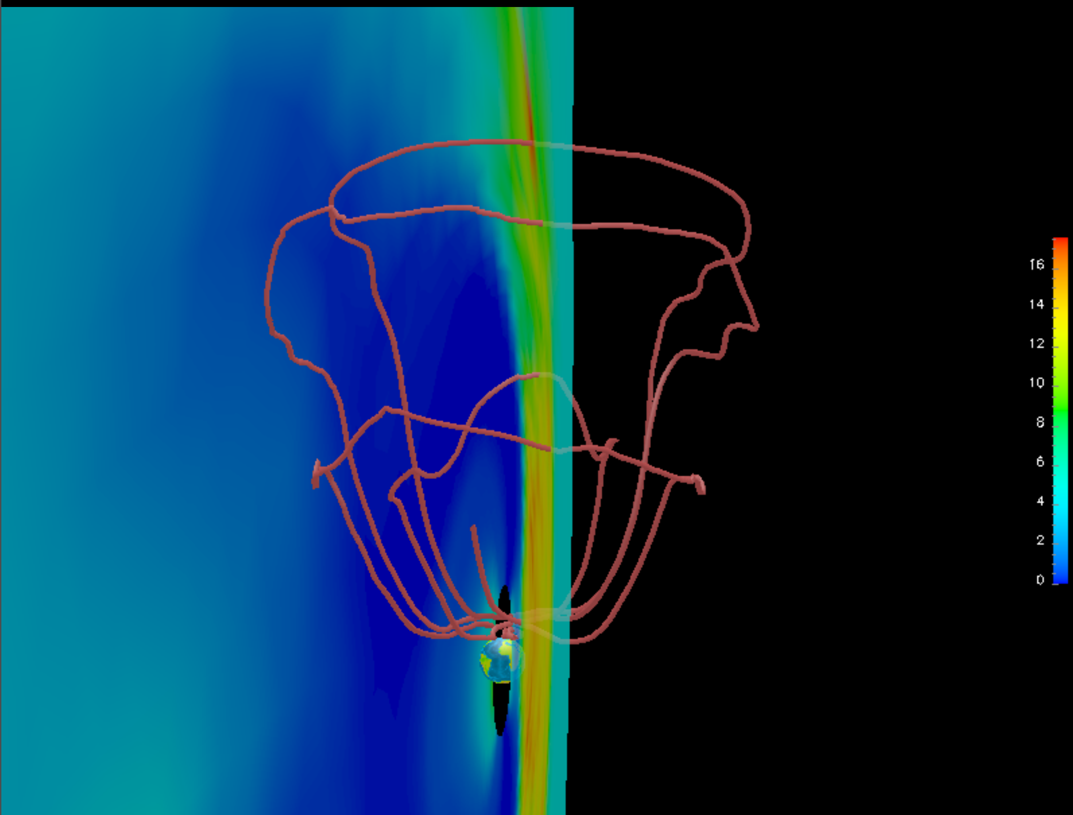
so

$$\frac{P_x}{\frac{1}{2}\rho V^2} = \frac{B_z{}^2(r^2-1)}{\mu_0 \rho V^2} = \frac{(r^2-1)}{M_a^2}$$


compression ratio r
Bz = -12 nT
Cs = 40 km/s
V = 400 km/s
ratio of pressures
solar wind density


compression ratio r
Bz = -4 nT
Cs = 40 km/s
V = 400 km/s
ratio of pressures
solar wind density

Driving via the Bow Shock Generator



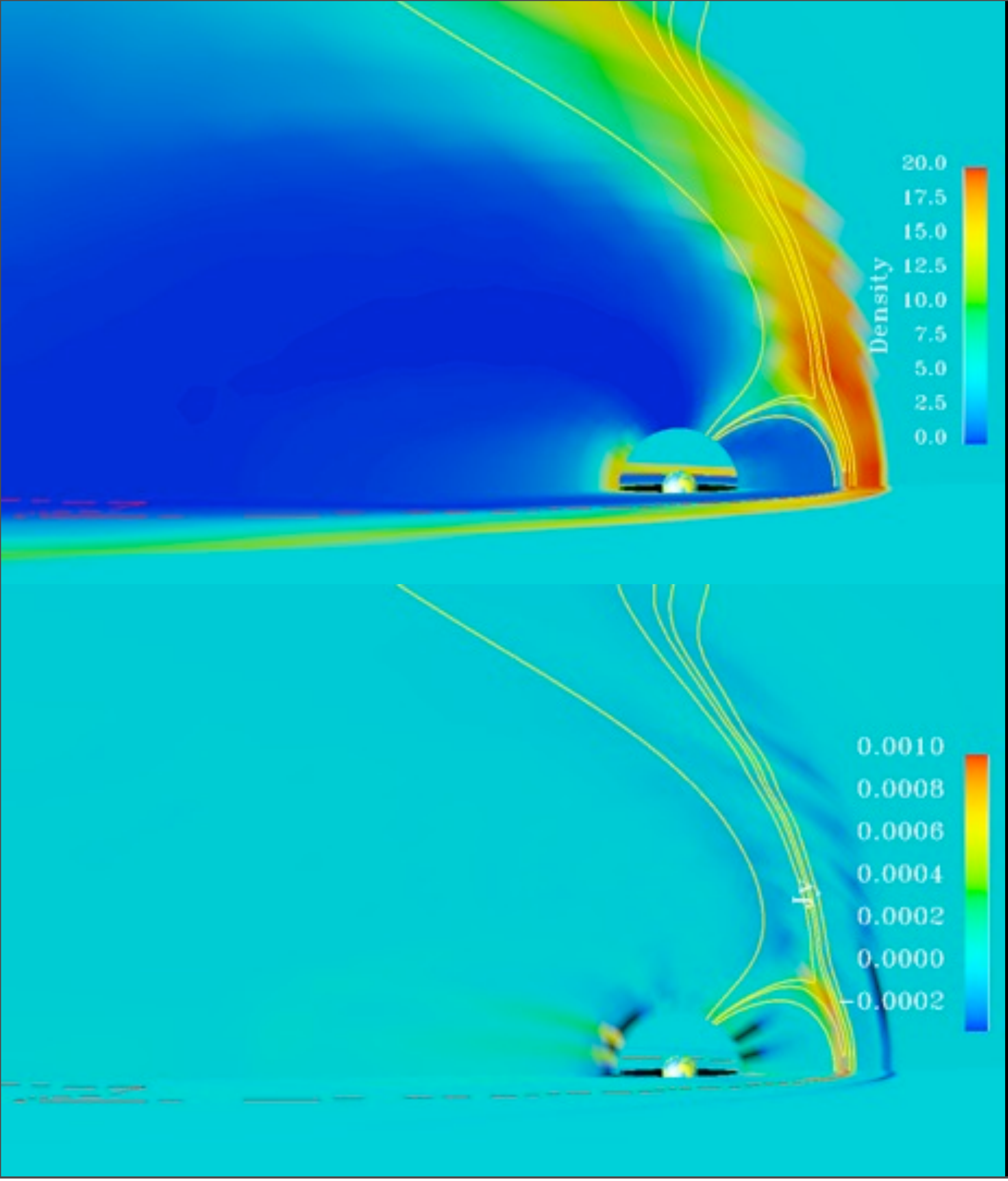
The current in the bow shock is a generator

$$\vec{J} \bullet \vec{E} < 0$$

This dynamo current acts as a source for potential

$$J_{\parallel} = \Sigma_p \nabla^2 \Phi$$

Bz = -20 nT, V = 400 km/s, n = 5/cc

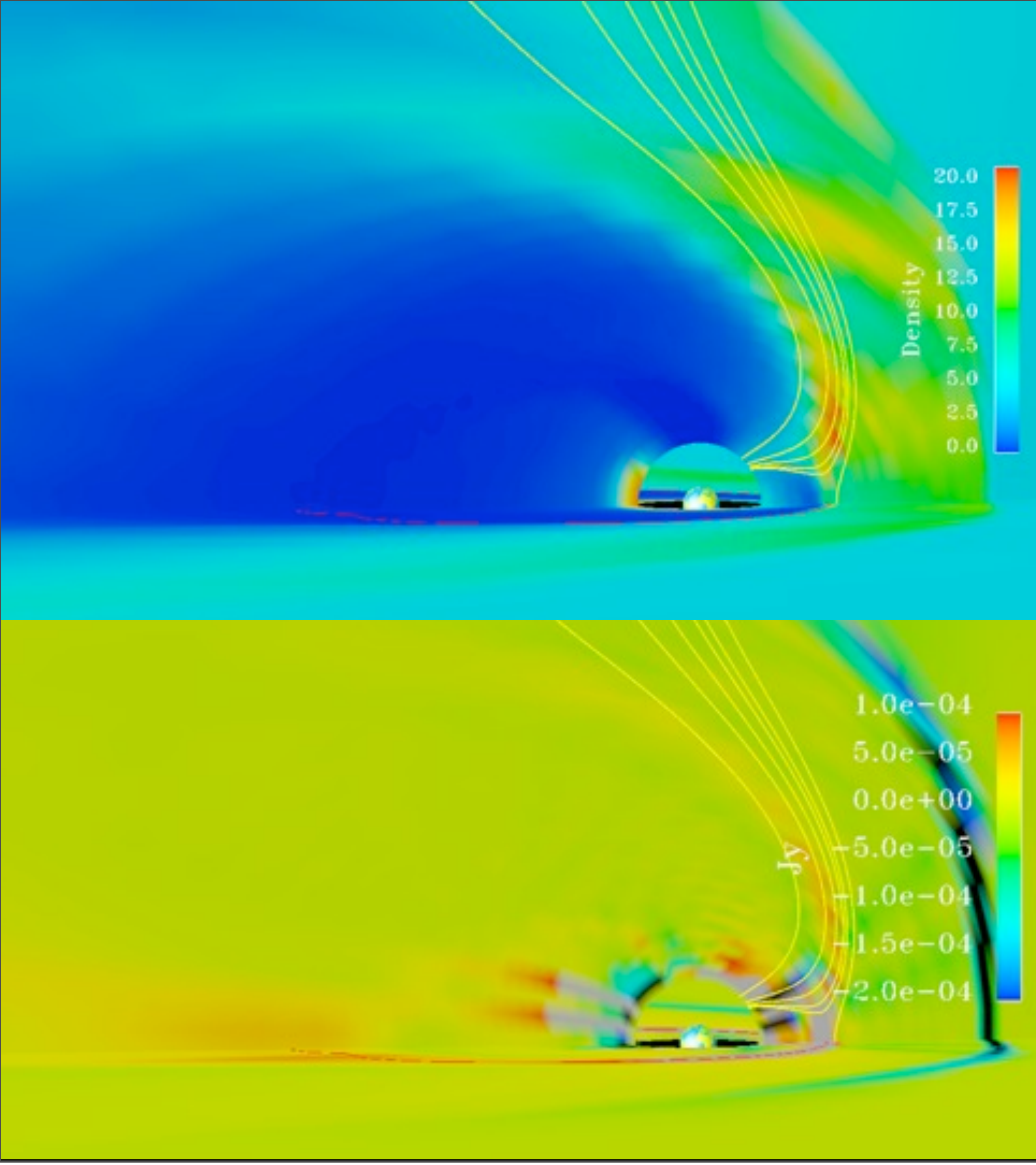


C-F generator and load for nominal solar wind conditions

Bz = -5 nT

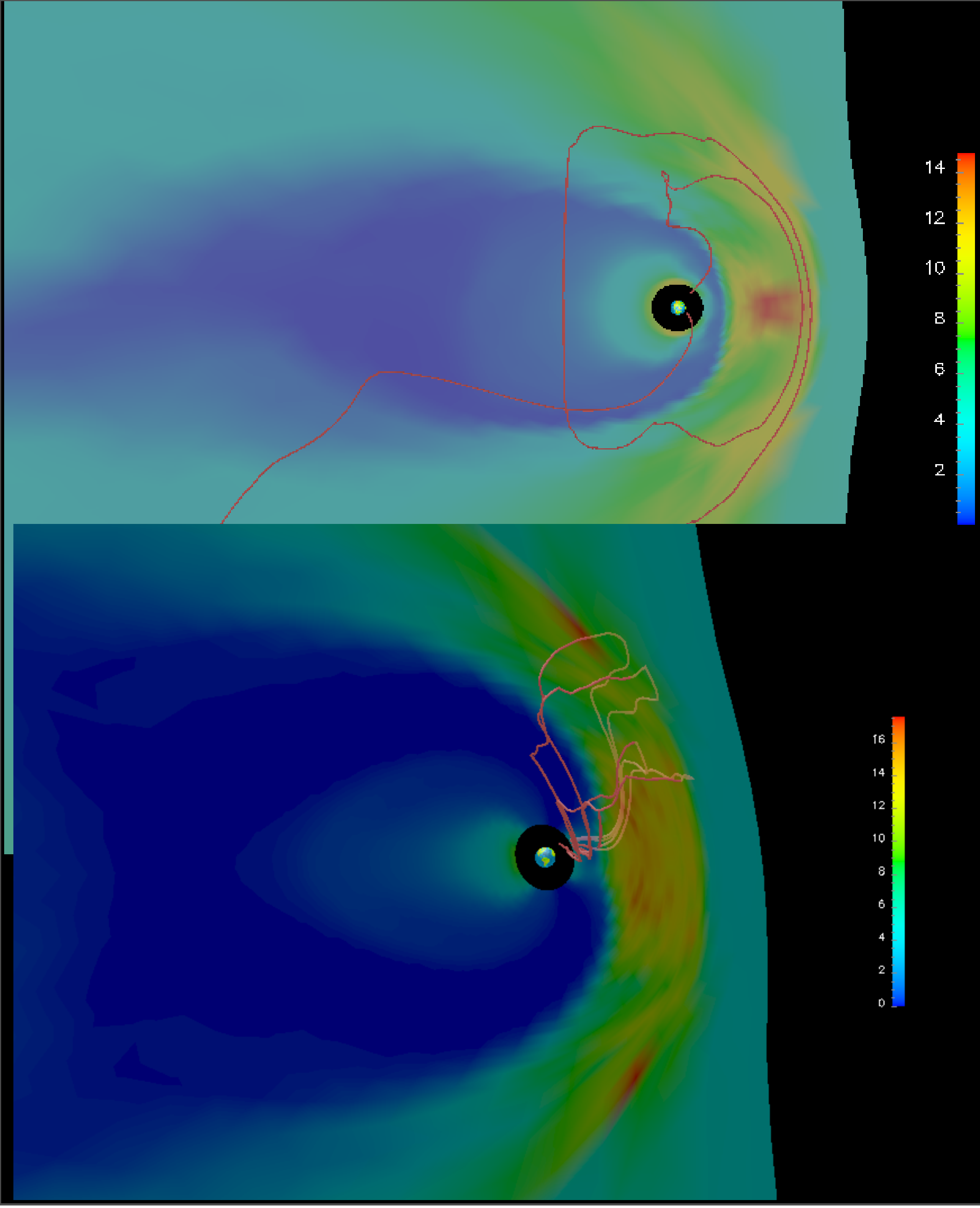
V = 400 kms

n = 5/cc



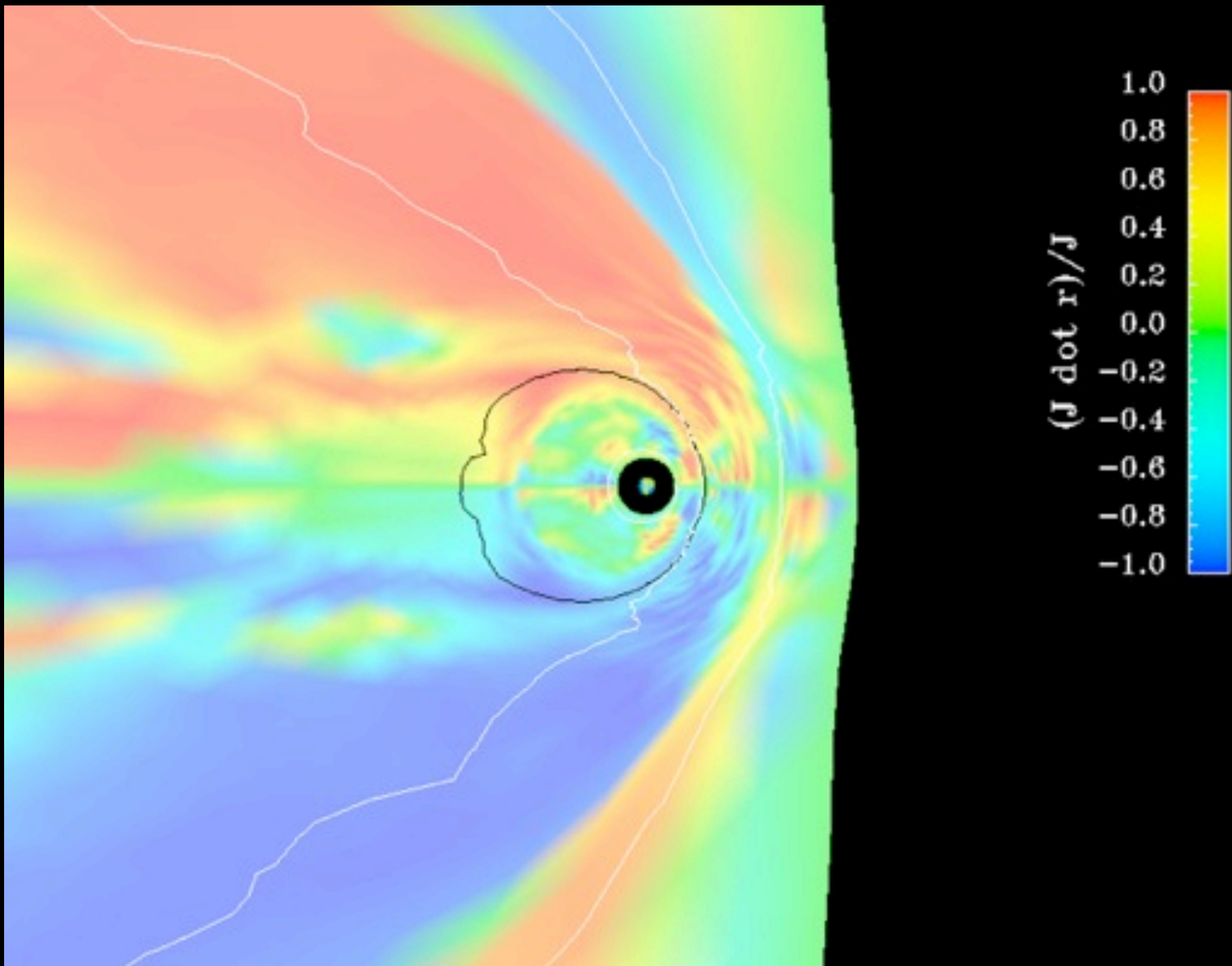
Bz= -20 nT
C-F generator disappears.

This means that the bow shock as the only generator in the system!

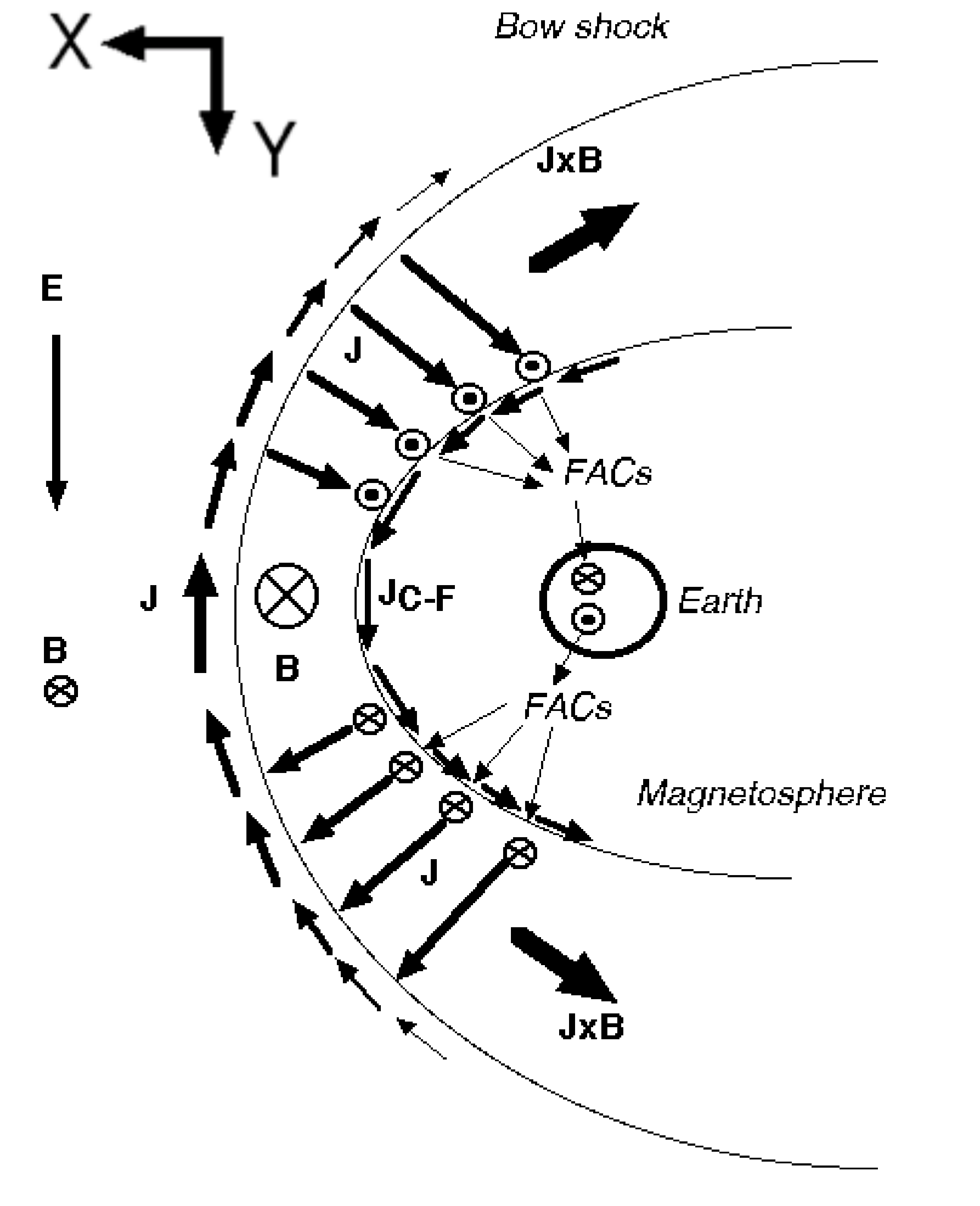


Where does the current go?

Look at the direction of the current in the volume at Z=0



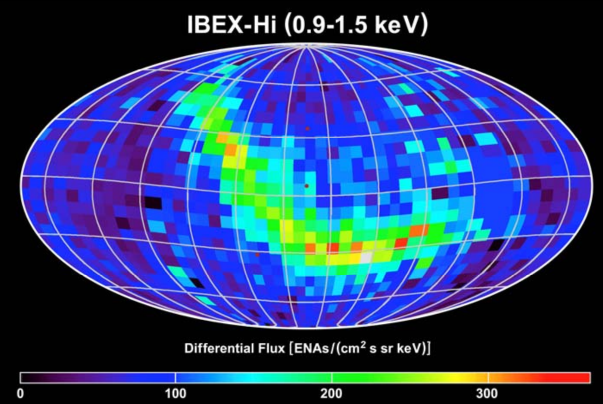
Bz = -20 nT
V = 400 km/s
n = 5
Cs = 40 km/s

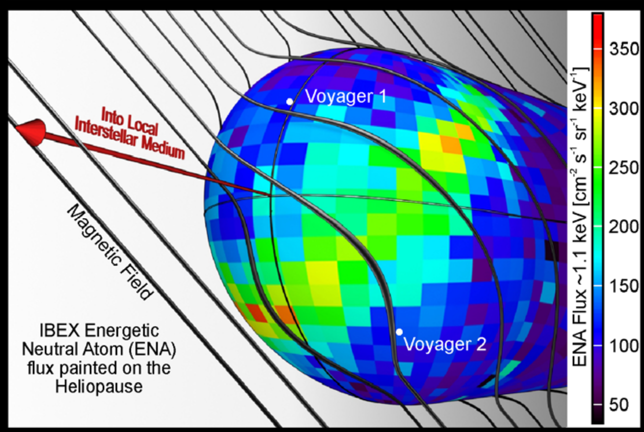


The magnetic force can be the largest force in the magnetosheath if beta<1

Astrophysical connections?

- What about current closure in astrophysical shocks? Where is the electromagnetic energy extracted from the flow at the shock dissipated?
- And what about the Heliopause? Where does the energy extracted at the termination shock go?





Bow shock dynamo and coupling to geospace

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- The solar wind flow energy dissipated at the bow shock creates a dynamo ($\boldsymbol{J} \bullet \boldsymbol{E} < 0$). This in part powers dayside merging (Siebert and Siscoe, 2002). For large enough IMF (low Mach number shock), this is the *only* generator in the system!

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- This represents a means of transferring energy from the solar wind to the geospace system ***without reconnection or viscous interaction at the magnetopause - perhaps a third fundamental mode of energy transfer!***
- In astrophysical plasmas, similar process will be at work in shocks. Where is the EM energy generated at such shocks dissipated? How do the current close?