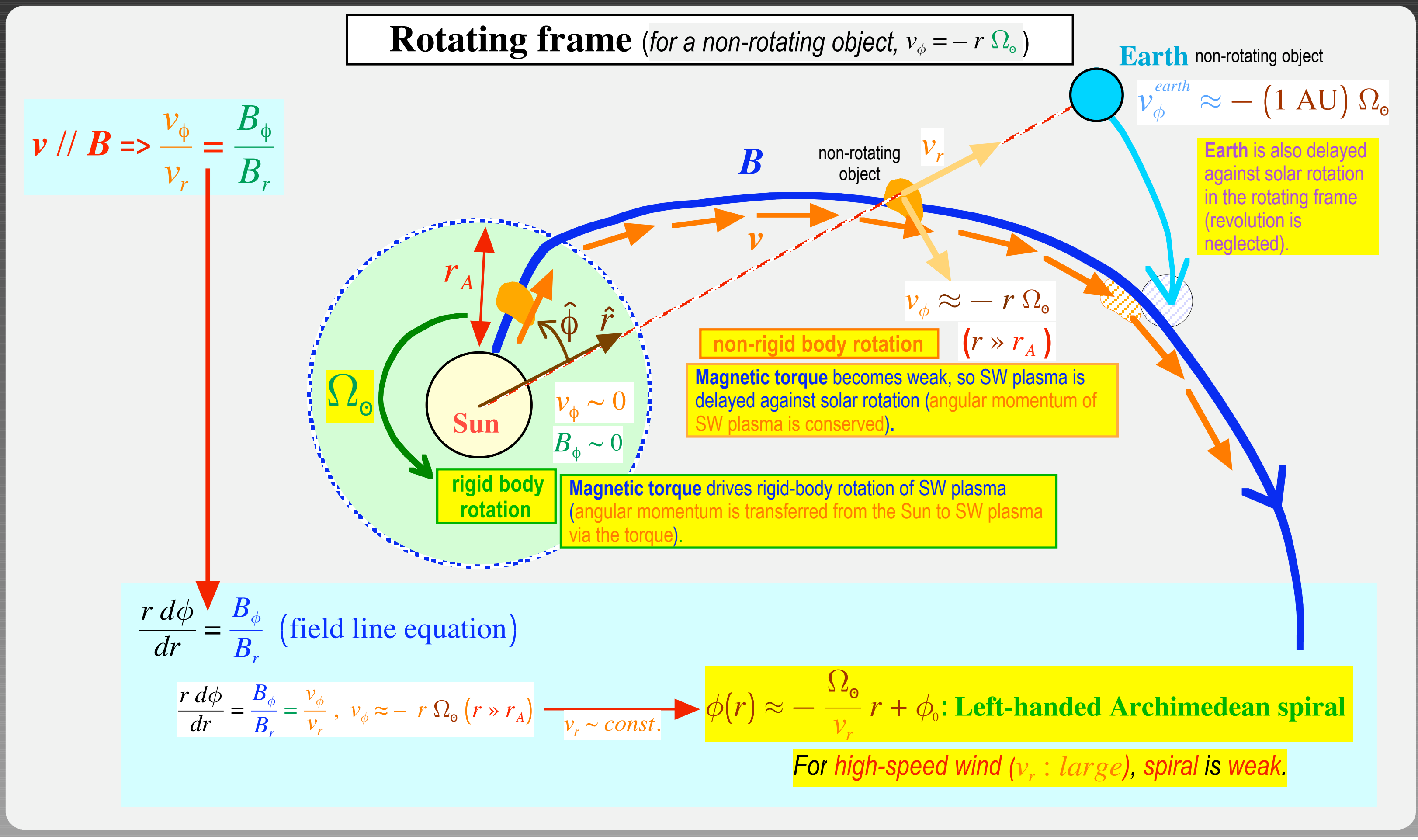
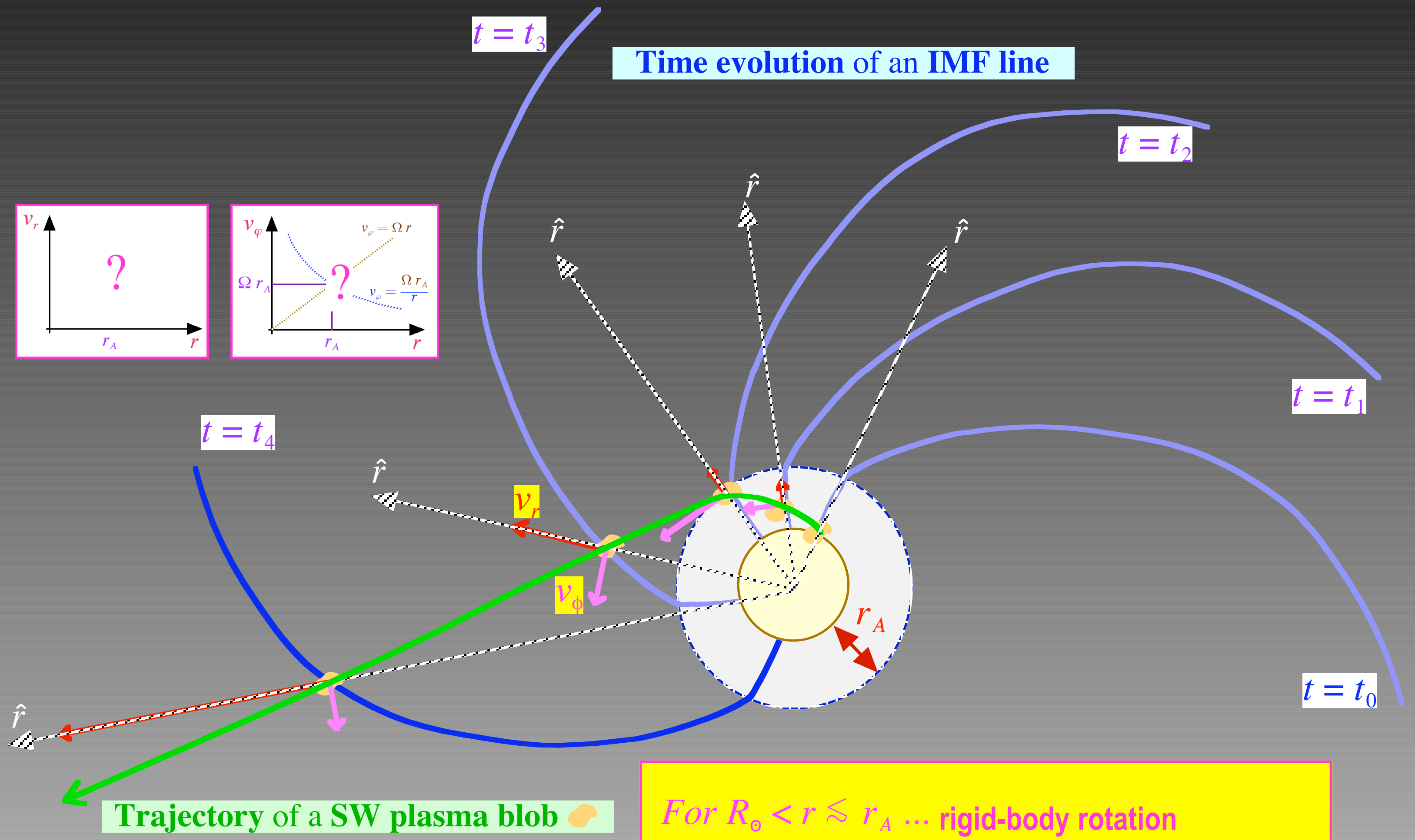
Archimedean spiral structure of IMF: $\phi(r) \propto r$

We assume a static IMF frozen into a SW plasma in a frame rotating at the solar rotation rate $\Omega_\odot$. In this frame, flow velocity of the plasma is parallel to the IMF:

$$\boldsymbol{v} \,//\, \boldsymbol{B} \Rightarrow \frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times \left(\boldsymbol{v} \times \boldsymbol{B}\right) = \boldsymbol{0}$$



In inertial frame...

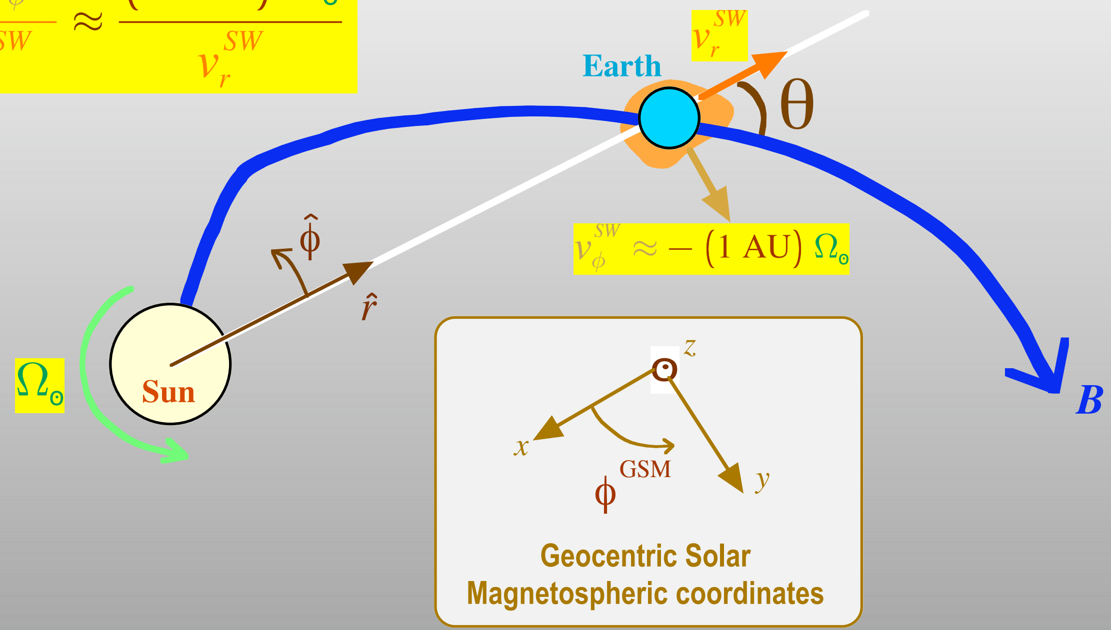


For $R_\odot < r \lesssim r_A$ … **rigid-body rotation**

For $r_A < r$ … **angular momentum conservation**

Spiral angle of IMF near an Earth orbit

$$\tan\theta \equiv \frac{-B_\phi^{IMF}}{B_r^{IMF}} = \frac{-v_\phi^{SW}}{v_r^{SW}} \approx \frac{(1\ \mathrm{AU})\,\Omega_\odot}{v_r^{SW}}$$

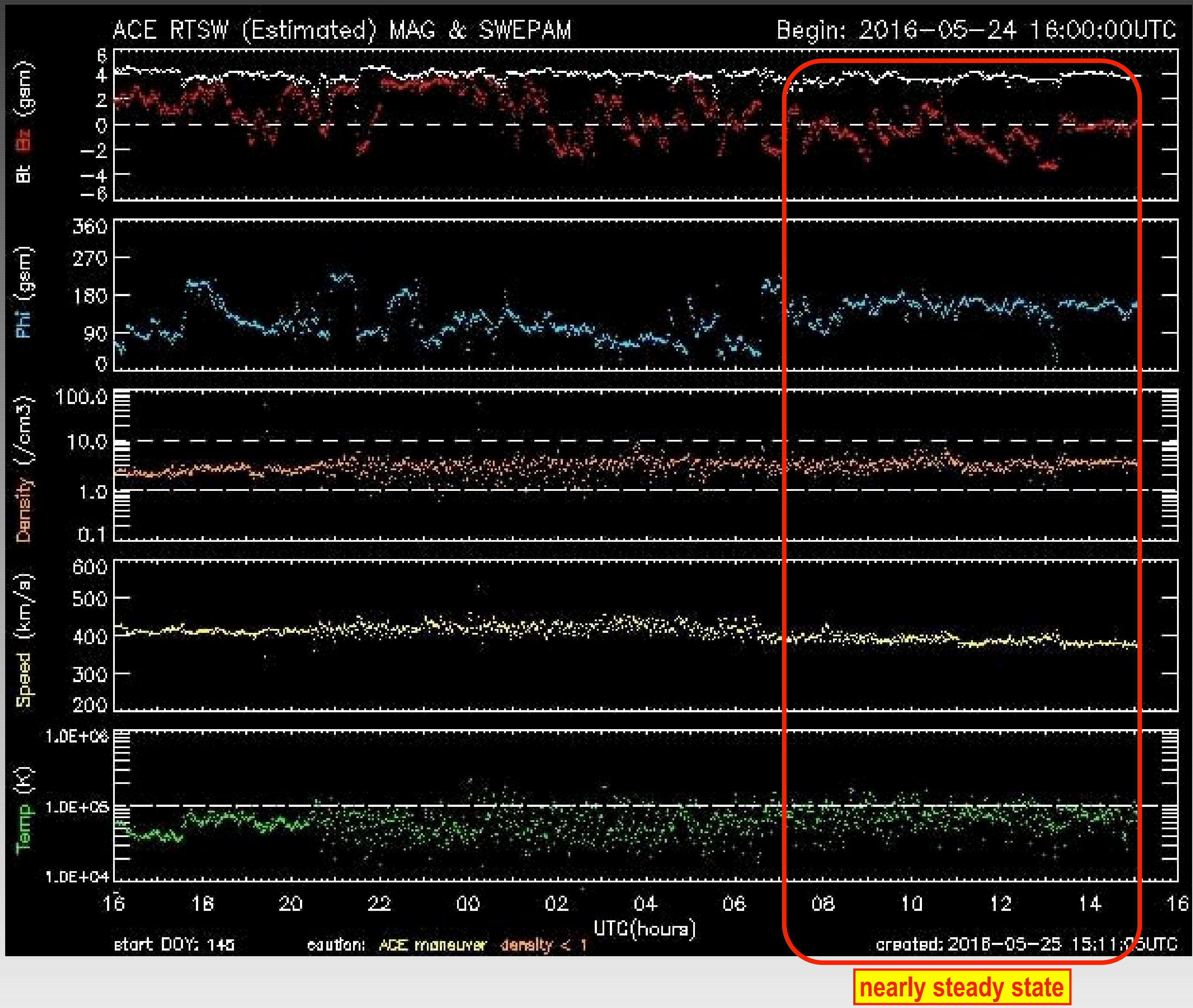


Near an Earth orbit, the **spiral angle** is

$$\tan\theta = \frac{-v_\phi^{SW}}{v_r^{SW}} \approx \frac{(1\ \mathrm{AU})\,\Omega_\odot}{v_r^{SW}} \sim \frac{1.5\times10^{8}\ \mathrm{km}\times\left(2.87\times10^{-6}\ \mathrm{rad\ s^{-1}}\right)}{400\ \mathrm{km\ s^{-1}}} = 1.07$$

$$\Rightarrow \theta \sim 47^\circ \quad \left(\phi^{GSM} \sim 133^\circ\right)$$

Solar wind observed near an Earth orbit

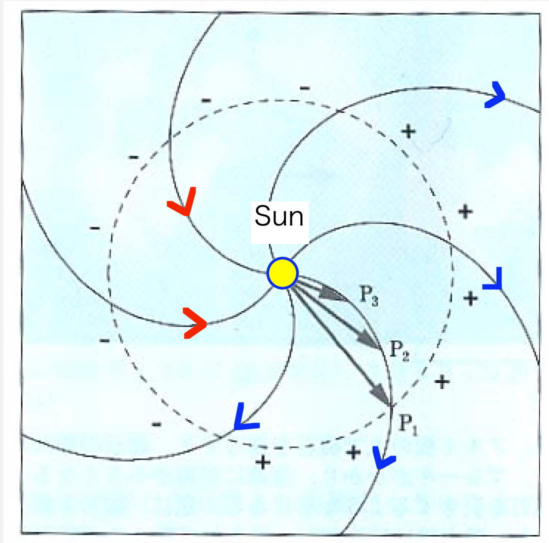


Sector structure of IMF

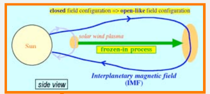
There are inward IMF area
and outward IMF area.

↓

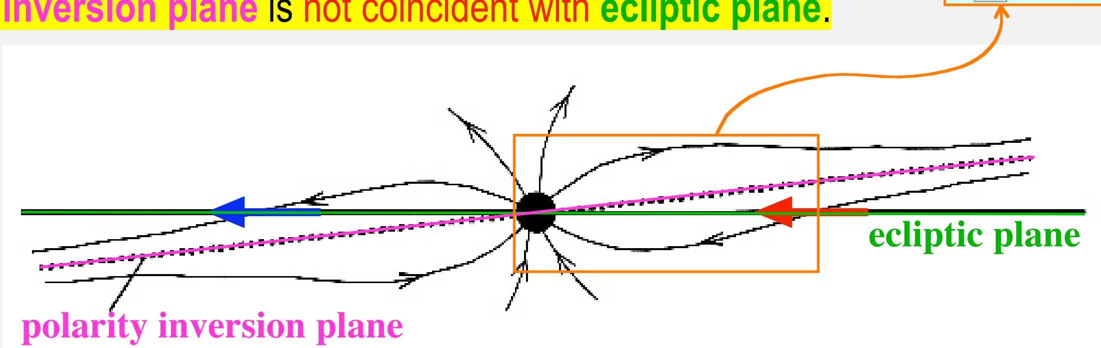
Sector structure



Origin of sector structure:

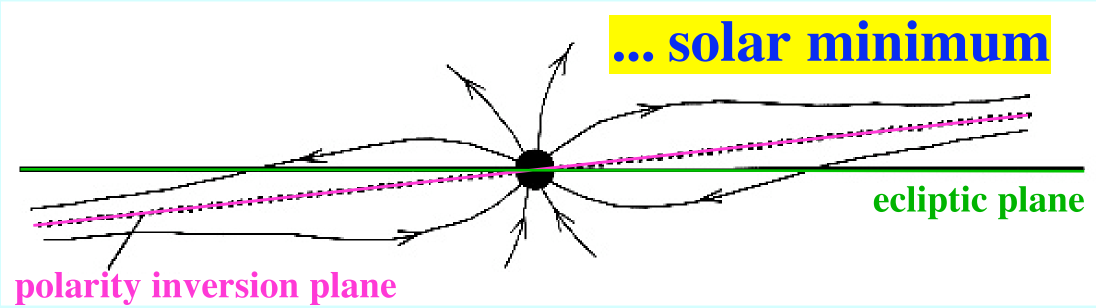


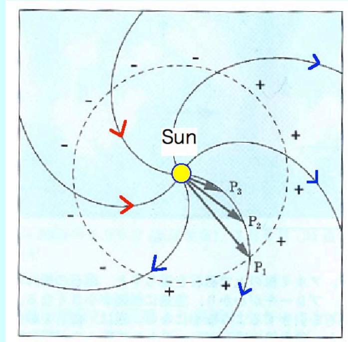
Polarity inversion plane is not coincident with ecliptic plane.



Time variation of the sector structure...

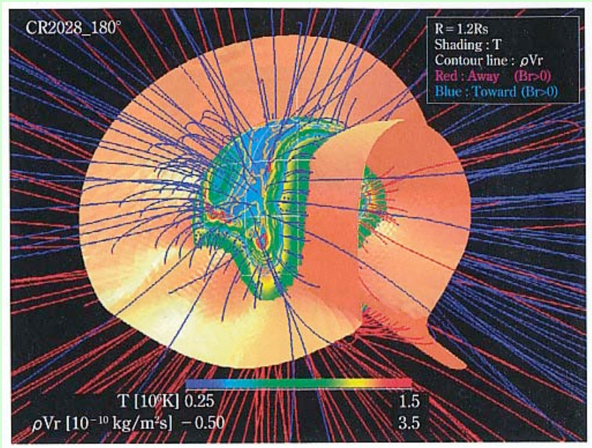
Two-sector structure





Polarity inversion plane is **almost flat**.

Multi-sector structure



From T. Tanaka

... solar maximum

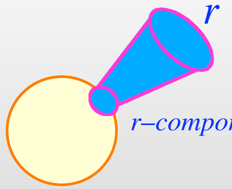
Polarity inversion plane is **strongly rippled** because a number of solar active regions exist.

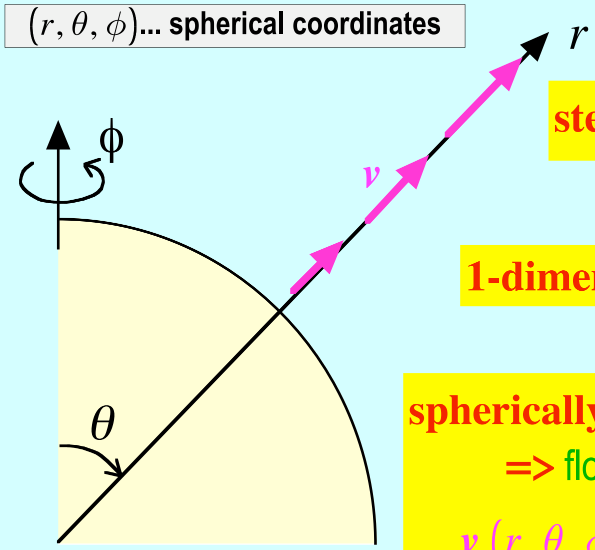
Solar wind model

Hydrodynamic model

Parker's 1-dimensional model

(spherically symmetric, isothermal, steady, no rotation)
(depends on r; *r–component of a vector* is considered)





steady => $\frac{\partial}{\partial t} = 0$ (time-independent)

1-dimensional model => all quantities depend only on r

spherically symmetric (isotropic) outflow
=> flow velocity has only a radial component (v_r)

$$\boldsymbol{v}(r,\theta,\phi) = v_r(r,\theta,\phi)\,\hat{\boldsymbol{r}} + v_\theta(r,\theta,\phi)\,\hat{\theta} + v_\phi(r,\theta,\phi)\,\hat{\phi}$$

$$\longrightarrow v_r(r)\,\hat{\boldsymbol{r}}$$

isothermal
=> $T = const.$
thermal conduction efficiently works to make temperature uniform

Basic equations:

Mass conservation.. $\rho\, v_r\, A = const.$

spherically symmetric => $A(r) \propto r^2$

Momentum equation...

$$\rho\, v_r \frac{\partial v_r}{\partial r} = -\frac{\partial p}{\partial r} - \frac{G M_\odot \rho}{r^2}$$

Energy equation... $T = const.\left(\frac{p}{\rho} = \frac{k_B T}{\bar{m}} = v_c^2 = const. \quad v_c = \sqrt{\frac{k_B T}{\bar{m}}} \right)$

isothermal sound speed

eliminate ρ and p

$$\left(v_r - \frac{v_c^2}{v_r} \right) \frac{\partial v_r}{\partial r} = \frac{2 v_c^2}{r} - \frac{G M_\odot}{r^2}$$