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

In a frame rotating at the solar rotation rate ($\Omega_\odot$), **steady** flow velocity of SW plasma **is parallel to** IMF **frozen into** the plasma.

$$v \mathbin{/\!/} B \Rightarrow \frac{\partial B}{\partial t} = \nabla \times (v \times B) = 0$$

Rotating frame (an object rotating rigidly is static in $\hat{\phi}$-direction)

$$v \mathbin{/\!/} B \Rightarrow \frac{v_\phi}{v_r} = \frac{B_\phi}{B_r}$$

Earth
$$v_\phi^{earth} \approx - (1\ \mathrm{AU})\,\Omega_\odot$$

Earth is delayed against solar rotation in rotating frame (revolution is neglected).

B

v

r_A

v_r

$\hat{\phi}$ $\hat{r}$

$\Omega_\odot$

Sun

$v_\phi \sim 0$

$B_\phi \sim 0$

$v_\phi \approx - r\,\Omega_\odot$

no rotation $(r \gg r_A)$

Magnetic torque does not contribute, so SW plasma is delayed against solar rotation (angular momentum of SW plasma is conserved).

rigid body rotation

Magnetic torque drives the rigid-body rotation of SW plasma (angular momentum is transferred from the Sun to SW plasma via the torque).

$$\frac{r\,d\phi}{dr} = \frac{B_\phi}{B_r} \quad \text{(field line equation)}$$

$$\frac{r\,d\phi}{dr} = \frac{B_\phi}{B_r} = \frac{v_\phi}{v_r}\,,\ v_\phi \approx - r\,\Omega_\odot\ (r \gg r_A) \xrightarrow[v_r \sim const.]{} \phi(r) \approx - \frac{\Omega_\odot}{v_r}\,r + \phi_0 : \textbf{Left-handed Archimedean spiral}$$

For **high-speed wind** ($v_r : large$), **spiral** is **weak**.