Counter rotation in Jets and Winds
RW Aur / Solar Wind
ApJL 2012, Nov 1st

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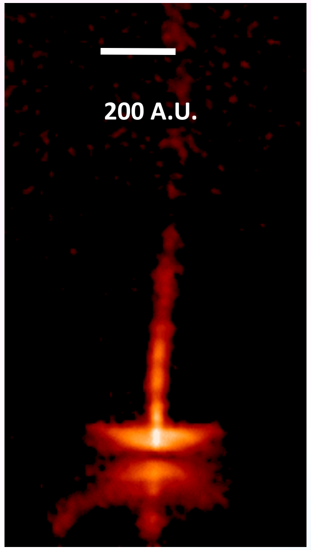
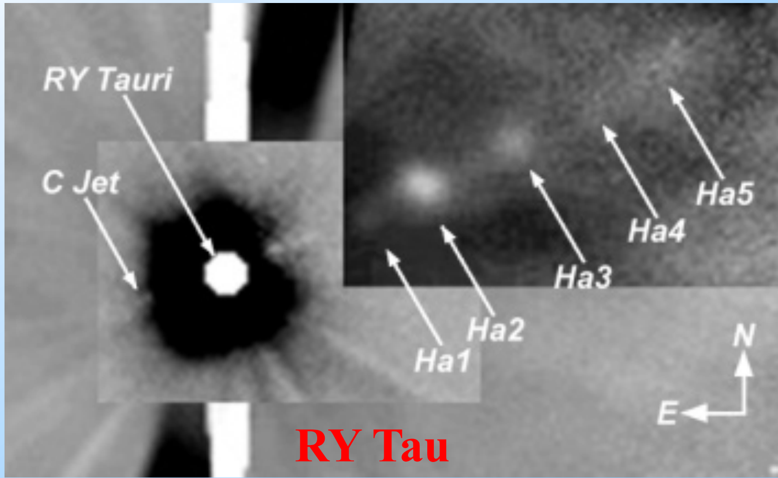
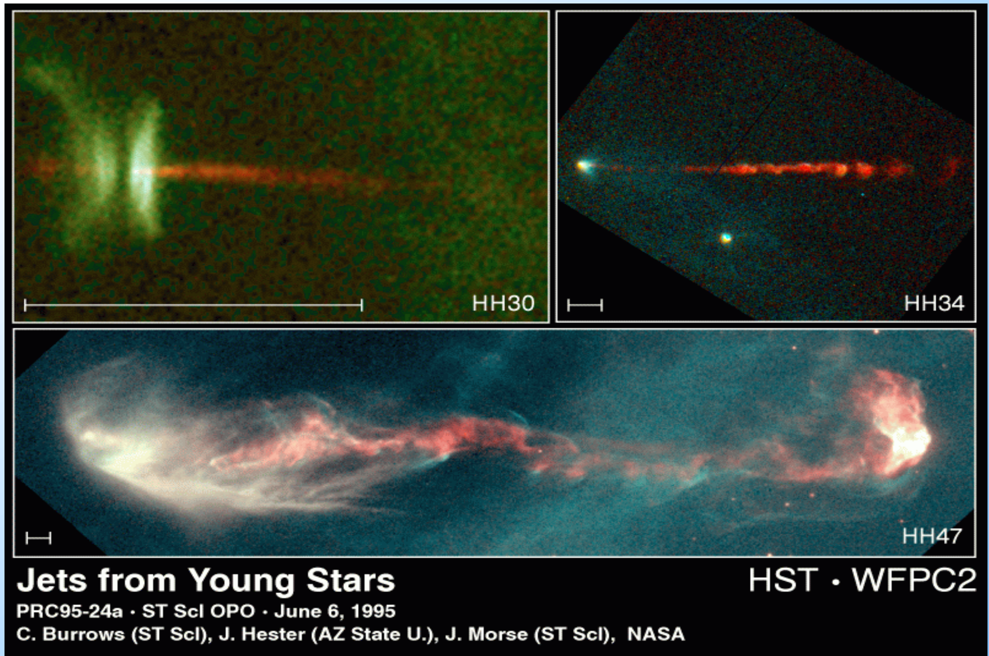
Jets and Winds : The Sun and RW Aur

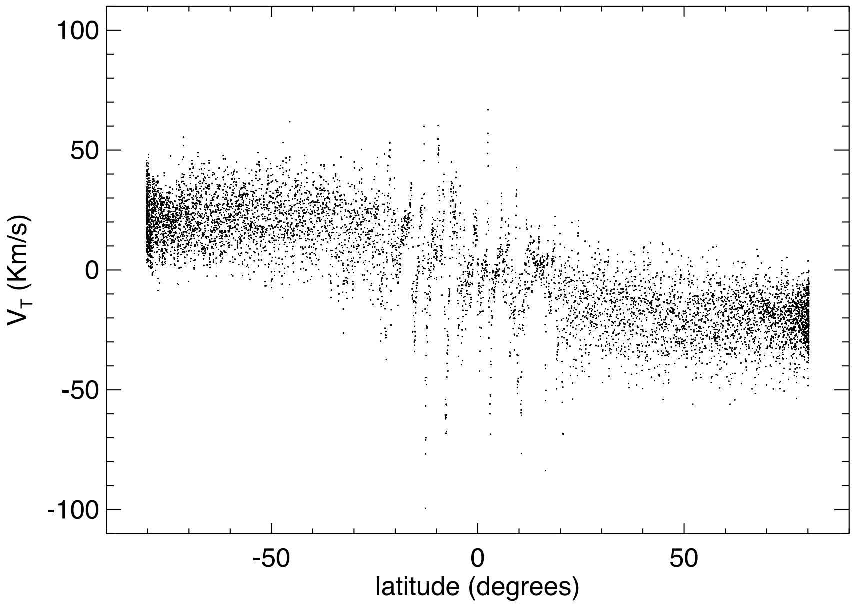


HH 30
HST WFPC2





The Sun rotation



Aibéo et al. 2007

Is the Sun counter rotating in the southern hemisphere?

….

Angular velocity is low

Counter rotation in RW Aur: fake or real ?

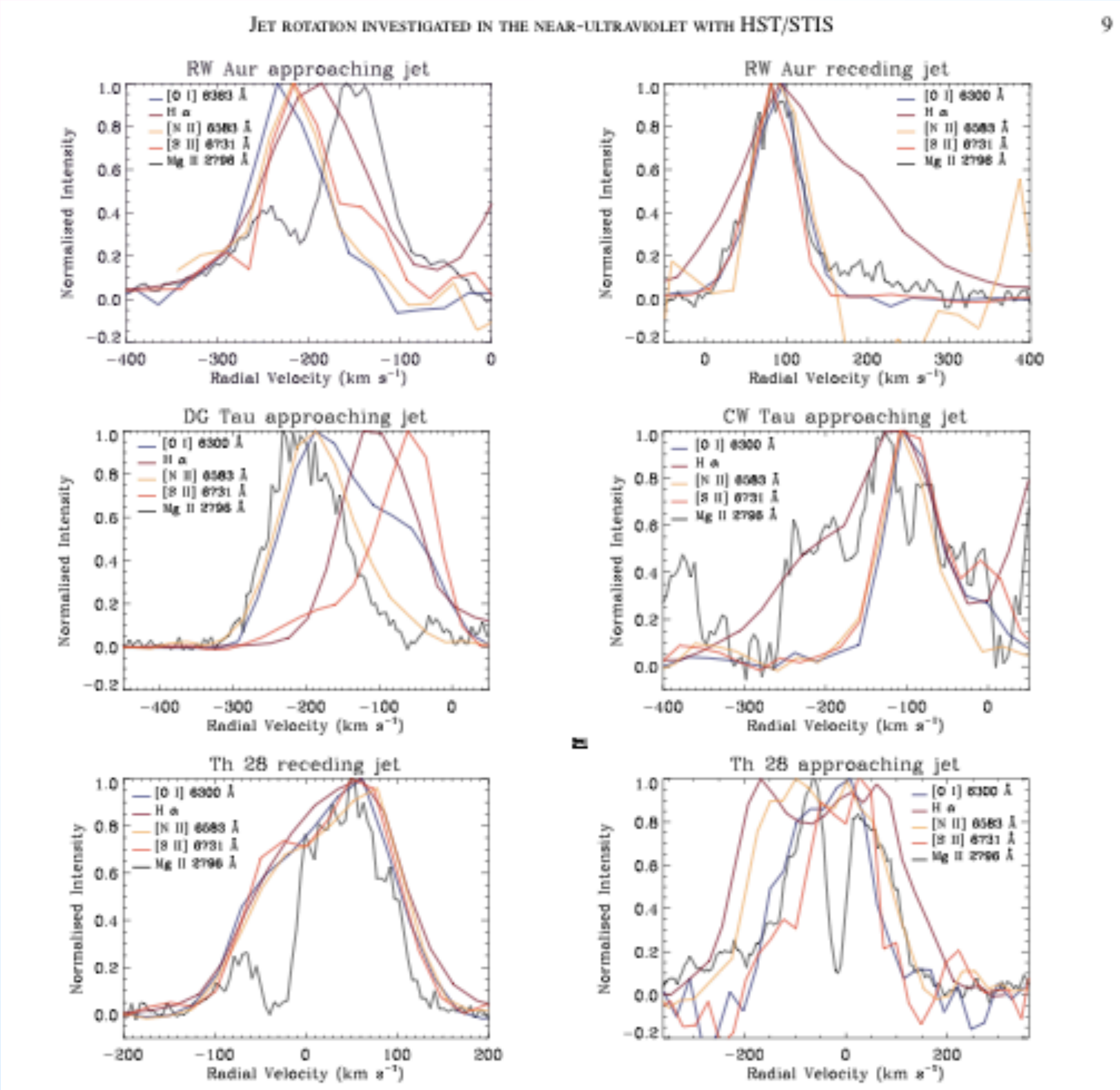
Receding Optical Jet counter rotating with respect to the disk (Coffey et al. 2004)

Approaching UV Jet rotating with the disk (Coffey et al. 2012)

One knot in HH212 counter rotating with the disk, also HH111 (Coffey et al. 2011)

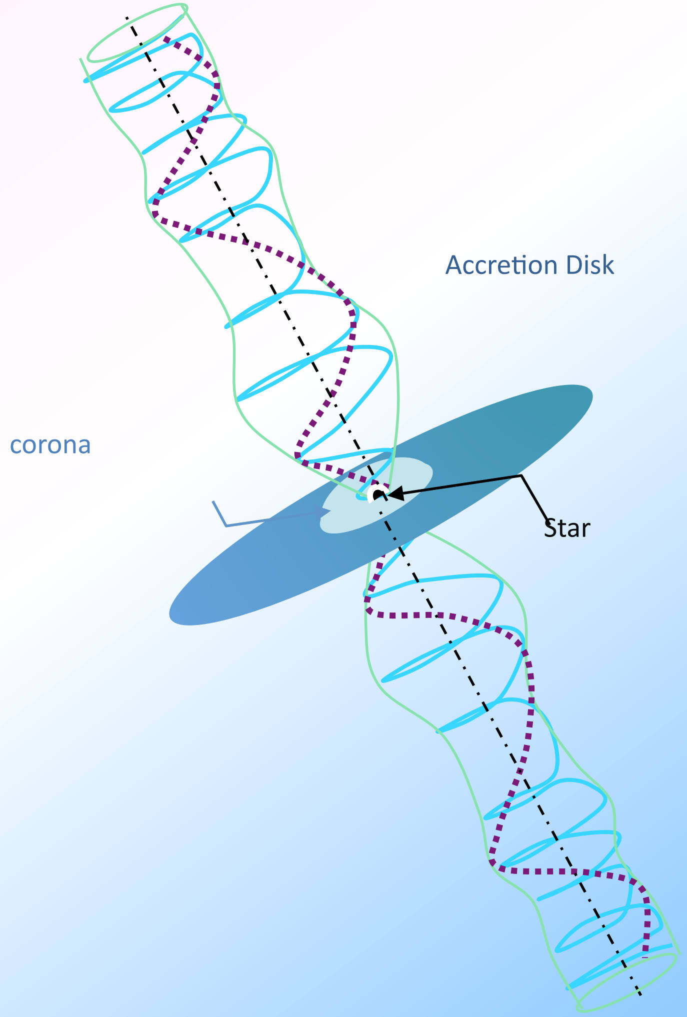
« Indeed, given the renowned complexity and variability of this system, it now seems likely that any rotation signature is confused by other influences, with the inevitable conclusion that RW Aur is not suited to a jet rotation study »

Counter rotation in RW Aur: fake or real ?

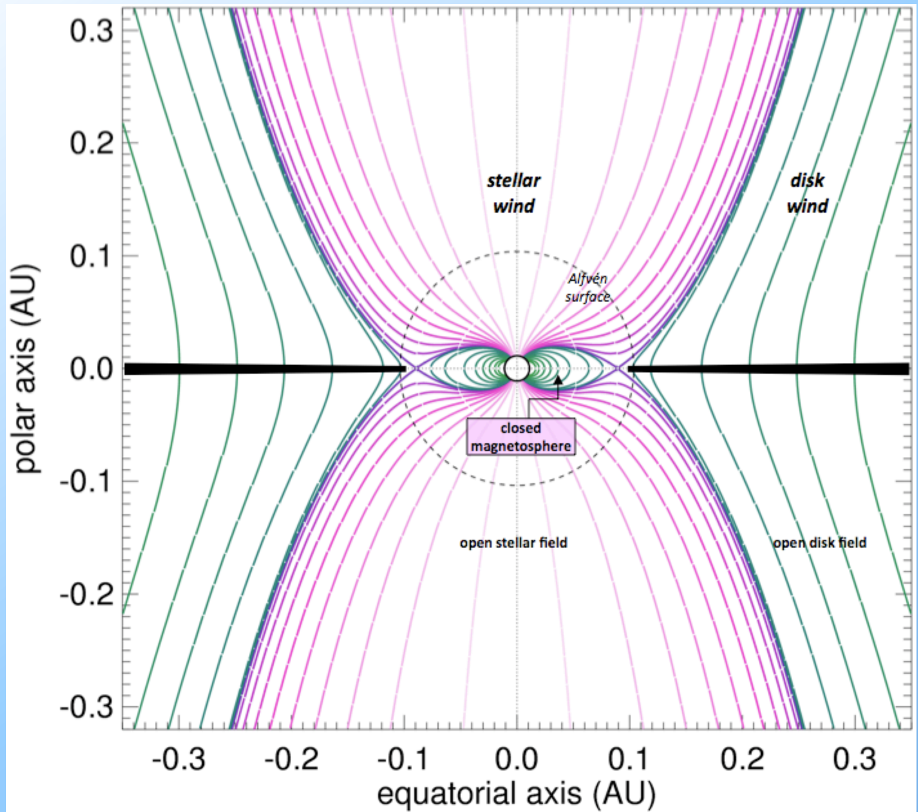


« Indeed, given the renowned complexity and variability of this system, it now seems likely that any rotation signature is confused by other influences, with the inevitable conclusion that RW Aur is not suited to a jet rotation study »

YSO Jets



Accretion Disk
corona
Star

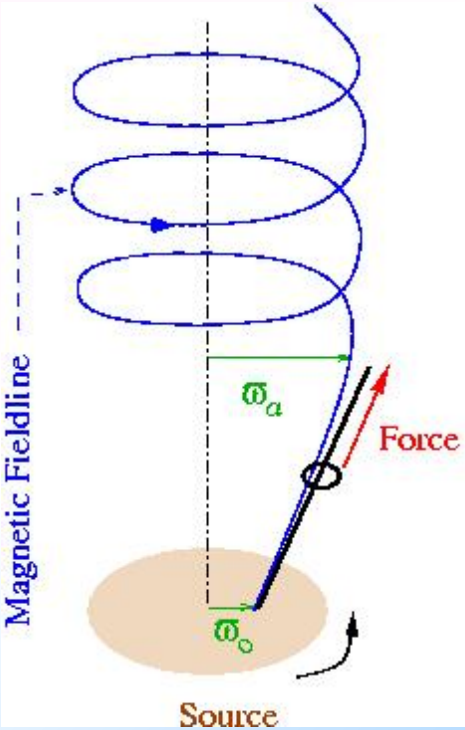


stellar wind
disk wind
Alfvén surface
closed magnetosphere
open stellar field
open disk field
polar axis (AU)
equatorial axis (AU)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3

Basics of steady, axisymmetrics outflows

$$\vec{V} = \vec{V}_p + V_\varphi \vec{e}_\varphi$$

$$\vec{B} = \vec{B}_p + B_\varphi \vec{e}_\varphi$$



$$\vec{\nabla}.\left(\rho\vec{V}\right) = 0 \Rightarrow \quad 4\pi\rho\vec{v}_p = \vec{\nabla}\times\left(\frac{\Psi}{\varpi}\vec{e}_\varphi\right)$$

$$\vec{\nabla}.\vec{B} = 0 \Rightarrow \quad \vec{B}_p = \vec{\nabla}\times\left(\frac{A}{\varpi}\vec{e}_\varphi\right)$$

$$\vec{\nabla}\times(\vec{v}\times\vec{B}) = \vec{0} \Rightarrow$$

ϕ

$$4\pi\rho\vec{v}_p // \vec{B}_p$$

p

$$\vec{v}\times\vec{B} = -c\vec{E} = \vec{\nabla}\Phi = \Omega\vec{\nabla}A$$

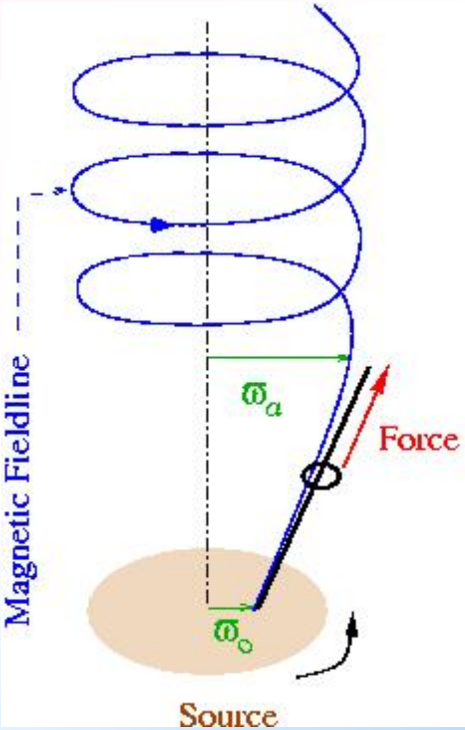
Euler equation in ϕ direction

Euler equation in ϕ direction

$$\varpi\left(v_\varphi - \frac{B_\varphi B_P}{4\pi\rho v_P}\right) = L(A)$$

$$V_\varphi - \frac{V_P}{B_P}B_\varphi = \varpi\Omega$$

Basics of steady, axisymmetrics outflows



$$L = \varpi\left(V_\varphi - \frac{B_\varphi B_P}{4\pi\rho V_P}\right)$$

$$\Omega = \frac{1}{\varpi}\left(V_\varphi - \frac{V_P}{B_P}B_\varphi\right)$$

$$\frac{B_\varphi}{\sqrt{4\pi\rho}} = -\frac{L}{\varpi}\frac{V_P}{V_A}\frac{1-\varpi^2\frac{L}{\Omega}}{1-\frac{V_P^2}{V_A^2}} = -\frac{L}{\varpi}\frac{V_P}{V_A}\frac{1-\frac{\varpi^2}{\varpi_*^2}}{1-M^2}$$

$$v_\varphi = \frac{L}{\varpi}\frac{\varpi^2\frac{\Omega}{L}-\frac{V_P^2}{V_A^2}}{1-\frac{V_P^2}{V_A^2}} = \frac{L}{\varpi}\frac{\frac{\varpi^2}{\varpi_*^2}-M^2}{1-M^2}$$

$$M^2 = \frac{V_{\mathrm{p}}^2}{V_{\mathrm{p}A}^2}$$

$$\varpi_*^2 = \frac{L}{\Omega}$$

Counter Rotation

$$\frac{B_\varphi}{\sqrt{4\pi\rho}} = -\frac{L}{\varpi}\frac{V_P}{V_A}\frac{\dfrac{\varpi^2}{\varpi_*^2}-1}{\dfrac{V_P^2}{V_A^2}-1}$$

$$V_\varphi = \frac{L}{\varpi}\frac{\dfrac{V_P^2}{V_A^2}-\dfrac{\varpi^2}{\varpi_*^2}}{\dfrac{V_P^2}{V_A^2}-1}$$

IF flow super alfvénic

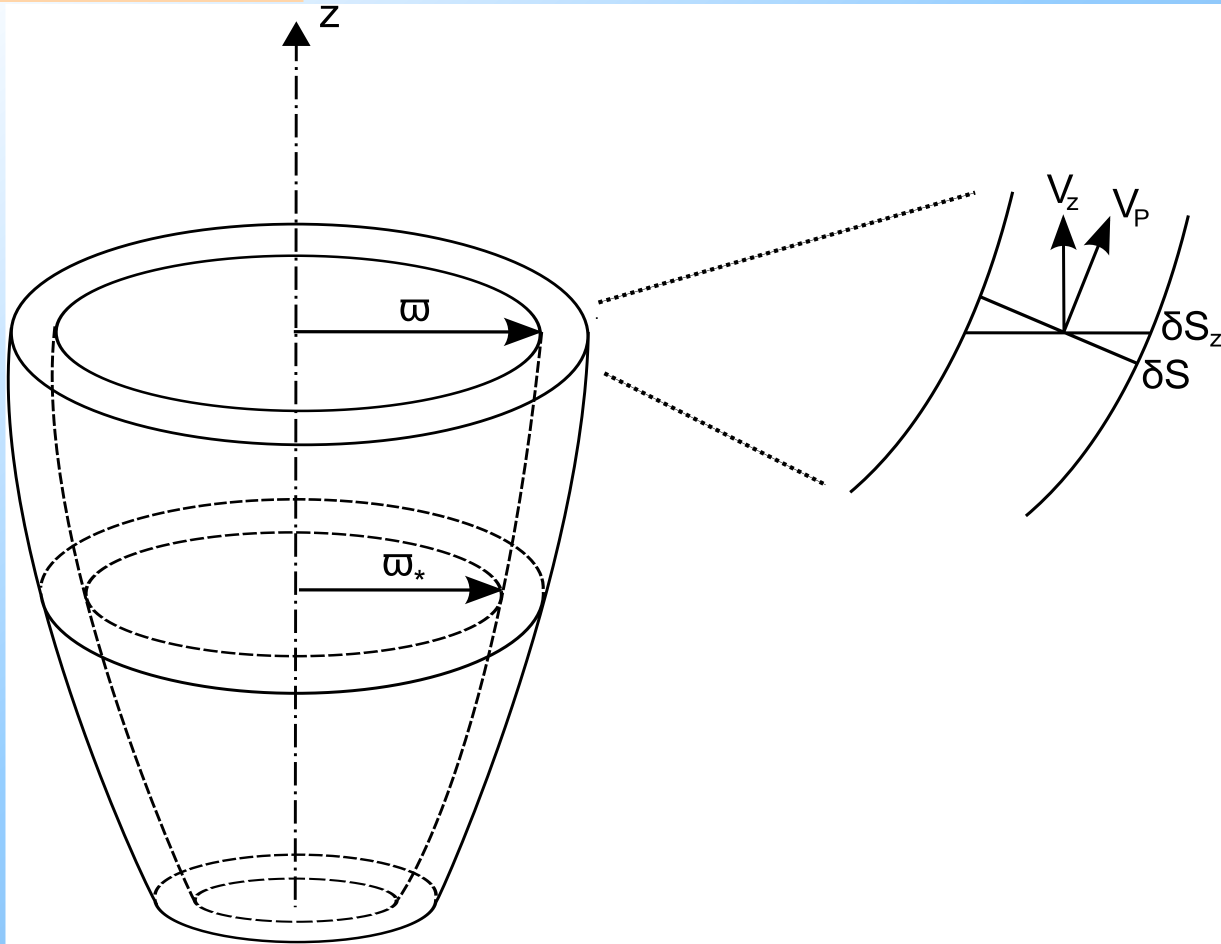
$$\frac{V_P^2}{V_A^2}-1>0 \Rightarrow \mathrm{sgn}(V_\varphi) = \left(\frac{V_P^2}{V_A^2}-\frac{\varpi^2}{\varpi_*^2}\right)$$

(opposite IF flow sub alfvénic)

Counter Rotation

$$\vec{\nabla}.\left(\rho\vec{V}\right)=0\Rightarrow 4\pi\rho V_P\delta S \;=cst\;=4\pi\rho_* V_*\delta S_*$$

$$\vec{\nabla}.\vec{B}=0\Rightarrow B_P\delta S \;=cst\;=B_*\delta S_*$$



Counter Rotation

$$\vec{\nabla}.\left(\rho\vec{V}\right) = 0 \Rightarrow 4\pi\rho V_P \delta S \;= cst = 4\pi\rho_* V_* \delta S_*$$

$$\vec{\nabla}.\vec{B} = 0 \Rightarrow B_P \delta S \;= cst = B_* \delta S_*$$

$$\frac{V_P^2}{V_A^2} - \frac{\varpi^2}{\varpi_*^2} = \frac{4\pi\rho V_P^2}{B_P^2} - \frac{\varpi^2}{\varpi_*^2} = \frac{4\pi\rho V_P}{B_P^2} V_P - \frac{\varpi^2}{\varpi_*^2} = \frac{4\pi\rho_* V_* \dfrac{\delta S_*}{\delta S}}{B_*^2 \dfrac{\delta S_*^2}{\delta S^2}} V_P - \frac{\varpi^2}{\varpi_*^2}$$

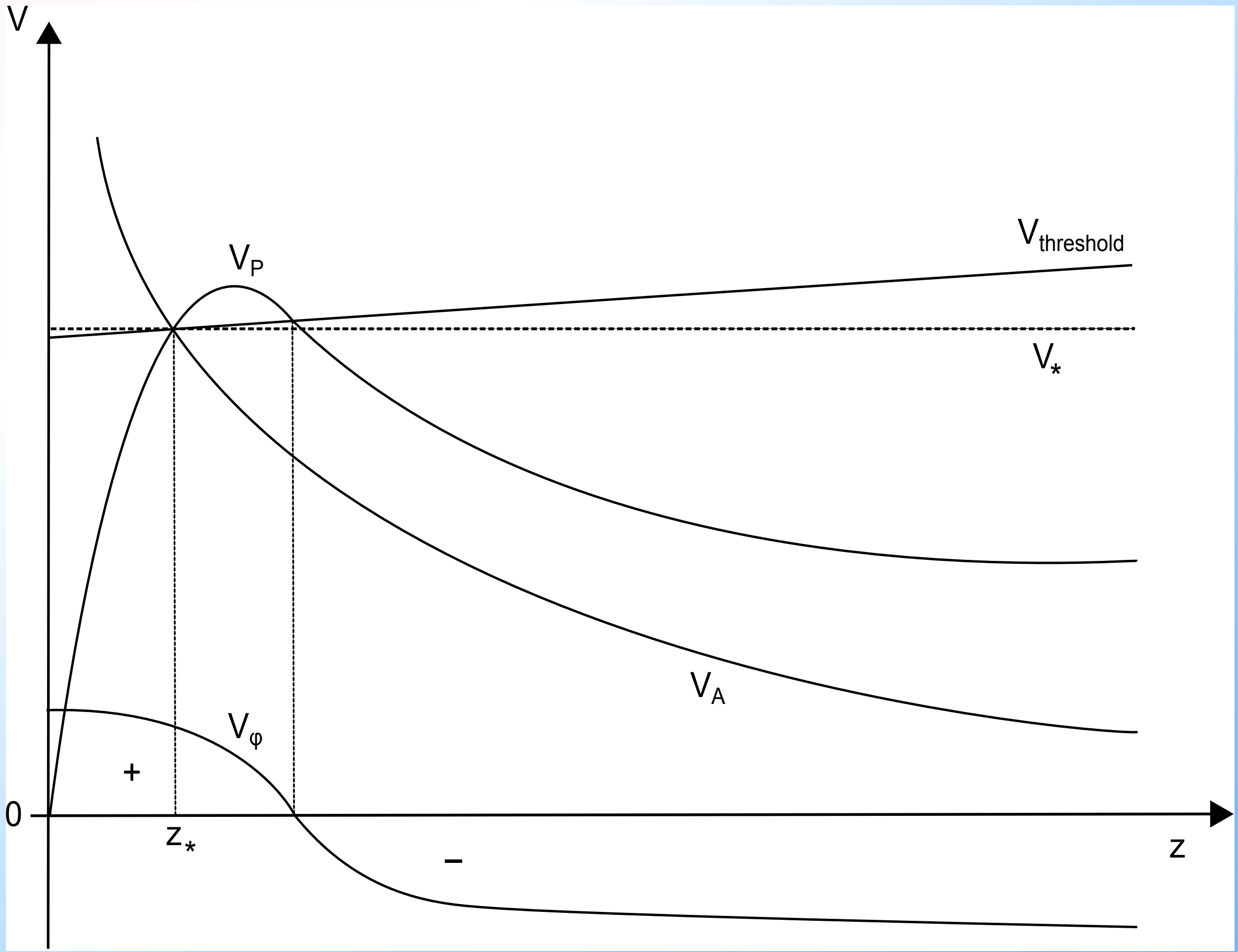
$$= \frac{4\pi\rho_* V_*^2}{B_*^2} \frac{\delta S \; V_P}{\delta S_* V_*} - \frac{\varpi^2}{\varpi_*^2} = \frac{\delta S \; V_P}{\delta S_* V_*} - \frac{\varpi^2}{\varpi_*^2}$$

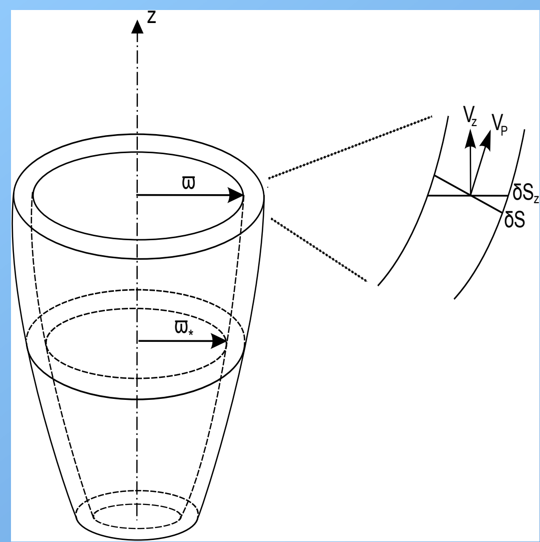
$$\operatorname{sgn}(V_\varphi) = \operatorname{sgn}\left(\frac{V_P^2}{V_A^2} - \frac{\varpi^2}{\varpi_*^2}\right) = \operatorname{sgn}\left(\frac{V_P}{V_*} - \frac{\varpi^2}{\varpi_*^2}\frac{\delta S_*}{\delta S}\right)$$

Counter Rotation

$$\mathrm{sgn}(V_\varphi) = \mathrm{sgn}\left(\frac{V_P}{V_*} - \frac{\varpi^2}{\varpi_*^2}\frac{\delta S_*}{\delta S}\right)$$

$$V_\varphi < 0 \Rightarrow V_P < V_* \frac{\varpi^2}{\varpi_*^2}\frac{\delta S_*}{\delta S} = V_{threshold}$$





Jets and Winds : The Sun and RW Aur

$$V_\varphi < 0 \Rightarrow V_P < V_* \frac{\varpi^2}{\varpi_*^2}\frac{\delta S_*}{\delta S} = V_{threshold}$$

For the Sun (spherically symmetric)

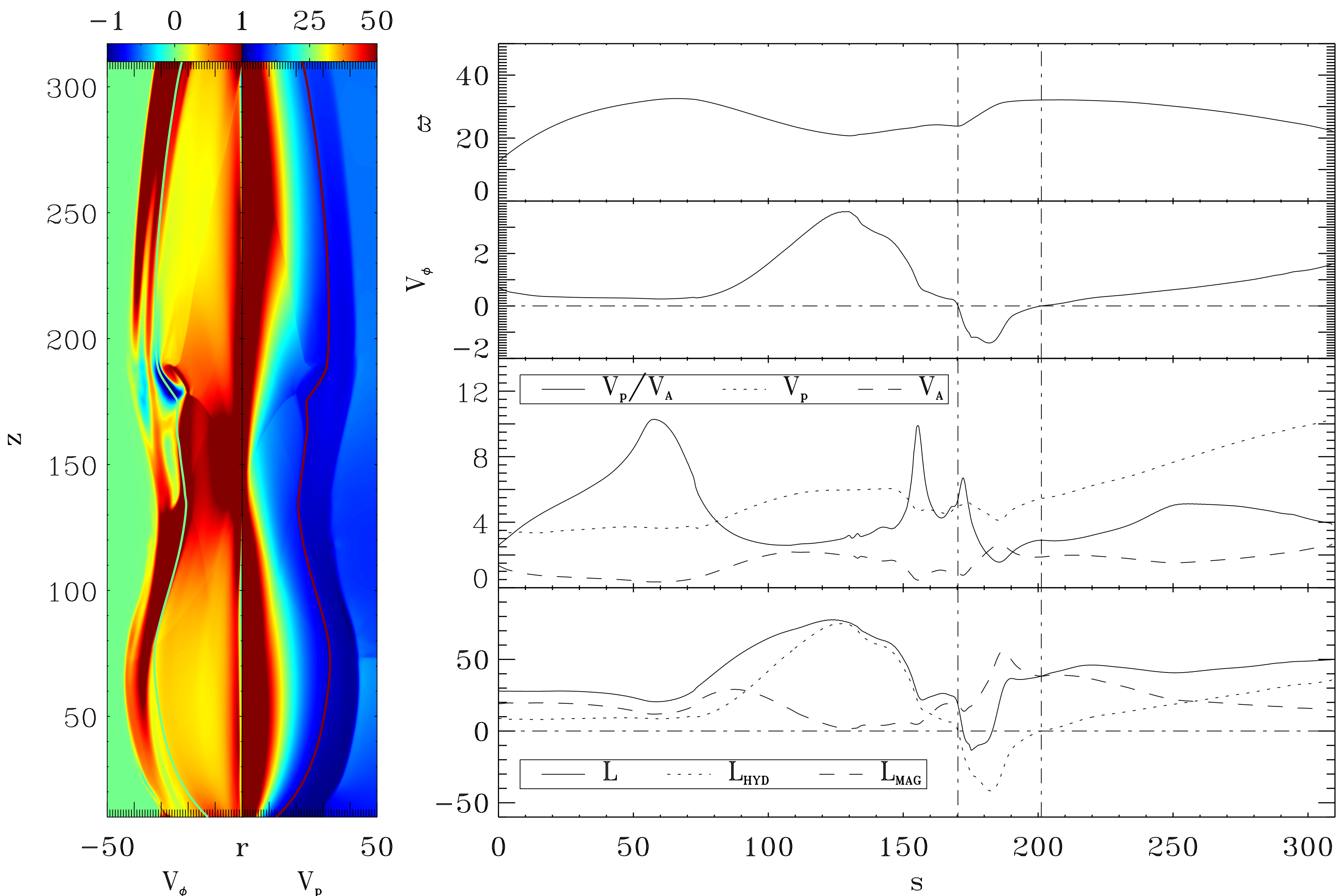
$$V_{threshold} = V_* \frac{\varpi^2}{\varpi_*^2}\frac{\delta S_*}{\delta S} \approx V_*$$

For the RW aur (averaging over the jet)

$$\overline{V} = \frac{\int V_P \delta S}{\int \delta S} = \frac{\int V_P \delta S}{4\pi\varpi^2} < \frac{\int V_* \delta S}{\varpi_*^2} = \frac{\int V_* \delta S}{\int \delta S_*} = \overline{V}_* = V_{threshold}$$

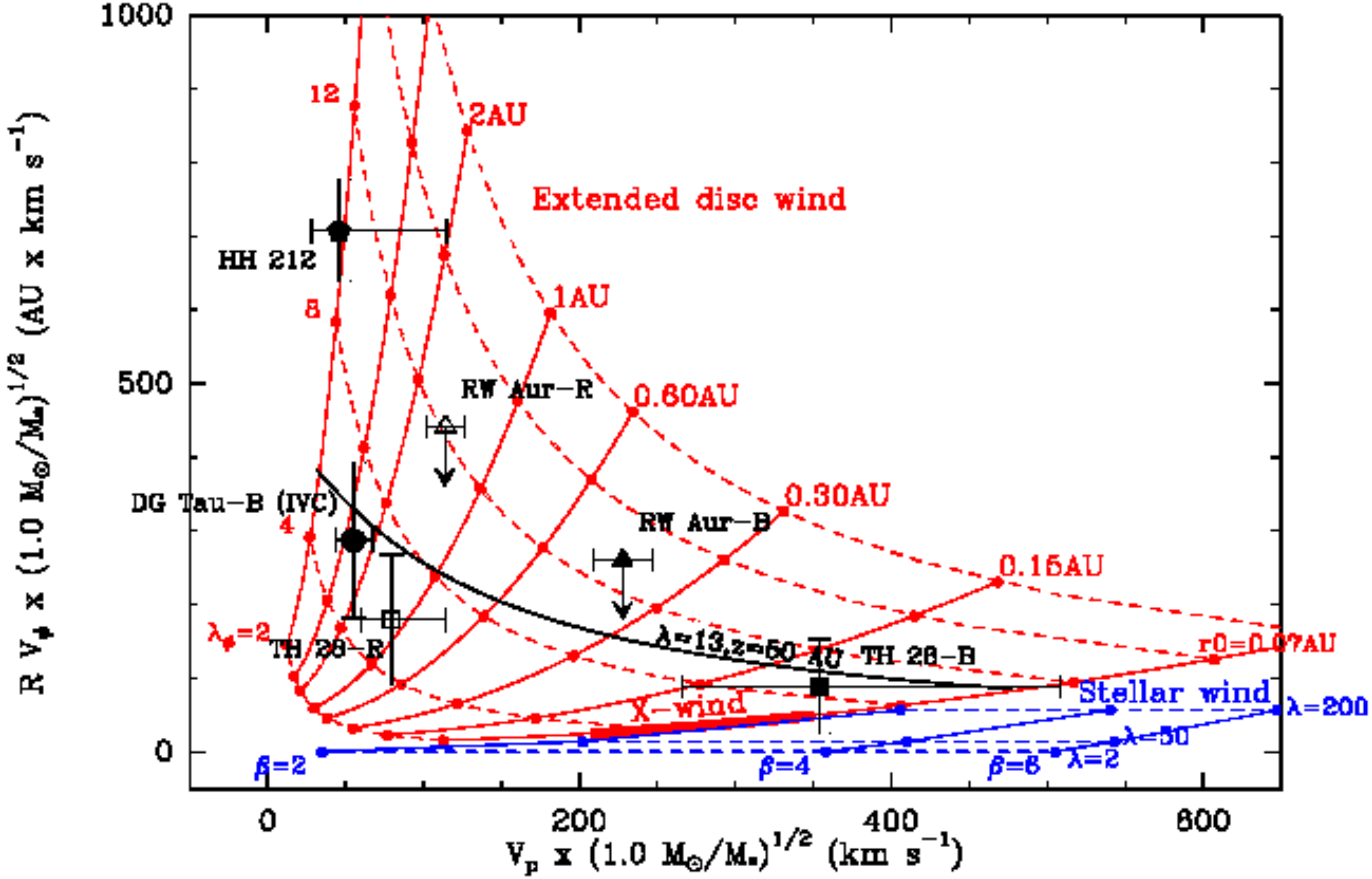
.... For analytical self similar solutions other expressions etc....

Jet simulations : from jet asymmetries to counter rotation



Does it contradict magnetocentrifugal driving ?

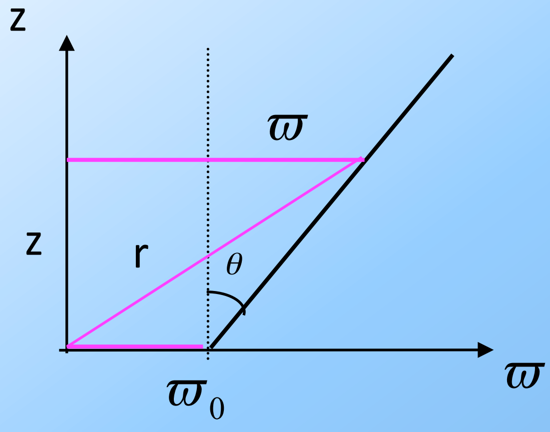
Ferreira et al. (2006)



Does it contradict magnetocentrifugal driving ?

$$\varpi_*^2 = \frac{L}{\Omega}$$

$$E(A) = \frac{1}{2}V_P^2 + \frac{1}{2}V_\varphi^2 + h + \Phi_{grav} - \frac{\varpi\Omega}{\Psi_A}B_\varphi$$



In the co-rotating frame (Anderson et al 2003 ApJ)

$$F(A) = E(A) - L\Omega$$

$$= \frac{1}{2}V_P^2 + \frac{1}{2}(V_\varphi - \varpi\Omega)^2 + h + \Phi_{grav} - \frac{1}{2}(\varpi\Omega)^2$$

Cold Plasma $\quad h \approx 0$

$$V_\infty^2 \approx \frac{GM_*}{\varpi_0} = V_K^2$$

Cf. Observations

$$F = \frac{V^2}{2} - \varpi v_\varphi \Omega + \Phi_G$$

$$\Phi_G = -\frac{Gm}{\varpi_0} = -V_{Keplerian}^2$$

Close to the disk

$$F = \frac{V_{Keplerian}^2}{2} - \varpi_0 V_{Keplerian}\Omega_{Keplerian} - V_{Keplerian}^2 = \left(\frac{1}{2} - 1 - 1\right)V_{Keplerian}^2 = -\frac{3}{2}V_{Keplerian}^2$$

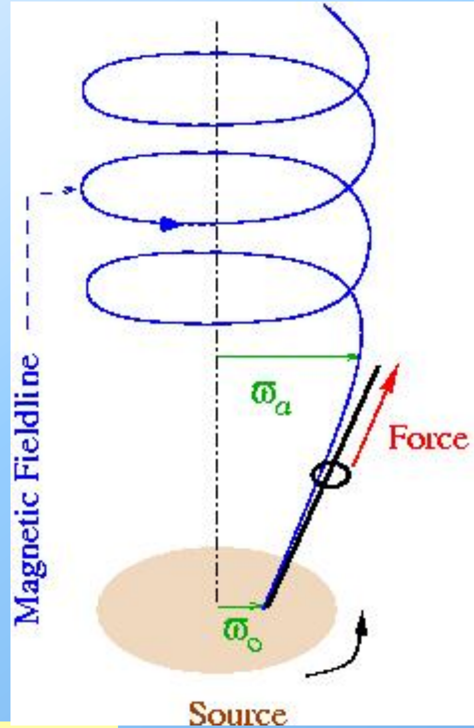
Does it contradict magnetocentrifugal driving ? NO !

$$F = -\frac{3}{2}V^2_{\mathrm{Keplerian}}$$

$$F = \frac{V_\infty^{\ 2}}{2} - \varpi_\infty V_{\varphi\infty}\Omega$$

$\Phi_{G\infty} << V_\infty^2$ $\quad V_{\mathrm{P}} = V_\infty$

$(\Omega\varpi v_\phi)_\infty$ Not negligible $\quad \varpi_\infty >> \varpi_0 \quad V_{\phi\infty} << V_\infty$



$$F = \frac{V_\infty^{\ 2}}{2} - \varpi_\infty V_{\varphi\infty}\Omega = -\frac{3}{2}V^2_{\mathrm{Keplerian}} \approx 0$$

$$\frac{3}{2}V^2_{\mathrm{Keplerian}} << \frac{1}{2}V_\infty^2$$

$$\frac{V_\infty^{\ 2}}{2} = \varpi_\infty V_{\varphi\infty}\Omega \Rightarrow \Omega = \frac{V_\infty^{\ 2}}{2\varpi_\infty V_{\varphi\infty}} \quad \& \quad \Omega = \sqrt{\frac{Gm}{\varpi_0^3}}$$

$$\varpi_0 = \left(\frac{4Gm\varpi_\infty^2 V_{\varphi\infty}^2}{V_\infty^4}\right)^{1/3}$$

$$\Omega = \frac{V_\infty^{\ 2}}{2\varpi_\infty V_{\varphi\infty}}$$

Same sign for Ω and Vϕ but NO THERMODYNAMICS
So no valid contradiction !

Conclusions : Counter rotatingJets and Winds, the Sun, RW Aur and others

Not necessarily permanent (transient even if steady)

Not necessarily global - local counter rotation possible

Difficult to detect, more resolution is needed

Does not contradict magnetocentrifugal lauching

Obvious generalisation to relativistic jets