Simulation of Magnetic Spindown in Rotating Hot-Star Winds

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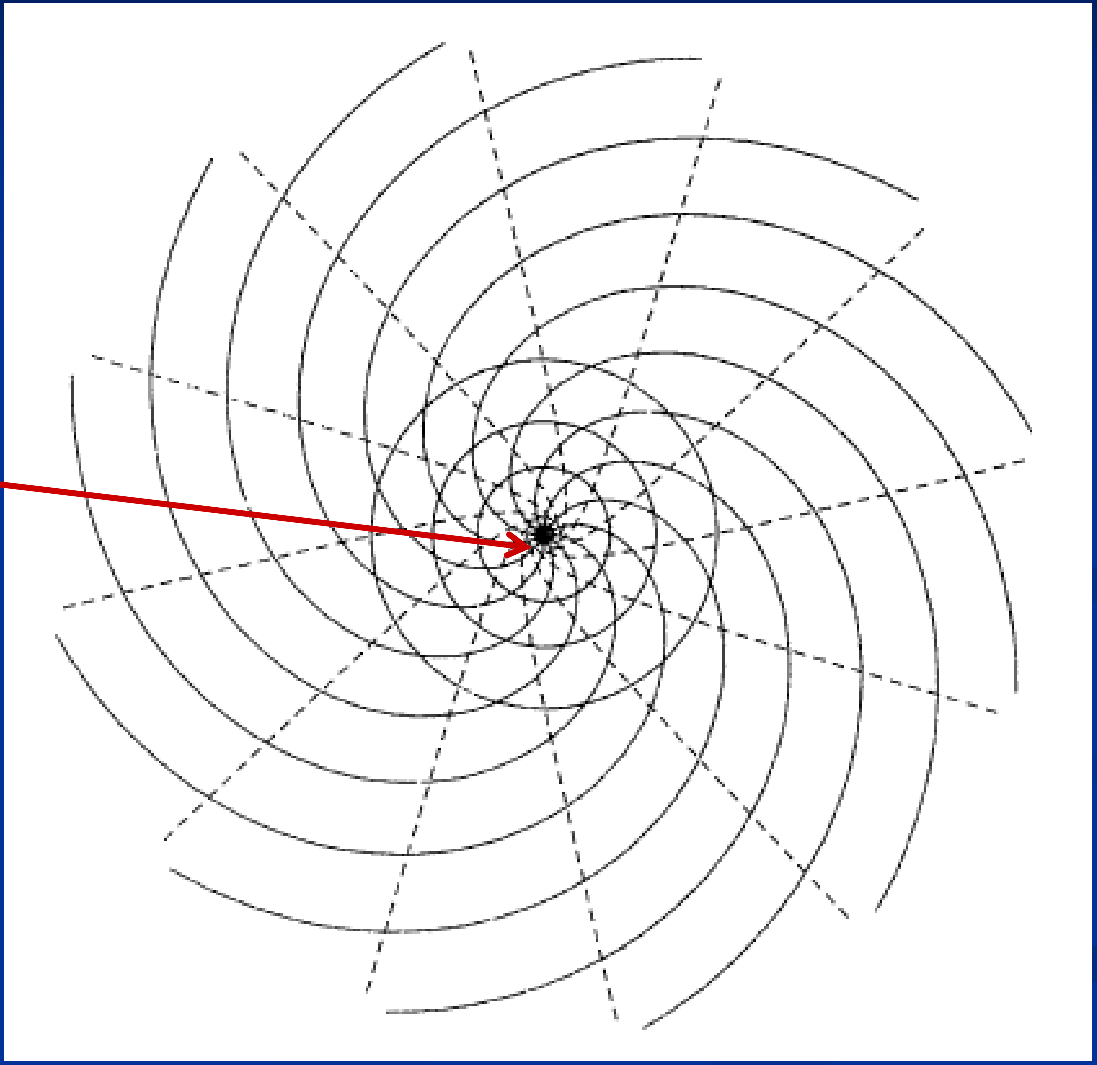
Collaborators: Stan Owocki, Rich Townsend

Weber and Davis (1967)

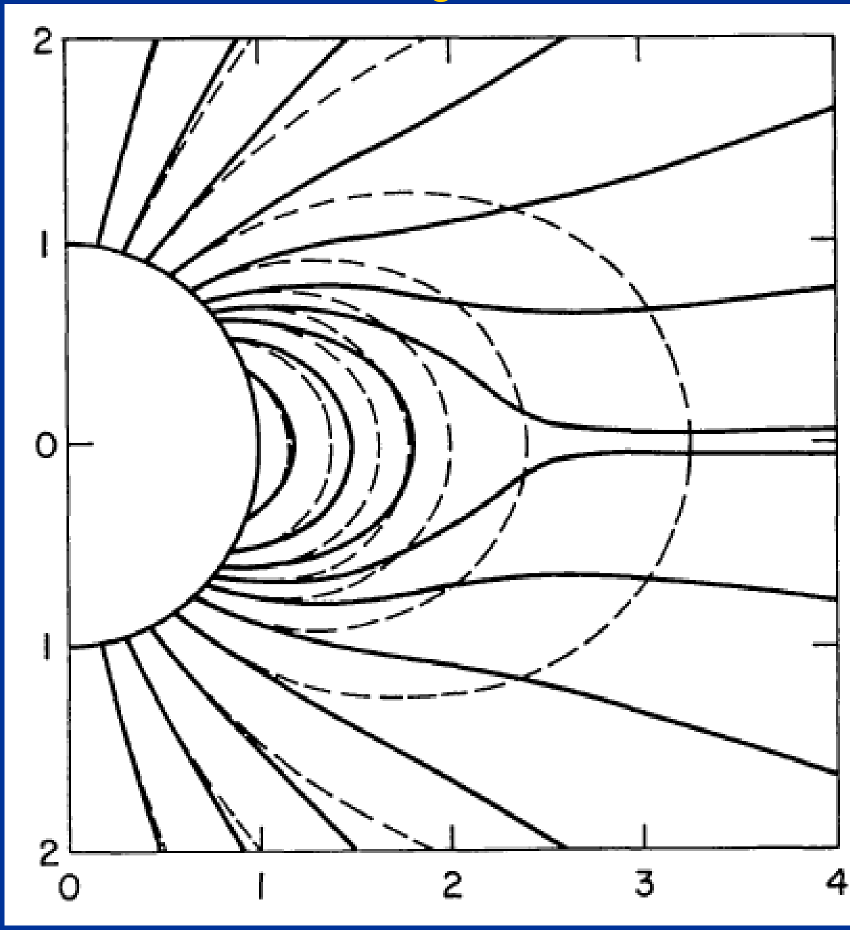
Monopole field at solar surface



Pneuman and Kopp (1971)

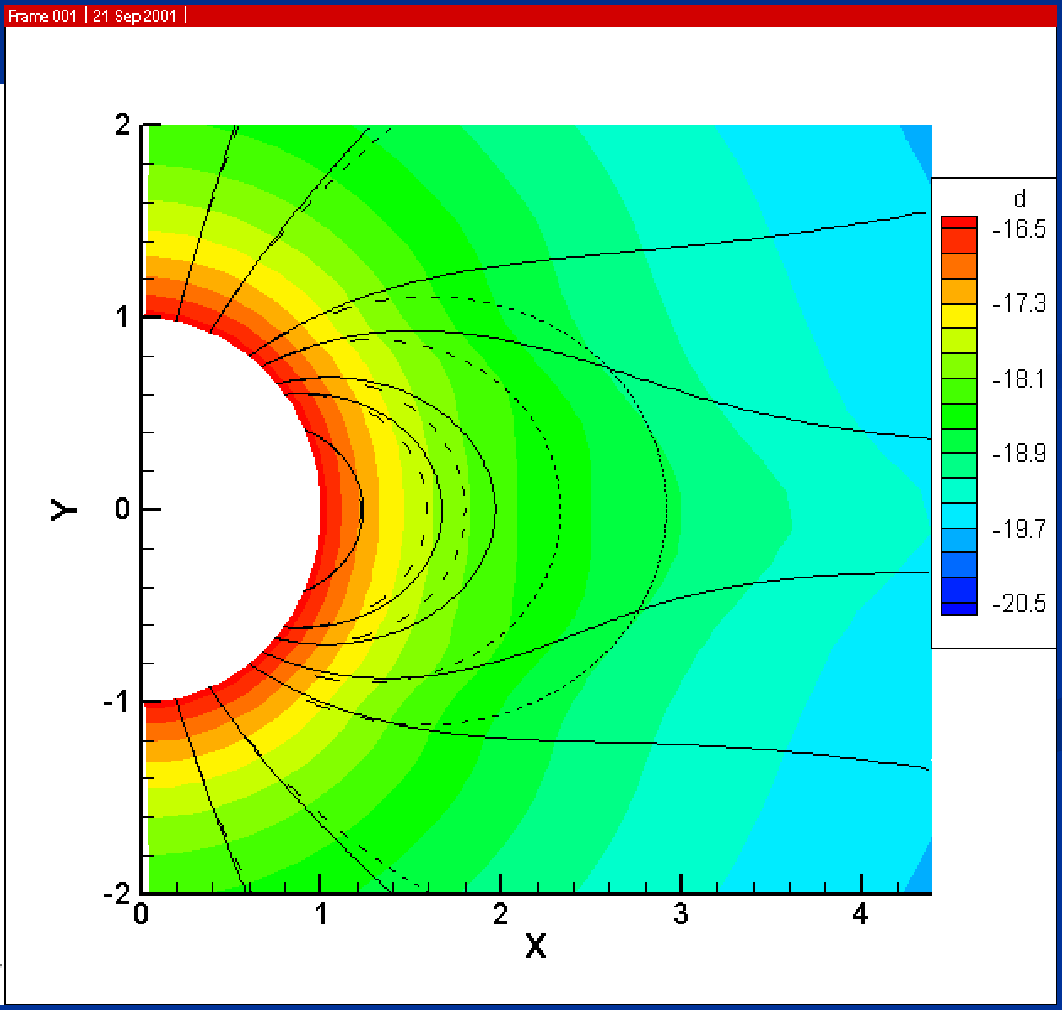
Iterative scheme

MHD model for base dipole with B_o=1 G



Fully dynamic, time dependent

Our Simulation



Wind Magnetic Confinement Parameter

$$\eta(r) = \frac{B^2 r^2}{\dot{M} v} = \underbrace{\left[\frac{B_0^2 R_*^2}{\dot{M}\, v_\infty}\right]}_{\equiv \eta_*} \left[\frac{(r/R_*)^{(2-2q)}}{(1-(R_*/r))^{\beta}}\right]$$

Angular Momentum Loss

Contribution from the field

$$\dot{J}_B = \int -\frac{B_r B_\phi(r,\theta)}{4\pi} r \sin\theta dA$$

Contribution from gas

$$\dot{J}_{gas} = \int \rho v_r v_\phi r \sin\theta dA$$

Need to compute

Total loss $$\dot{J}_{tot} = \dot{J}_B + \dot{J}_{gas}$$

Weber and Davis $$\dot{J}_{tot} \approx \frac{2}{3} \dot{M} \Omega R_A^2$$

As if gas co-rotates to R_A

Computing Alfven Radius

$$\eta(r) = \eta_* \left[\frac{(r / R_*)^{2-2q}}{(1-(R_* / r))^{\beta}} \right]$$

For hot stars, β~1

Alfven radius

$$\eta(R_A) \equiv 1$$

For a monopole q=2

$$\frac{R_A}{R_*} \approx \eta_*^{1/2}$$

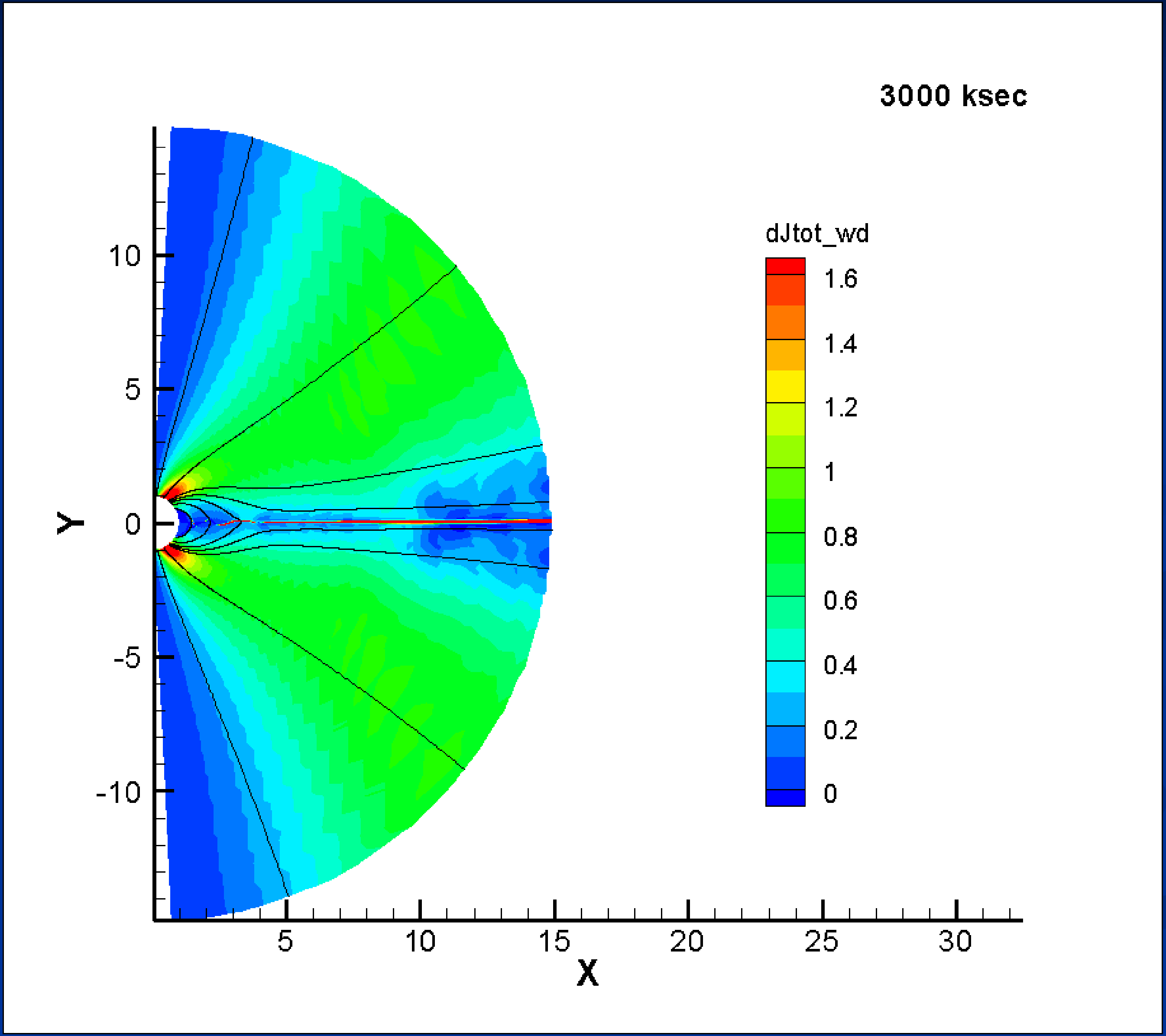
$$\dot{J} \approx \tfrac{2}{3} \dot{M} \Omega R_*^2 \eta_*$$

For a dipole q=3

$$\frac{R_A}{R_*} \approx \eta_*^{1/4}$$

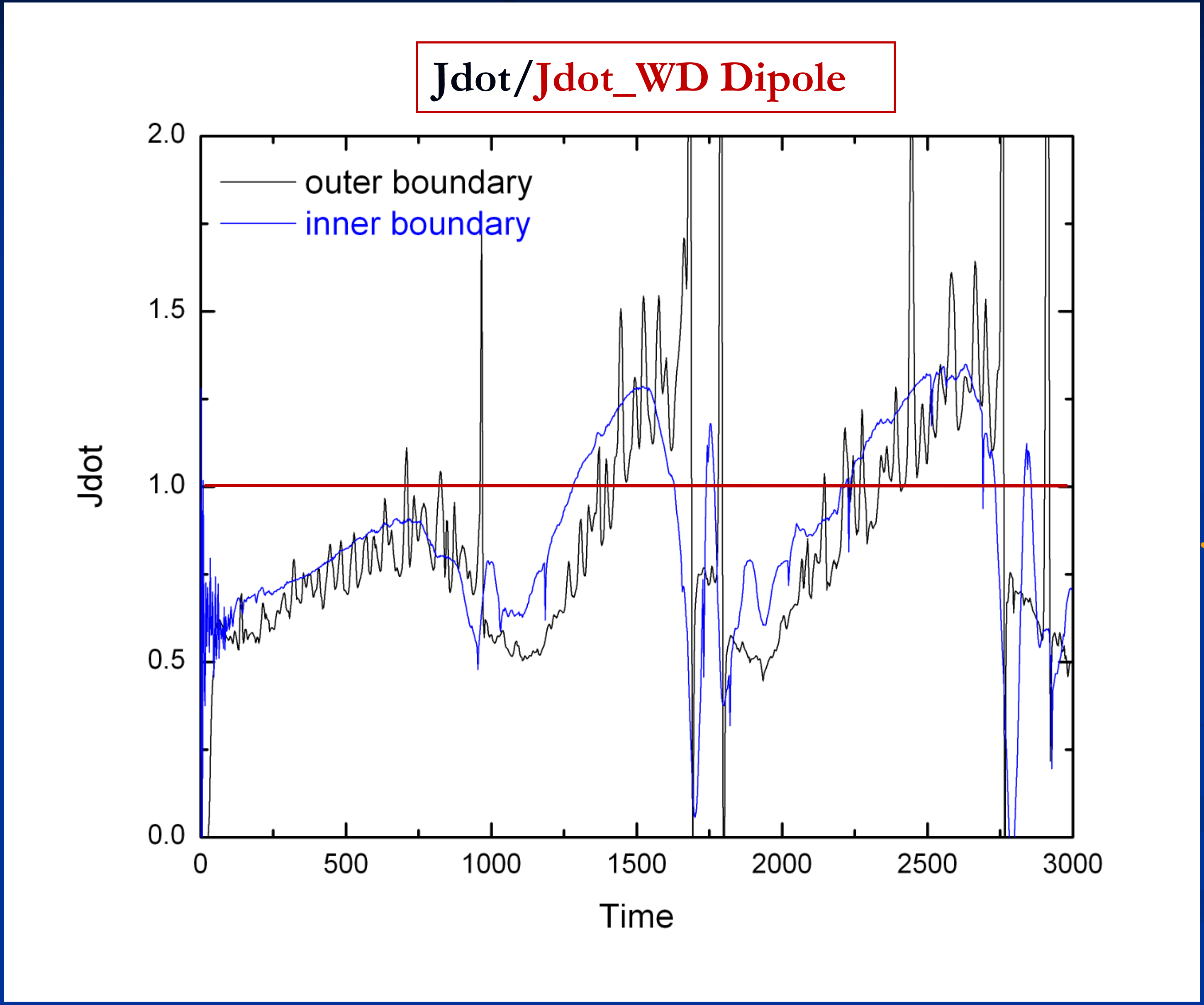
$$\dot{J} \approx \tfrac{2}{3} \dot{M} \Omega R_*^2 \sqrt{\eta_*}$$

Angular Momentum Loss: Sims



Dead Zone Lives!

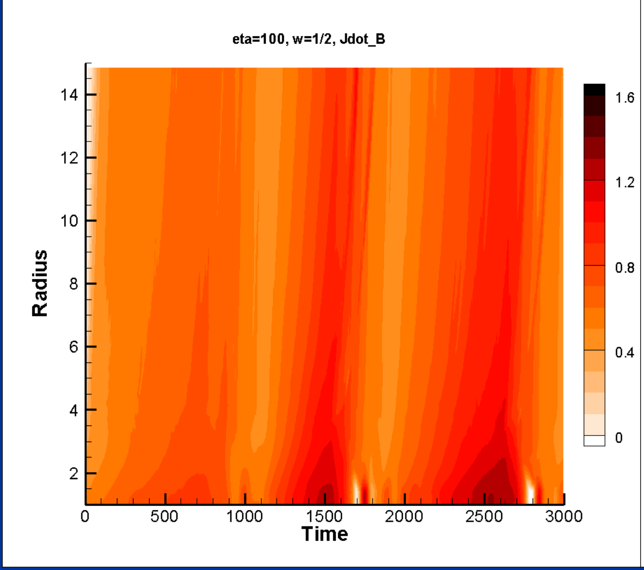
Angular Momentum Loss

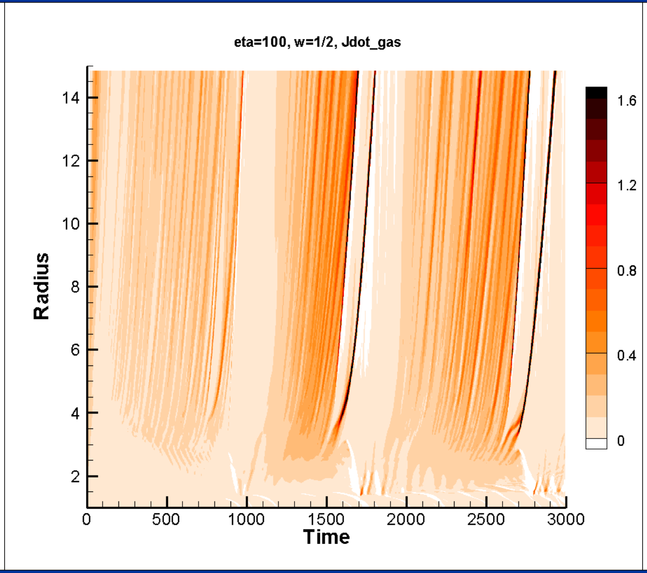


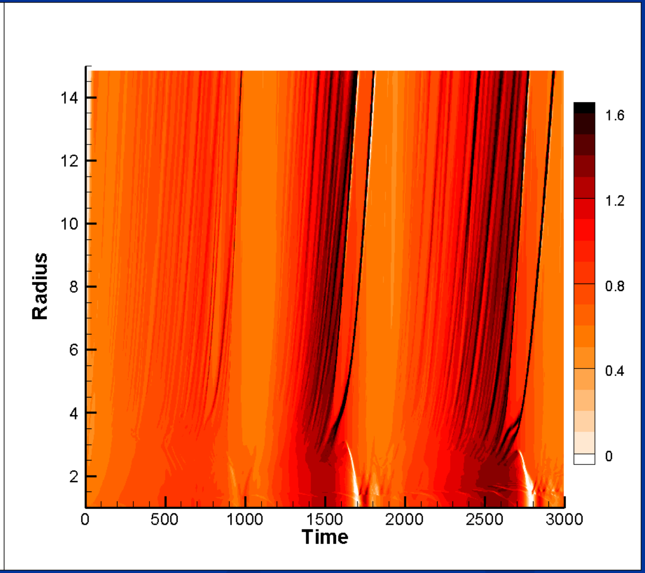
Jdot goes down during outbreaks.
Sorry, Trigiolo (2008)!

Angular Momentum Loss

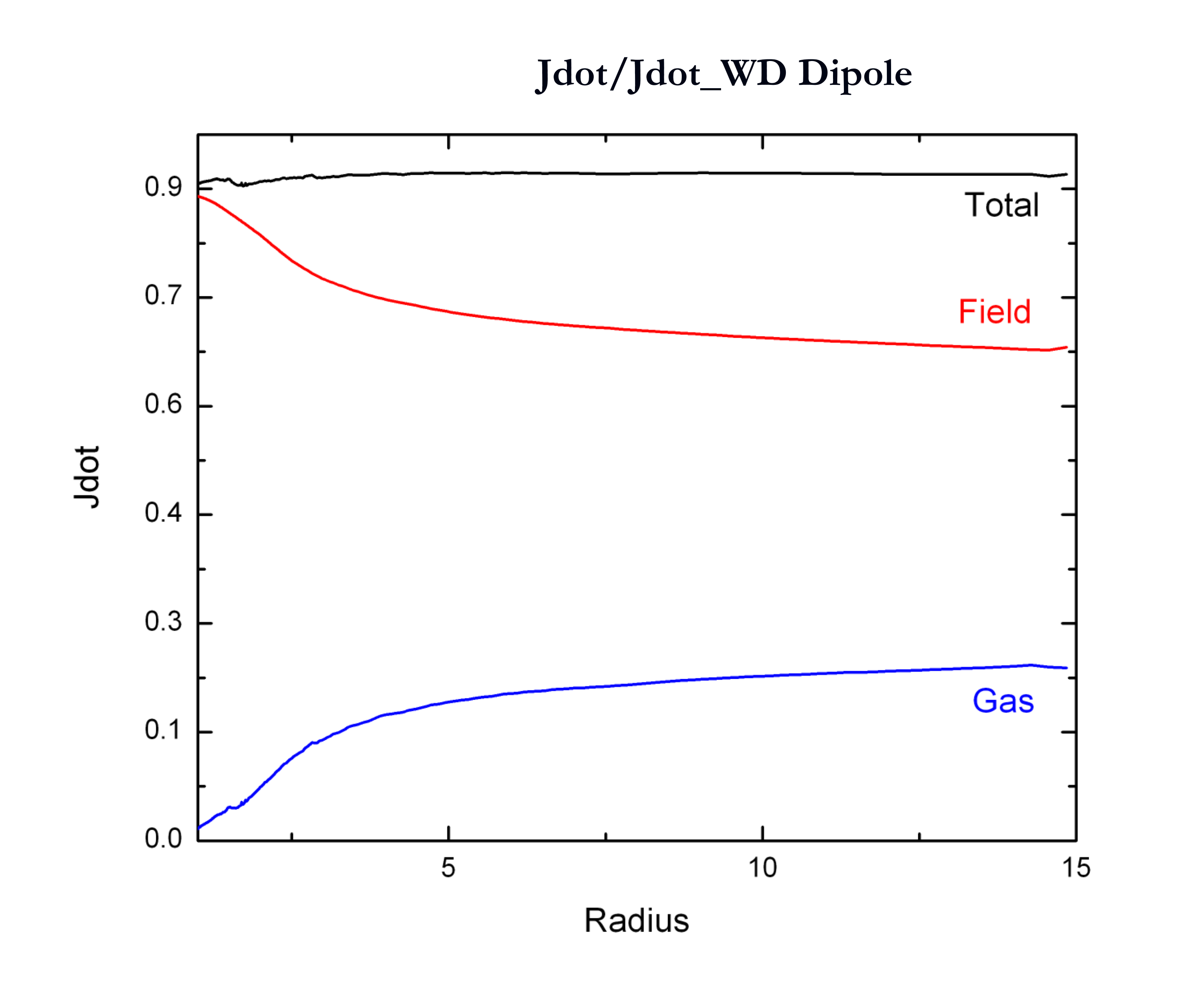
Magnetic Field + Gas = Total







Time-Averaged Angular Momentum Loss



Angular Momentum Loss
Weber and Davis

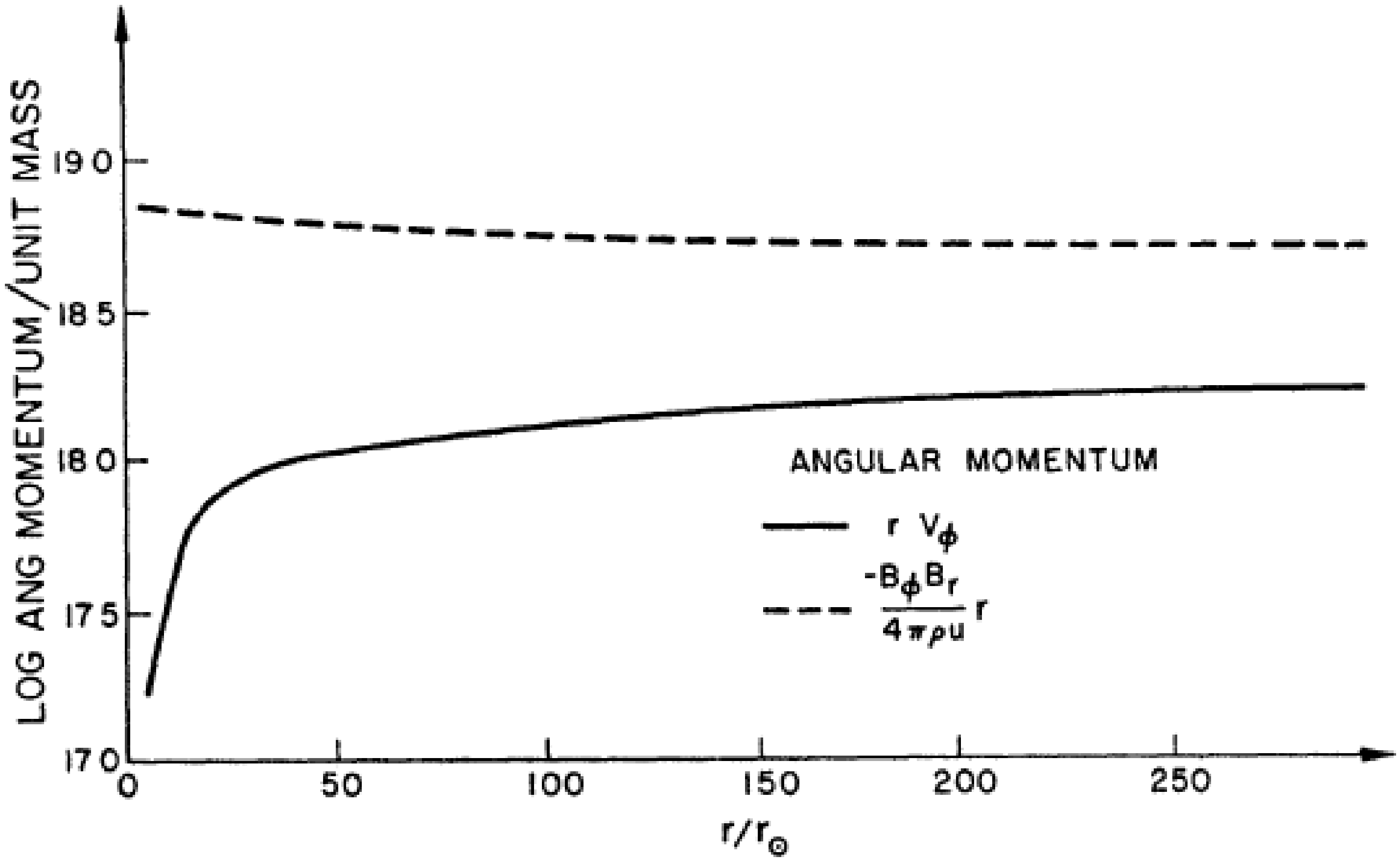


FIG. 5.—Angular momentum and magnetic torque in the solar wind

Spindown

$$\dot{J} \approx \frac{2}{3}\dot{M}\Omega R_A^2$$

contribution from both field and gas

For Dipole

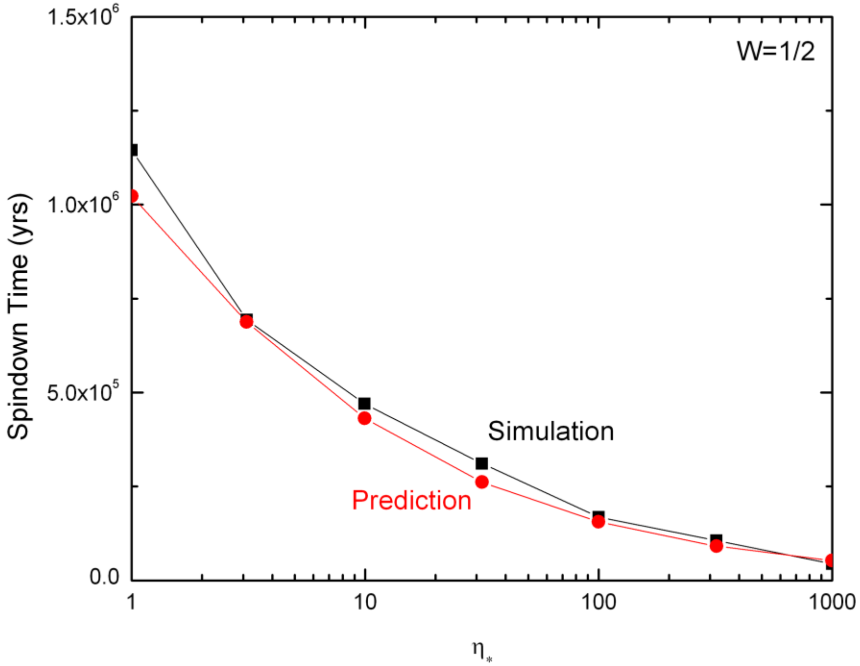
$$\tau_{spin} \equiv \frac{J}{\dot{J}} \approx \frac{\frac{3}{2}I}{MR^2}\frac{M}{\dot{M}}\frac{1}{\sqrt{\eta_*}} = \tau_{mass}\frac{\frac{3}{2}k}{\sqrt{\eta_*}}$$

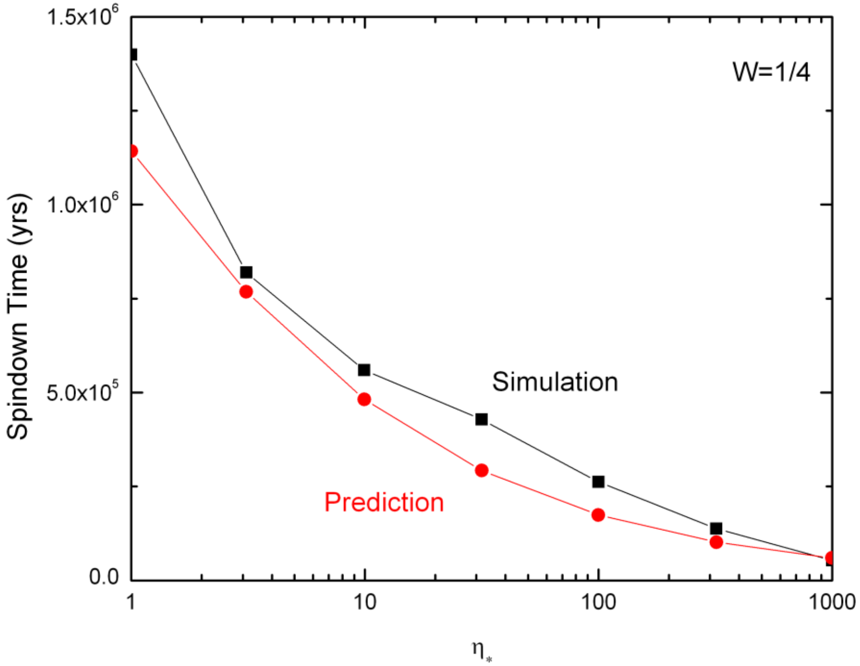
$$\frac{\tau_{spin}}{\tau_{mass}} \approx \frac{0.15}{\sqrt{\eta_*}}$$

Quiz: what is the scaling for monopole?

Spindown Time

W=1/2 **W=1/4**





Sample Spindown Time

Selected Stars on our target list

Name	M(Msun)	Mdot (Msun/yr)	Bp (G)	R(Rsun)	Vinf (km/s)	η_*	τ_m (Myr)	τ_sm(Myr)	τ_sd (Myr)
Theta 1 Ori C	44	4.0E-07	1100	8.2	2500	15.7	110.0	1.1	4.2
HD 191612	40	6.1E-06	1500	16.7	2600	7.6	6.6	0.1	0.4
Zeta Cas	8	3.0E-10	340	5.9	800	3.2E+03	2.7E+04	1.2	70.3
Sigma Ori E	8.9	1.0E-10	9600	5.3	420	1.2E+07	8.9E+04	1.1E-03	3.9

Monopole Dipole

Conclusions

- Angular momentum loss $\dot{J} \propto \Omega R_A^{\ 2}$
- Spindown time ~ Mass time / $\sqrt{\eta_*}$
- $\dot{J}_B > \dot{J}_{gas}$
- breakout events: J stored and released