Magnetic Activity of Solar-like Stars and Stellar Dynamos

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Plan of the Talk

- Summary of observational data on stellar cycles
- An introduction to solar flux transport dynamo model
- Extrapolation from the Sun to the stars

My limited experience:

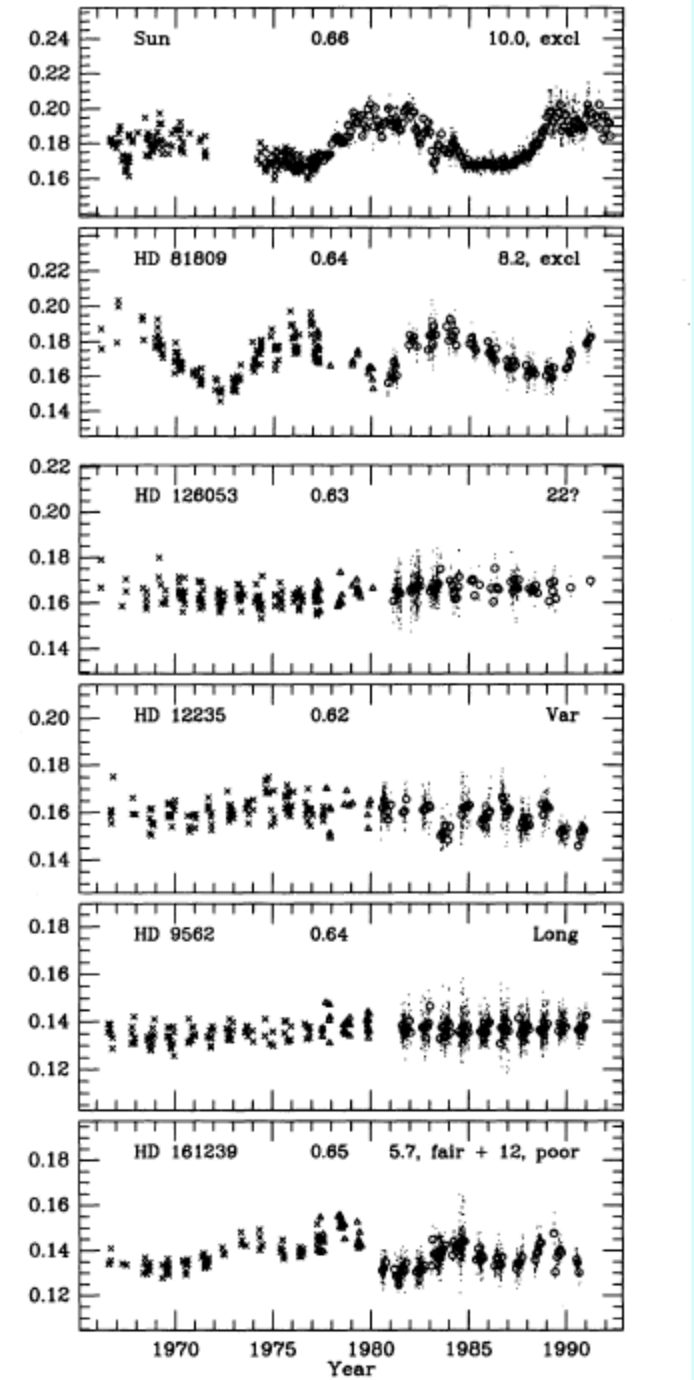
Karak, B. B., Kitchatinov, L. L., & Choudhuri, A. R., 2014, "A Dynamo Model of Magnetic Activity in Solar-like Stars with Different Rotational Velocities", *ApJ* **791,** 59.

Ca H/K lines have emission cores that indicate magnetic activity

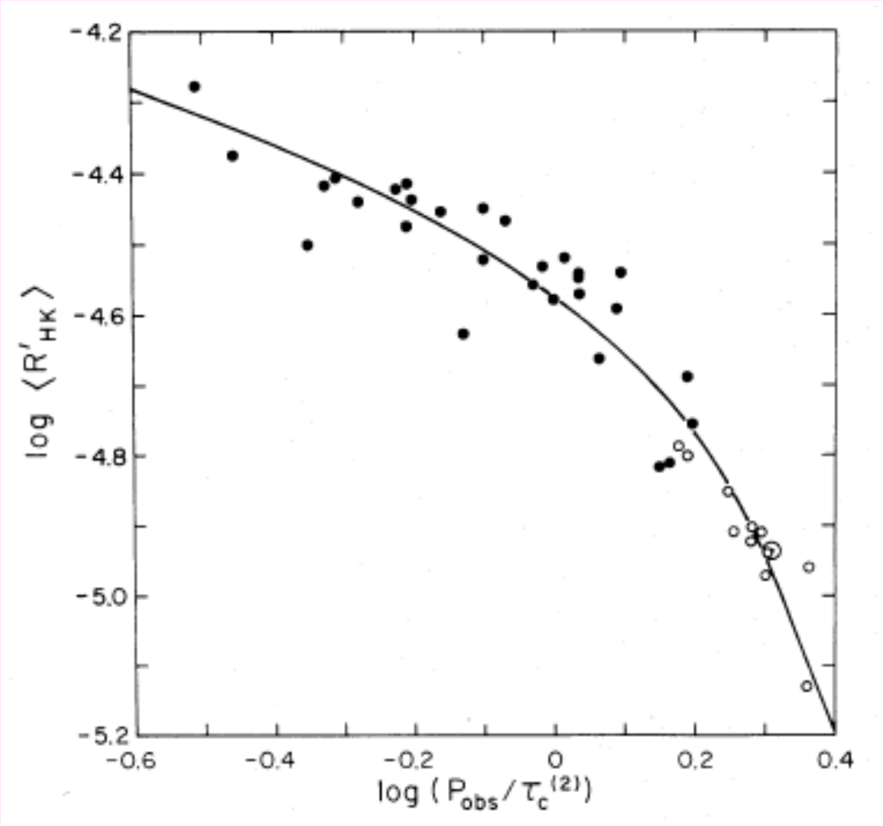
Schwarzchild & Eberhard (1913) discovered Ca H/K emission in solar-like stars

In 1960s Olin Wilson started a programme for Mt. Wilson Observatory of monitoring Ca H/K emission from several solar-like stars for many years

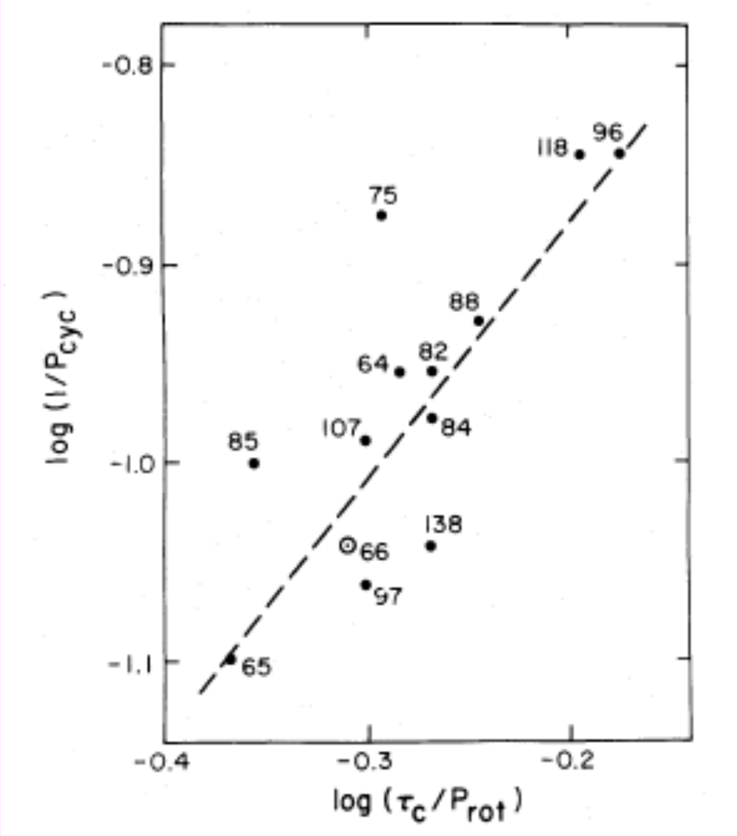
Sufficient data became available after two or three decades



From Baliunas & 26 co-authors (including Wilson) 1995

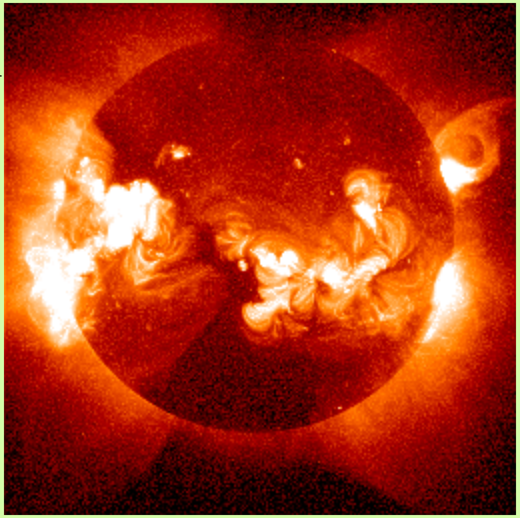


From Noyes et al. (1984): More rapidly rotating stars have more activity

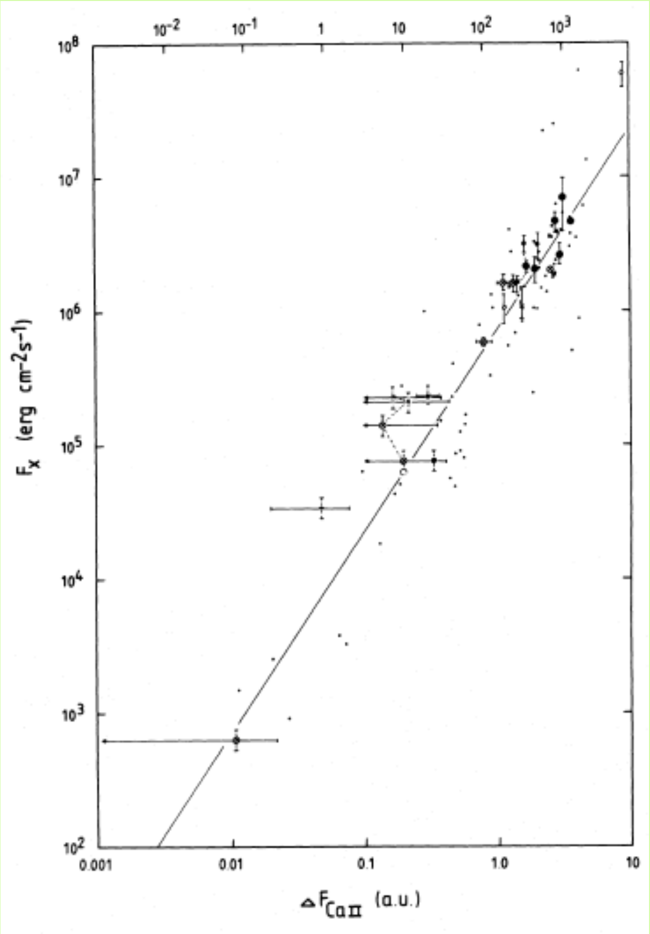


From Noyes, Weiss & Vaughan (1984)

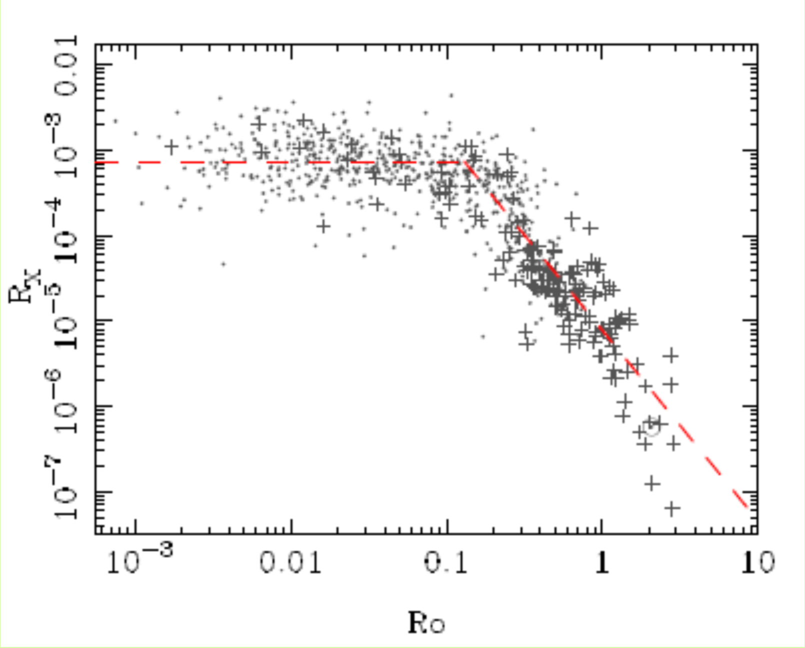
The Sun in X-rays imaged by Yohkoh



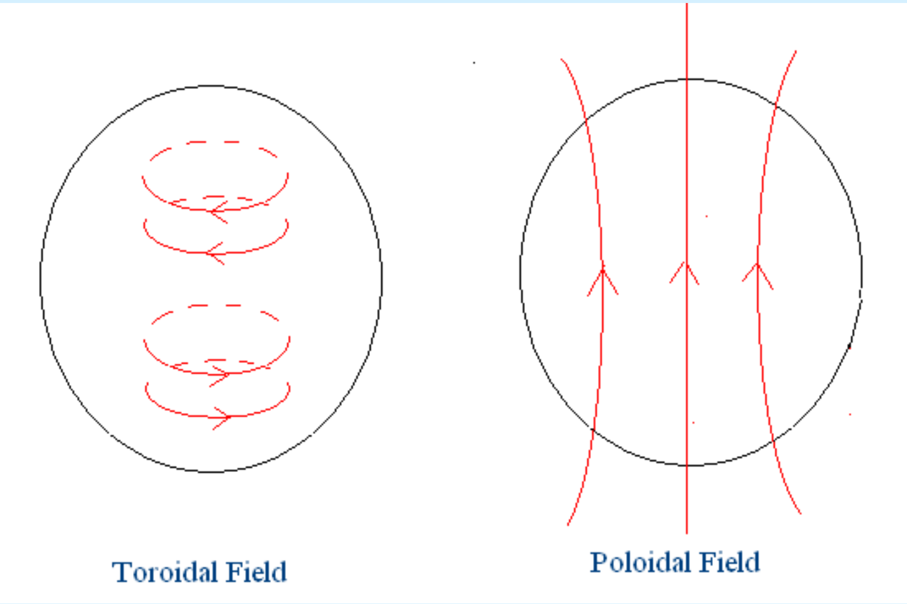
Einstein X-ray Observatory detected X-ray emission from stars (Pallavicini et al. 1981): proportional to luminosity for early-type stars, but not so for late-type stars



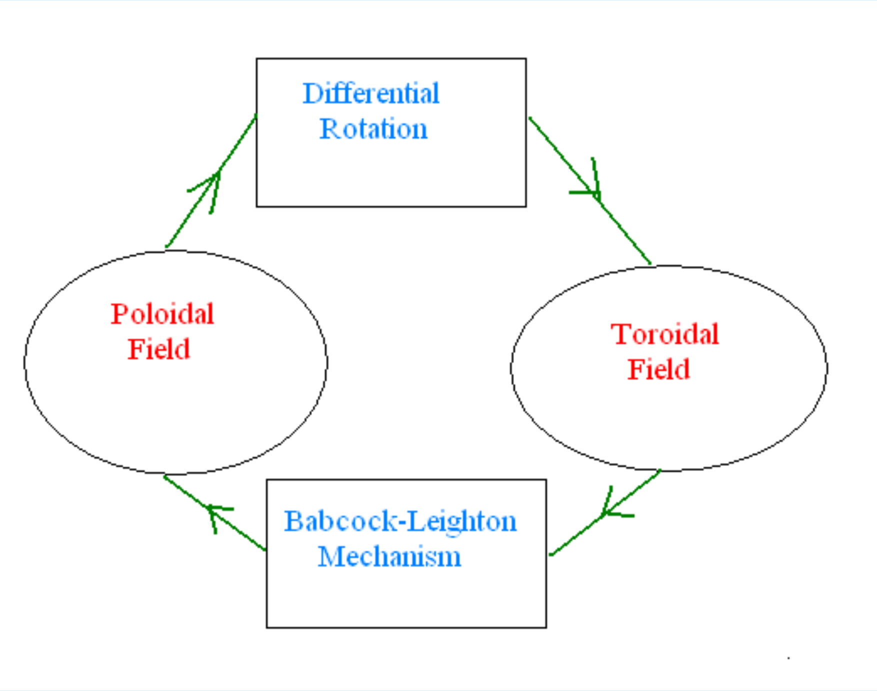
From Schrijver, Dobson & Radick 1992

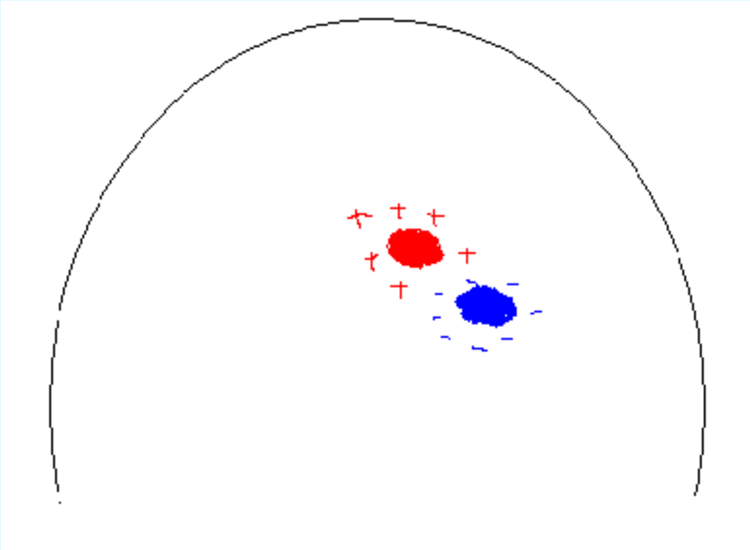


From Wright et al. (2011) [Ro goes as period]



Parker (1955) suggested oscillation between the toroidal and poloidal fields.





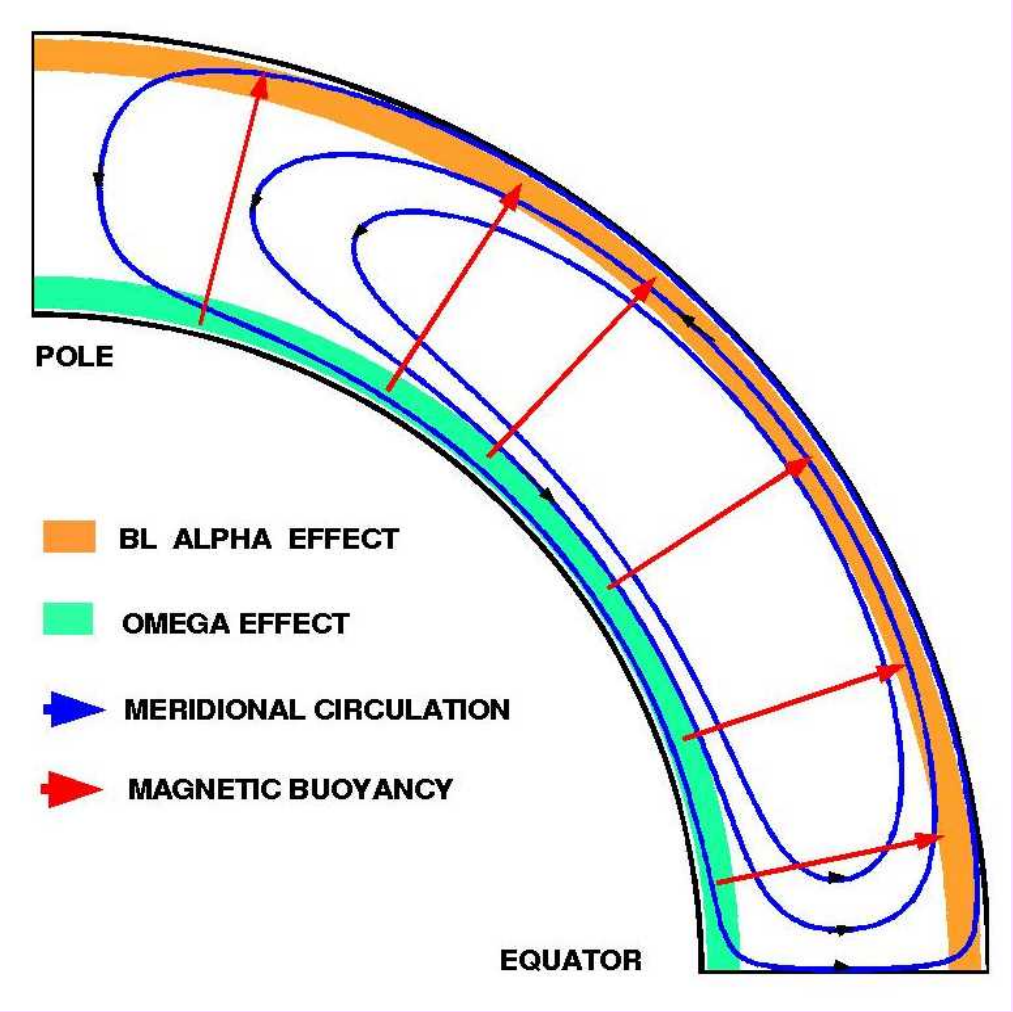
Babcock-Leighton mechanism

Flux transport dynamo in the Sun (Choudhuri, Schussler & Dikpati 1995; Durney 1995)

Differential rotation > toroidal field generation

Babcock-Leighton process > poloidal field generation

Meridional circulation carries toroidal field equatorward & poloidal field poleward



Basic idea was given by Wang, Sheeley & Nash (1991)

Basic Equations

Magnetic field

$$\boldsymbol{B} = B(r,\theta)\boldsymbol{e}_\phi + \nabla \times [A(r,\theta)\boldsymbol{e}_\phi],$$

Velocity field

$$\Omega(r,\theta)\, r \sin\theta\, \mathbf{e}_\phi + \mathbf{v}$$

$$\frac{\partial A}{\partial t} + \frac{1}{s}(\boldsymbol{v}.\nabla)(sA) = \eta_{\rm p}\left(\nabla^2 - \frac{1}{s^2}\right)A + \alpha B,$$

$$\frac{\partial B}{\partial t} + \frac{1}{r}\left[\frac{\partial}{\partial r}(r v_r B) + \frac{\partial}{\partial \theta}(v_\theta B)\right] = \eta_{\rm t}\left(\nabla^2 - \frac{1}{s^2}\right)B + s(\boldsymbol{B}_{\rm p}.\nabla)\Omega + \frac{1}{r}\frac{{\rm d}\eta_{\rm t}}{{\rm d}r}\frac{\partial}{\partial r}(rB)$$

The code *Surya* solves these equations

A stellar dynamo model needs differential rotation and meridional circulation inside the star

What causes these?

Kippenhahn (1963): Scalar viscosity => Solid body rotation

Vertical viscosity larger => faster rotation at equator

Horizontal viscosity larger => faster rotation near pole

Possible causes for anisotropy of turbulent viscosity in a stellar convection zone:

1. Gravity (vertical direction different from horizontal)
2. Rotation (polar direction special, transport easier)

Two possible approaches for calculating differential rotation and meridional circulation:

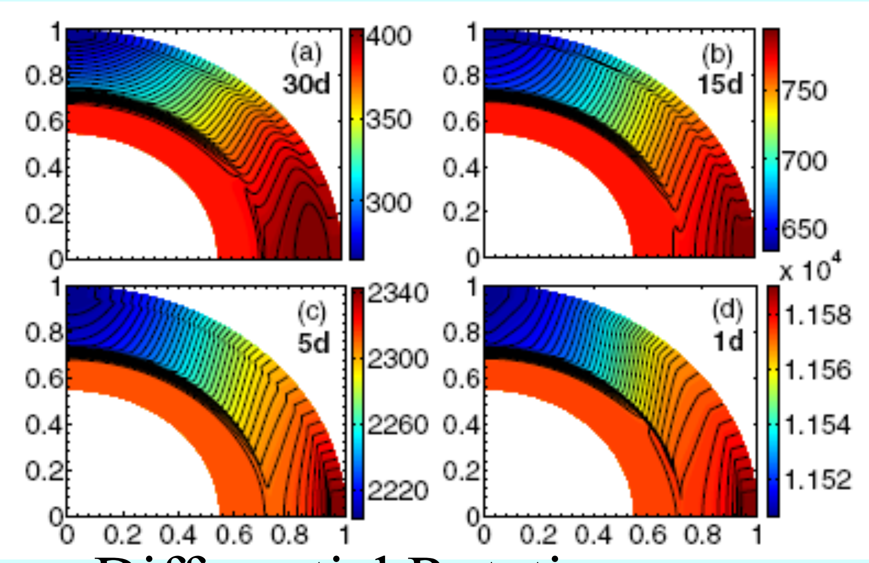
Approach I – Direct numerical simulation from first principles

Approach II – Calculate viscosity tensor from mixing length model of turbulence in convection zone (Kitchatinov & Rudiger 1995)

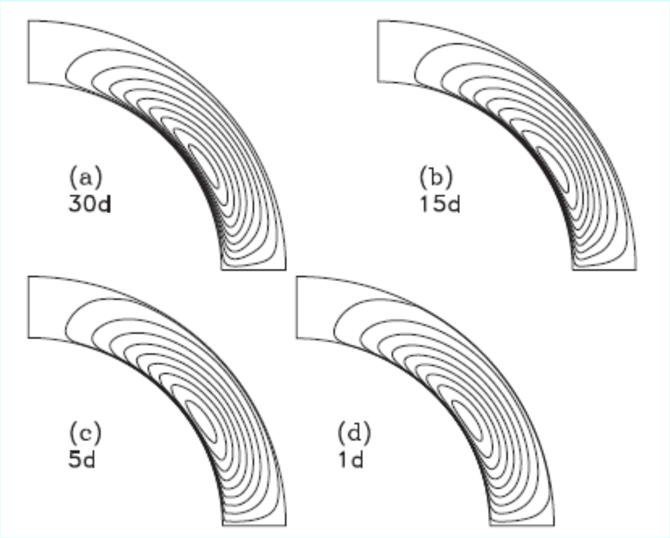
Jouve, Brown & Brun (2010) constructed stellar dynamo model based on approach I =>
Computationally intensive, limited parameter space study

Karak, Kitchatinov & Choudhuri (2014) constructed stellar dynamo model based on approach II =>
Extensive parameter space study, comparison with observations

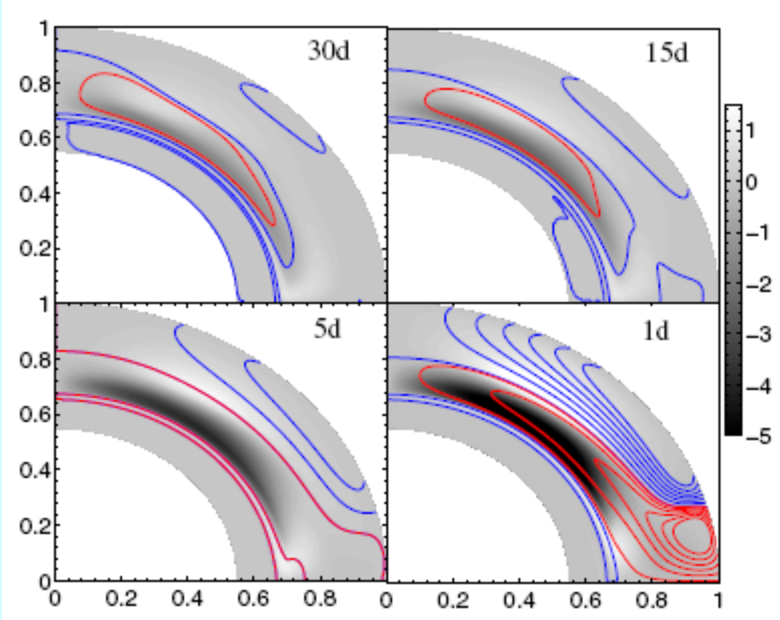
Solar mass stars with different rotation periods (Karak, Kitchatinov & Choudhuri 2014)



Differential Rotation



Meridional circulation (weaker for faster rotators!)



Magnetic field – toroidal (grey scale) and poloidal (field lines)

B_0 appearing in source term

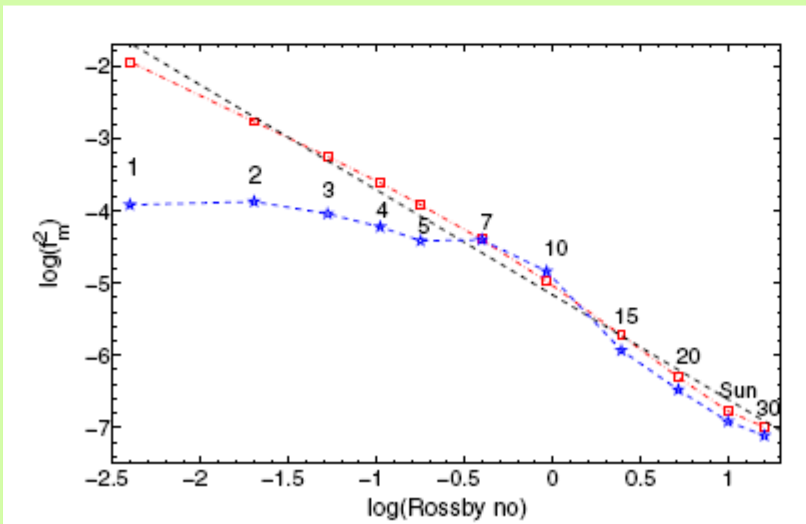
$$S(r,\theta;B) = \frac{\alpha(r,\theta)}{1+(\overline{B}(r_t,\theta)/B_0)^2}\overline{B}(r_t,\theta),$$

sets unit of magnetic field

Toroidal flux in the convection zone can be written as

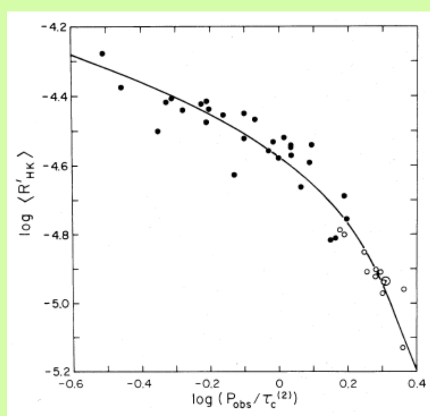
$$f B_0 R_s^2$$

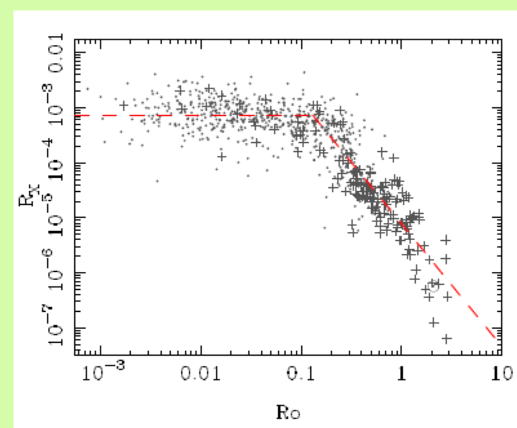
f is a measure of magnetic flux and emissions may go as its square

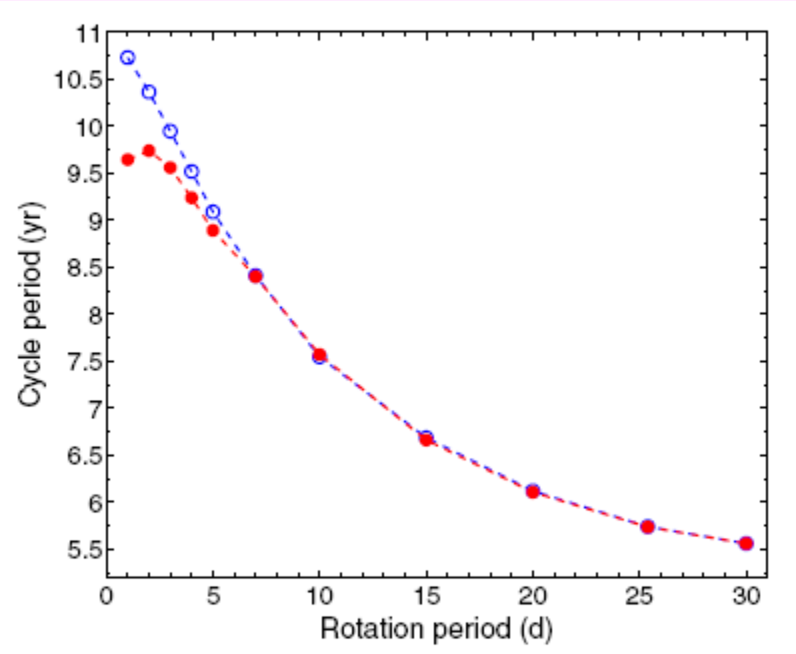


From Karak, Kitchatinov & Choudhuri (2014)
Saturation for faster rotation helps in matching data

Compare with observational Ca H/K and X-ray plots



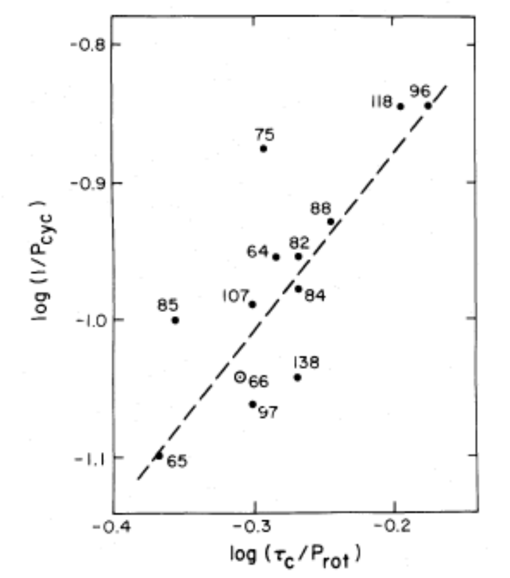




Karak, Kitchatinov & Choudhuri (2014) found cycle period decreases with increasing rotation period

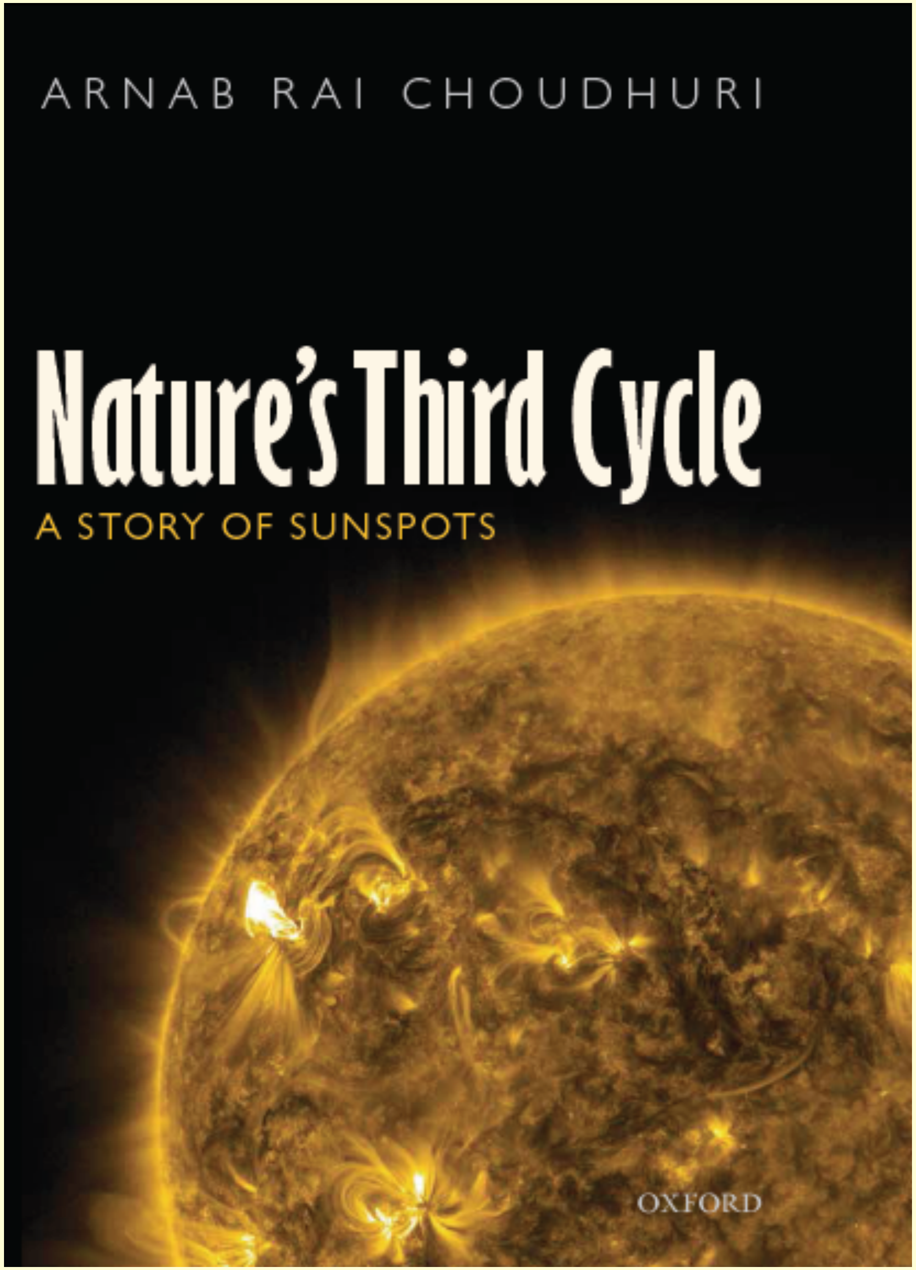
Jouve, Brown & Brun (2010) also found this

Contradiction with observations



Conclusions

- Many solar-like stars have magnetic cycles
- Flux transport dynamo provides a comprehensive model of solar magnetic activity
- Extrapolations to solar-like stars can explain many aspects of stellar cycles, but not all



My recent popular science book published by Oxford University Press in January 2015

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