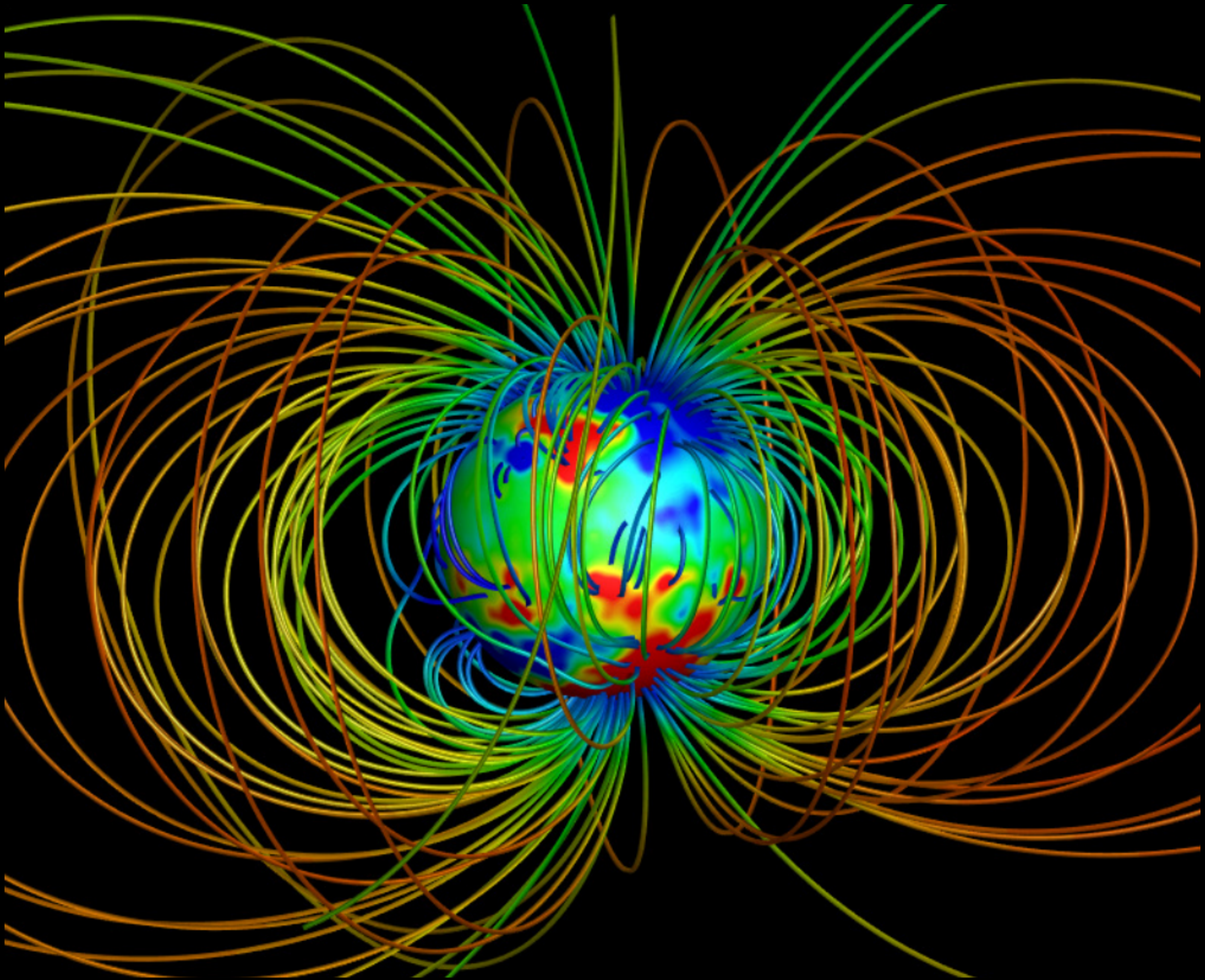
Stellar Activity and Rotation in Cool Stars

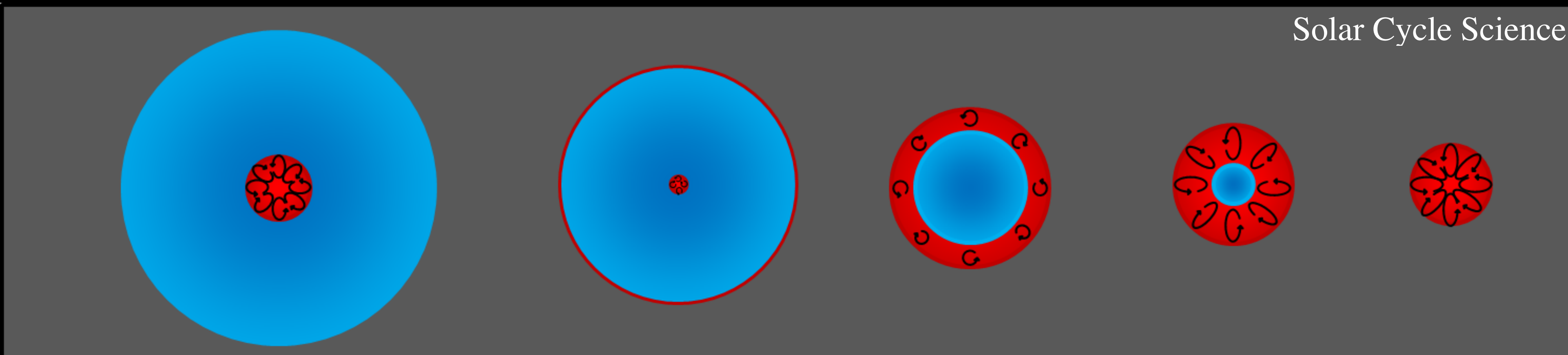


Cecilia Garraffo

IACS Harvard

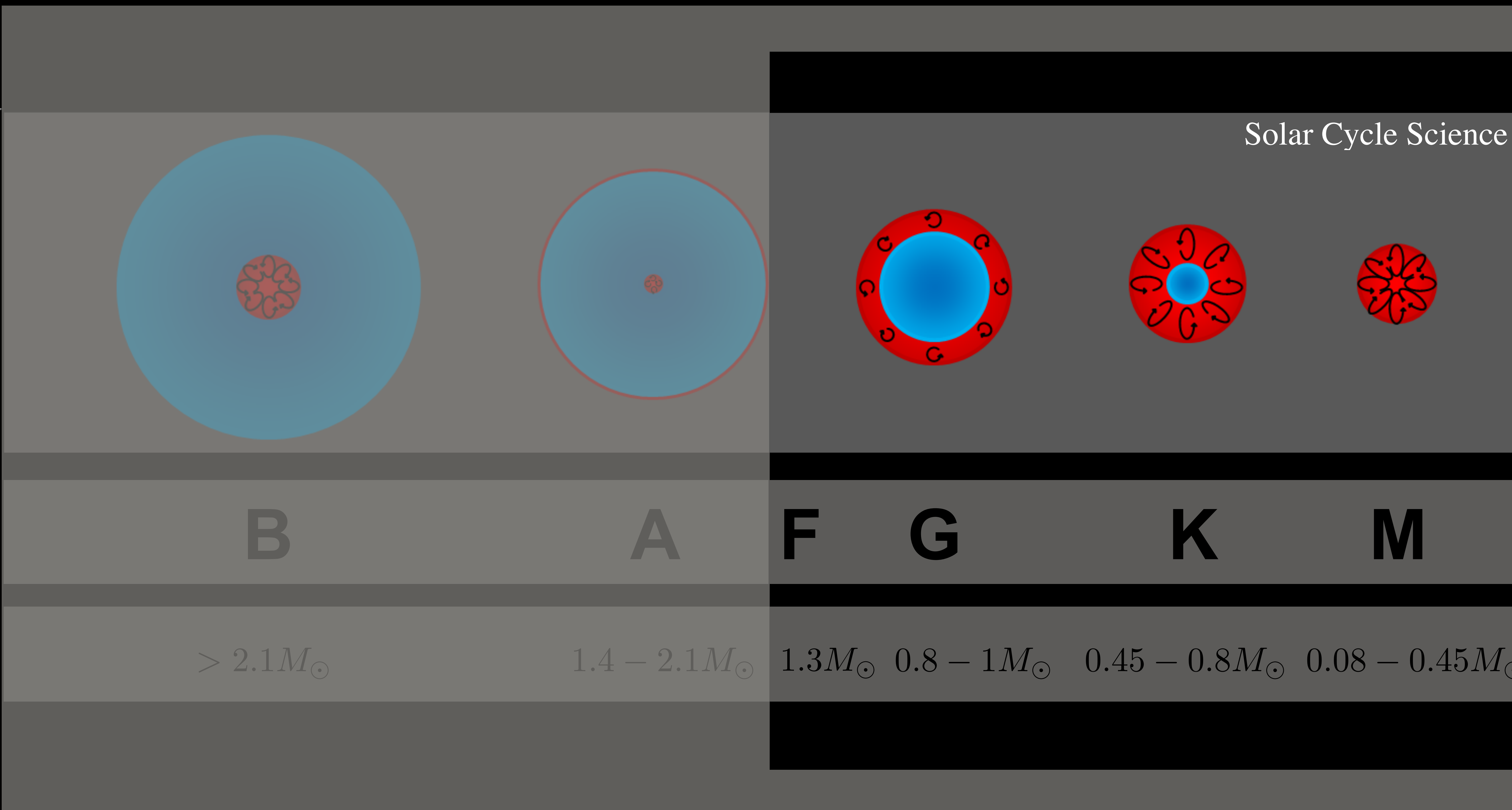
with J. J. Drake, O. Cohen, J. D. Alvarado-Gómez, and S. P. Moschou

Stellar Activity - Rotation

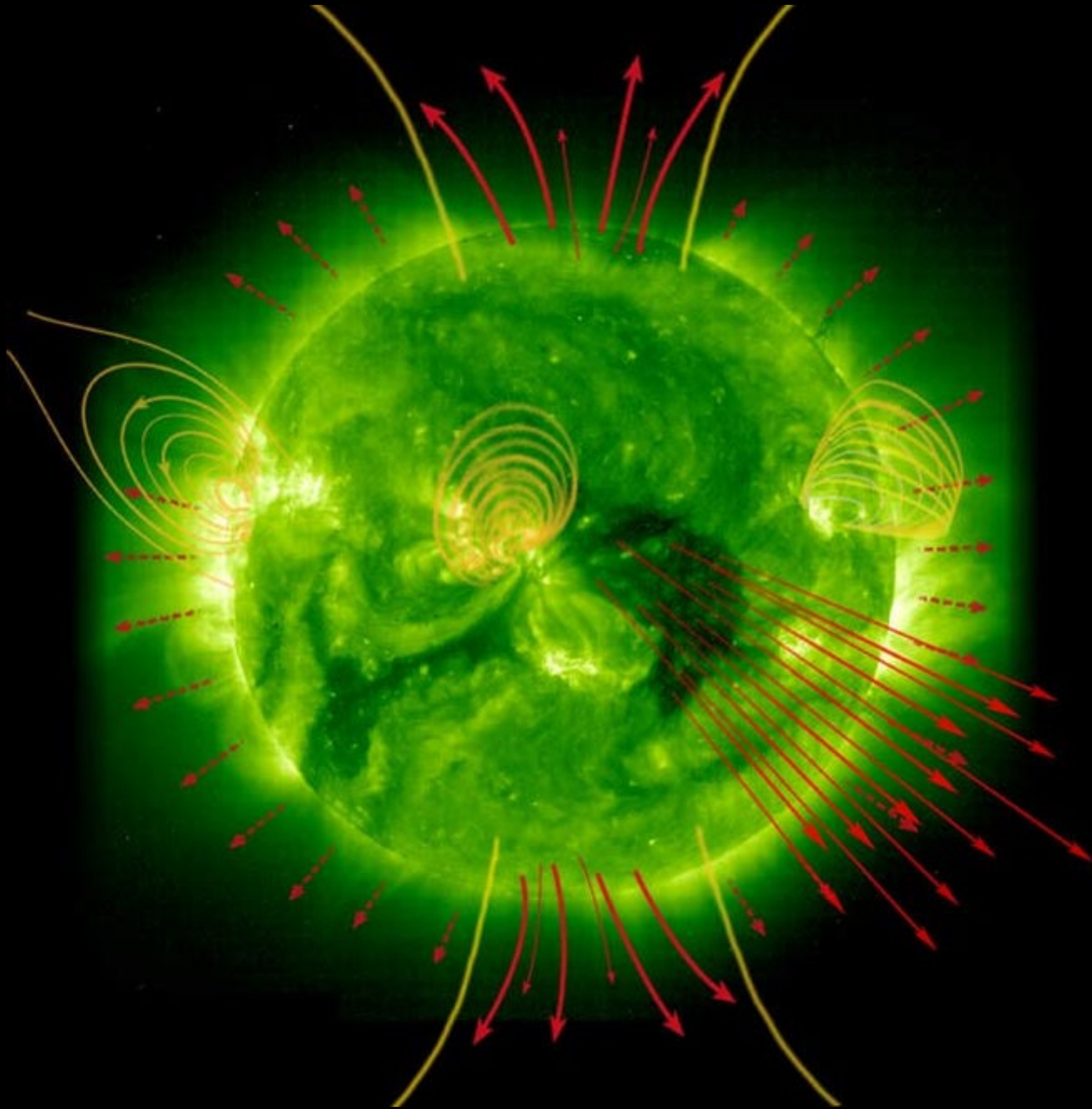


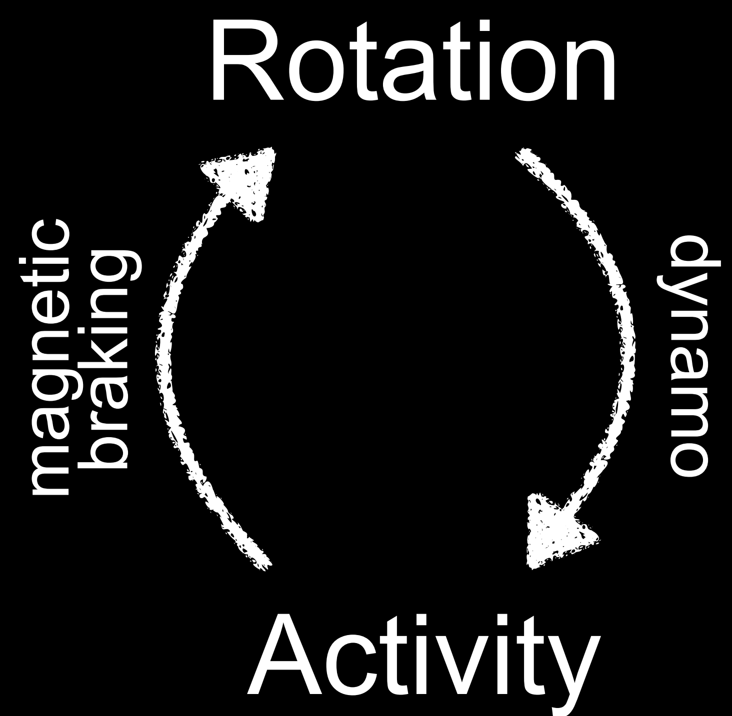
B	A	G	K	M
$> 2.1 M_\odot$	$1.4 - 2.1 M_\odot$	$0.8 - 1 M_\odot$	$0.45 - 0.8 M_\odot$	$0.08 - 0.45 M_\odot$

Stellar Activity - Rotation

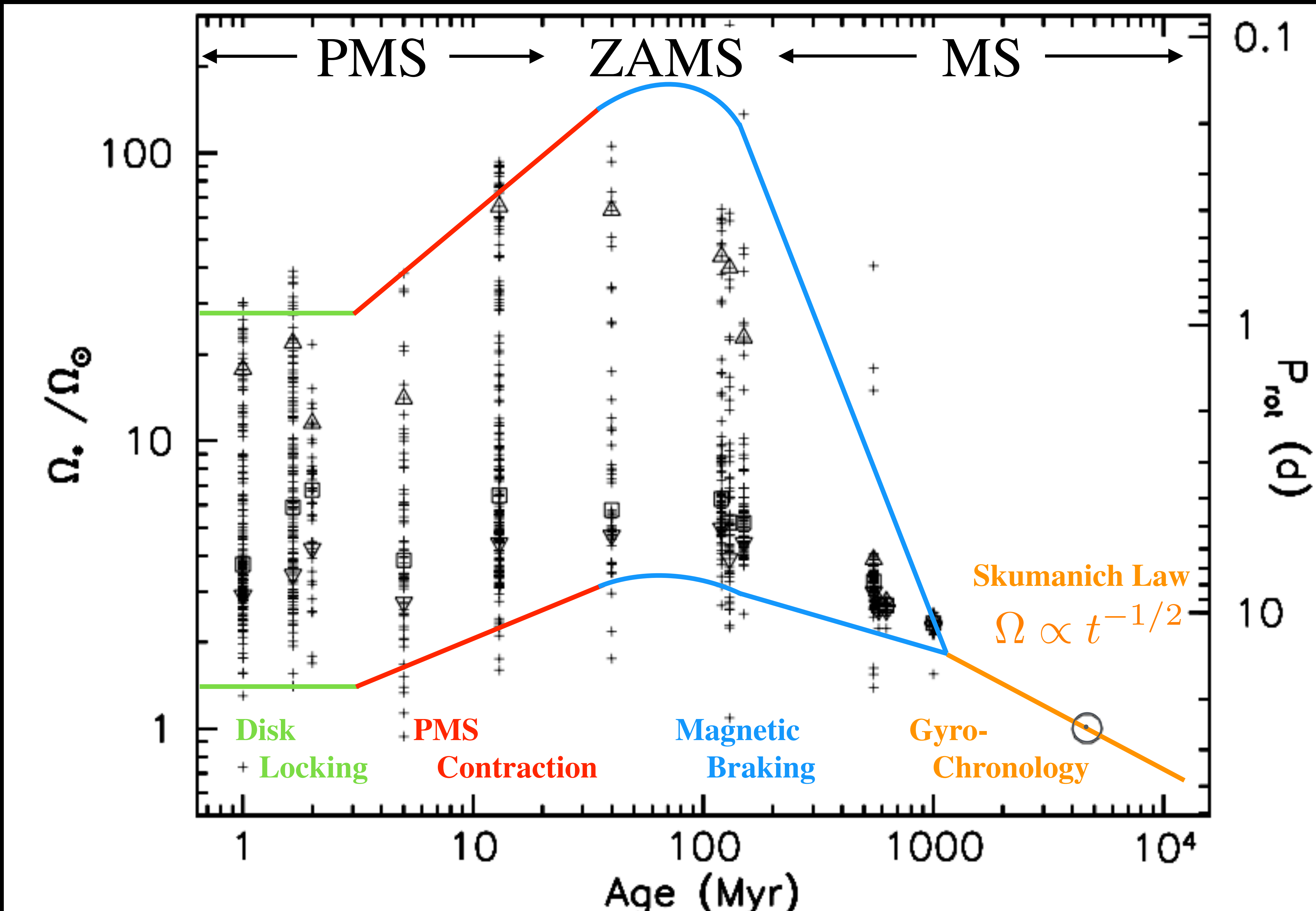


Stellar Activity - Rotation





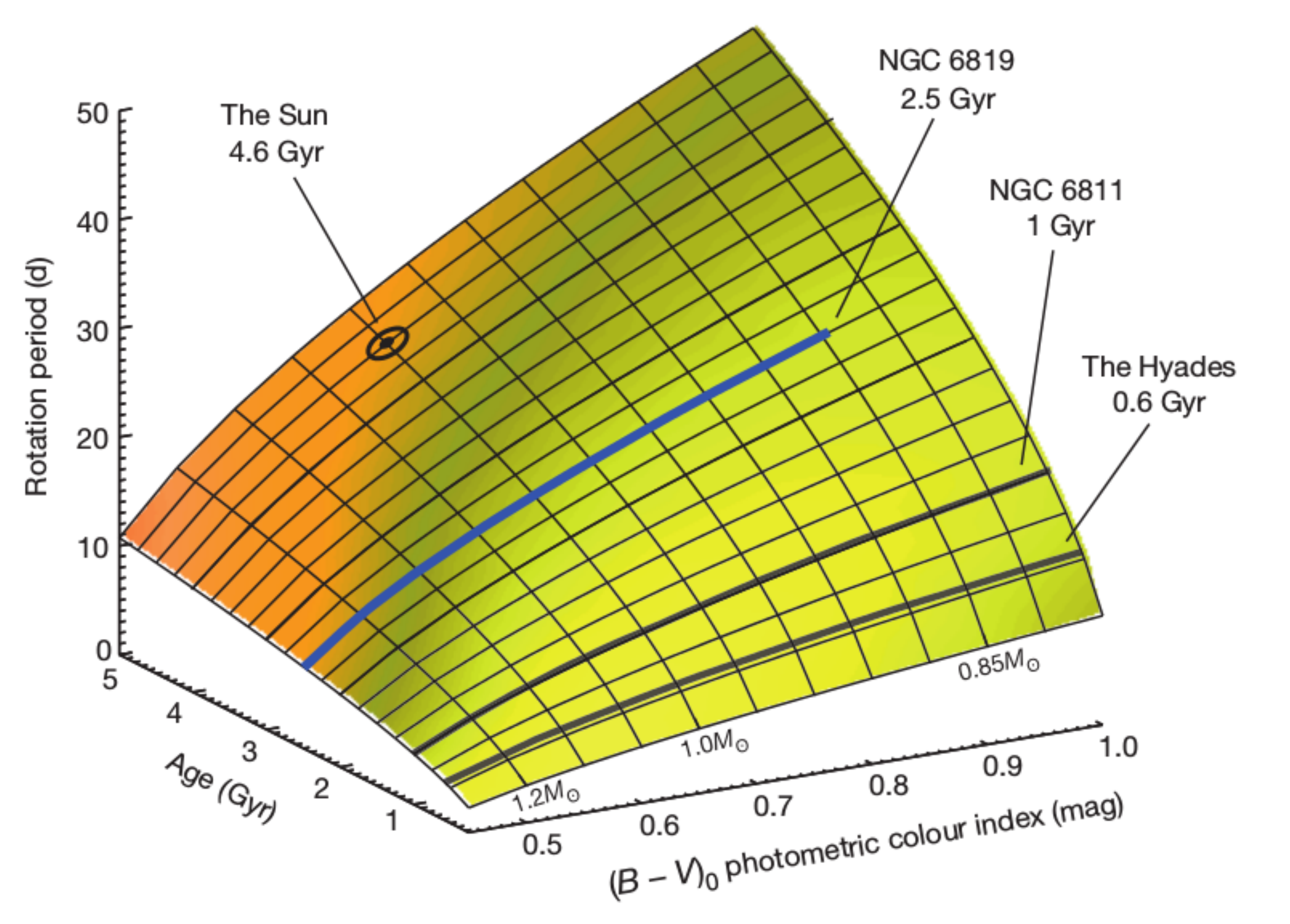
Stellar Activity - Rotation



Gallet & Bouvier 2013

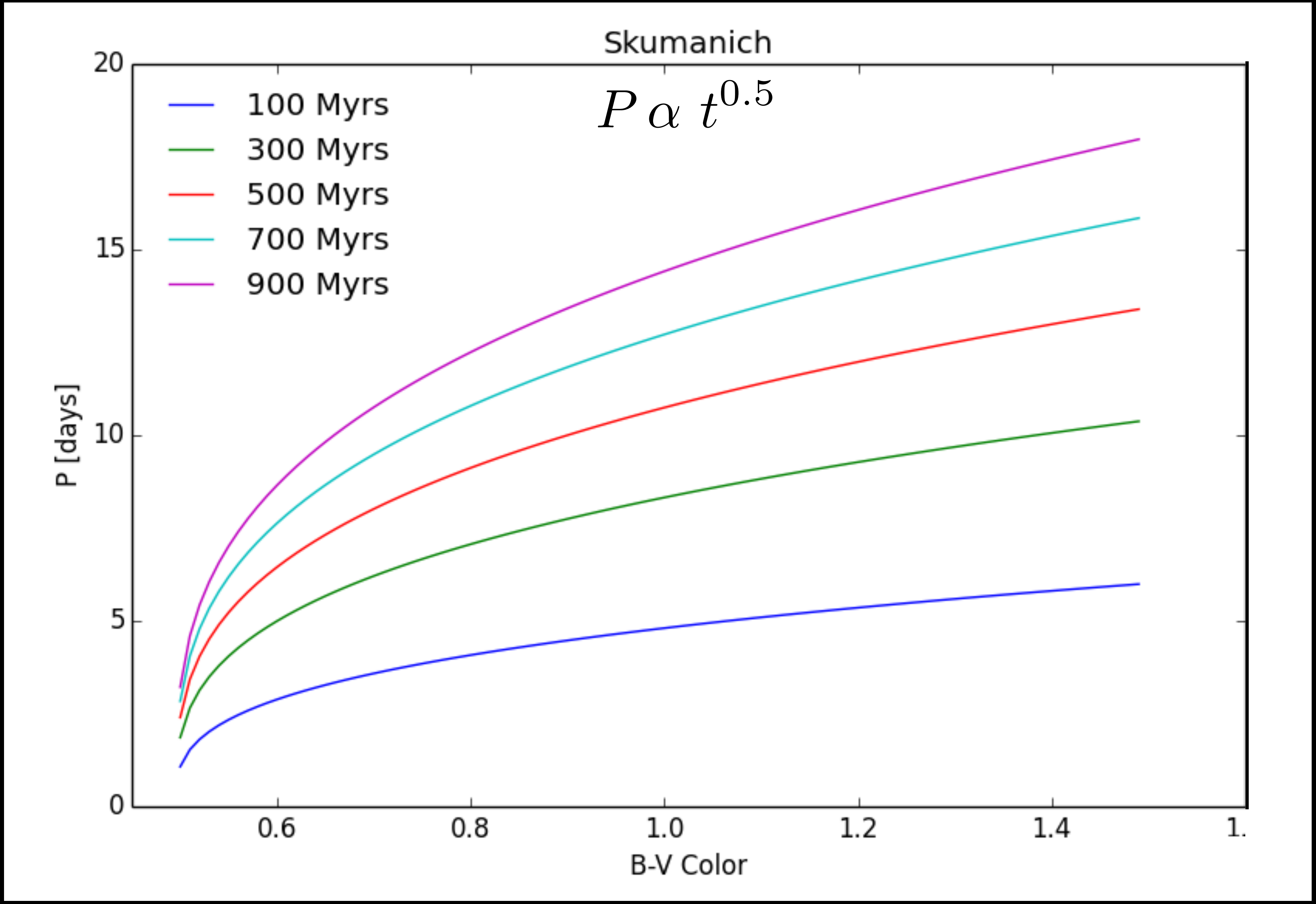
Stellar Activity - Rotation

Meibom et al. 2015, Nature



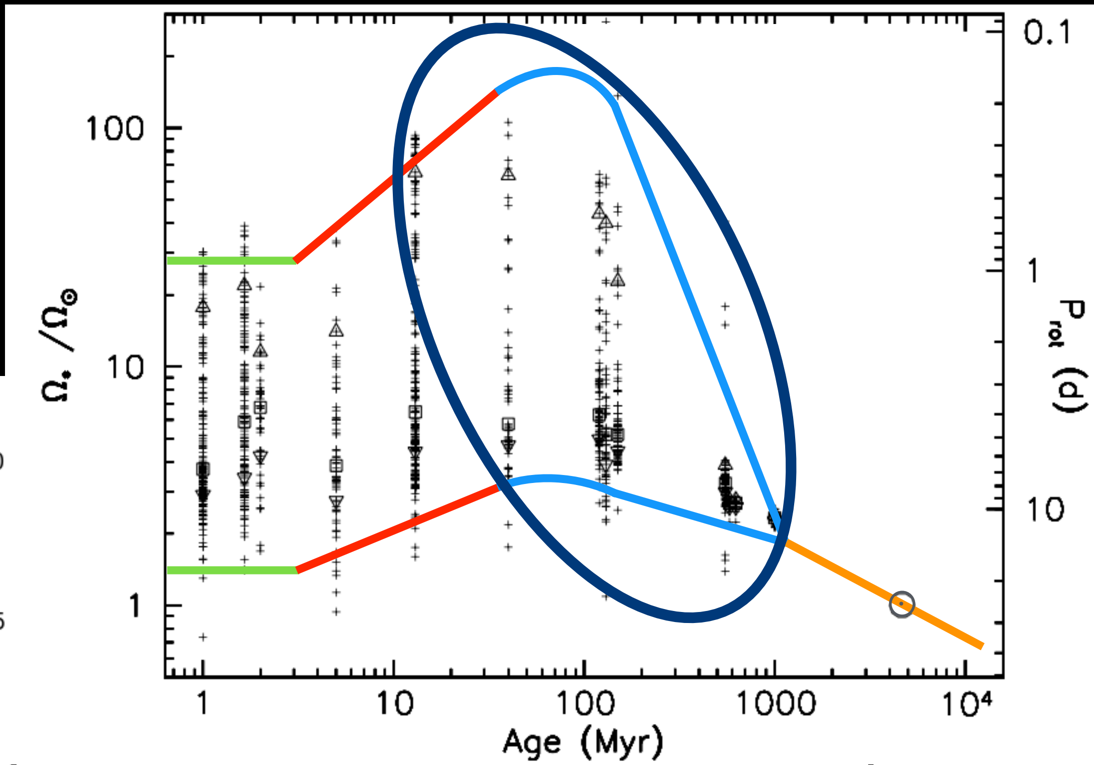
Gyrochronology

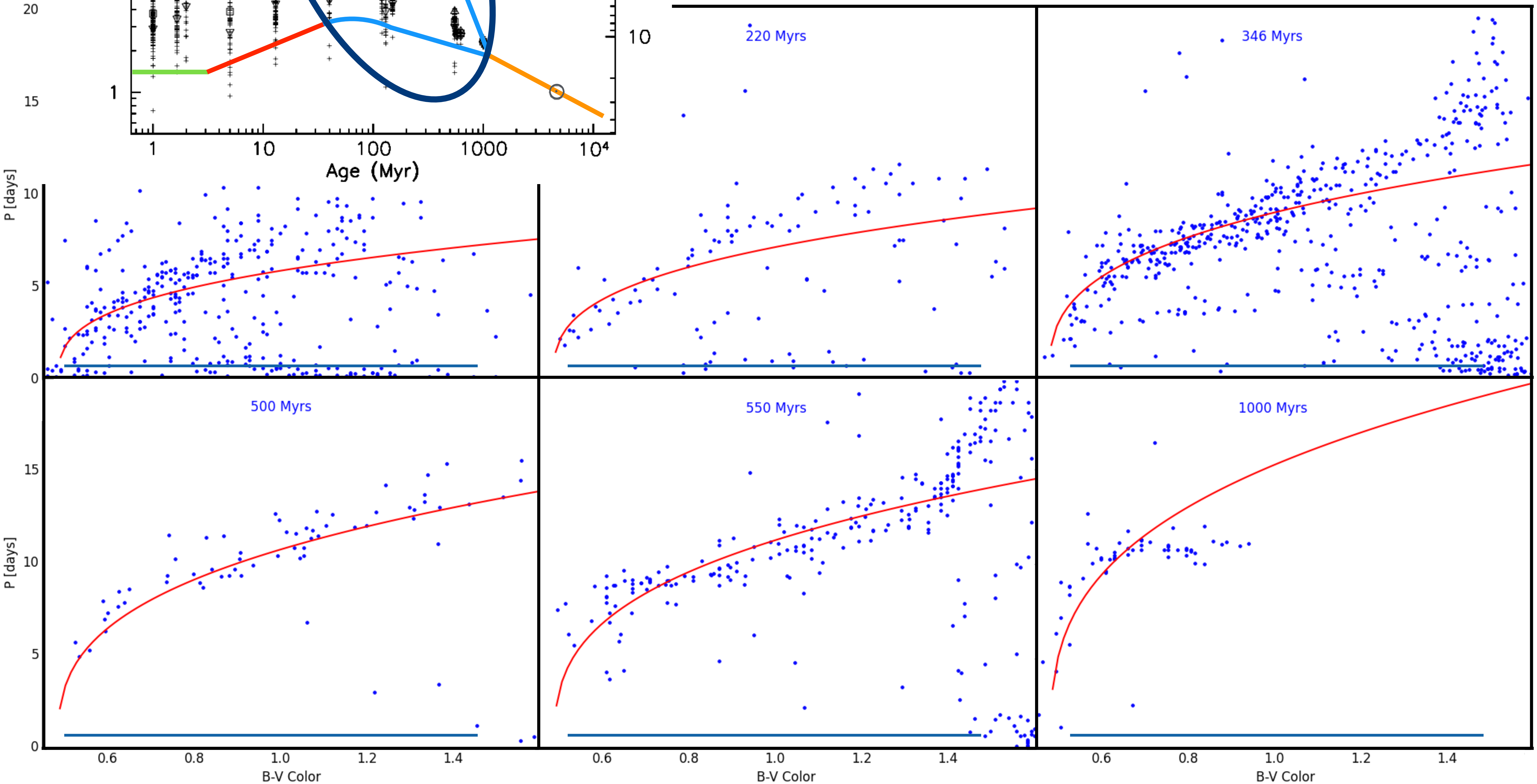
Stellar Activity - Rotation



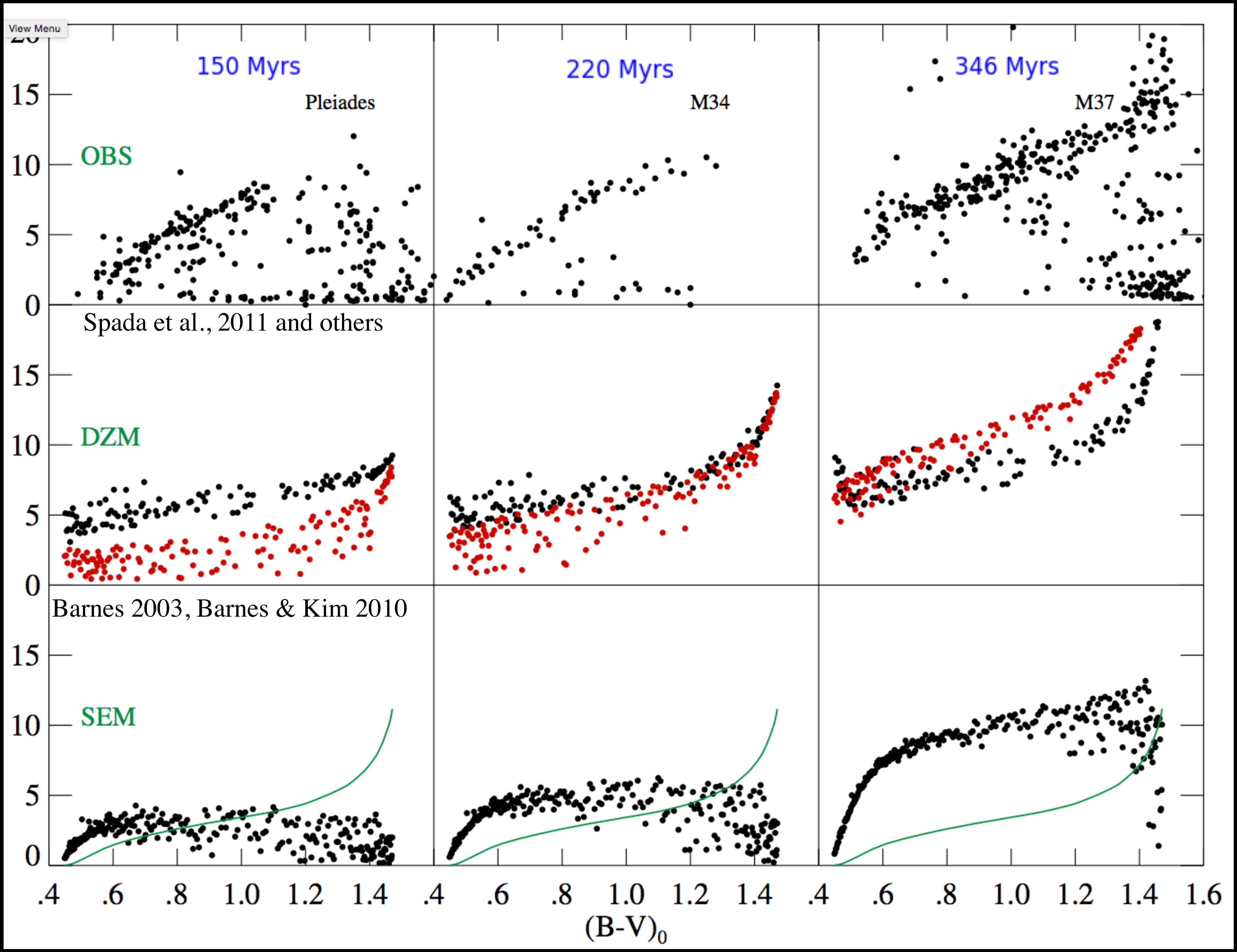
Gyrochronology

...ter Observations





Spin-down models



$$\Omega = J/I$$

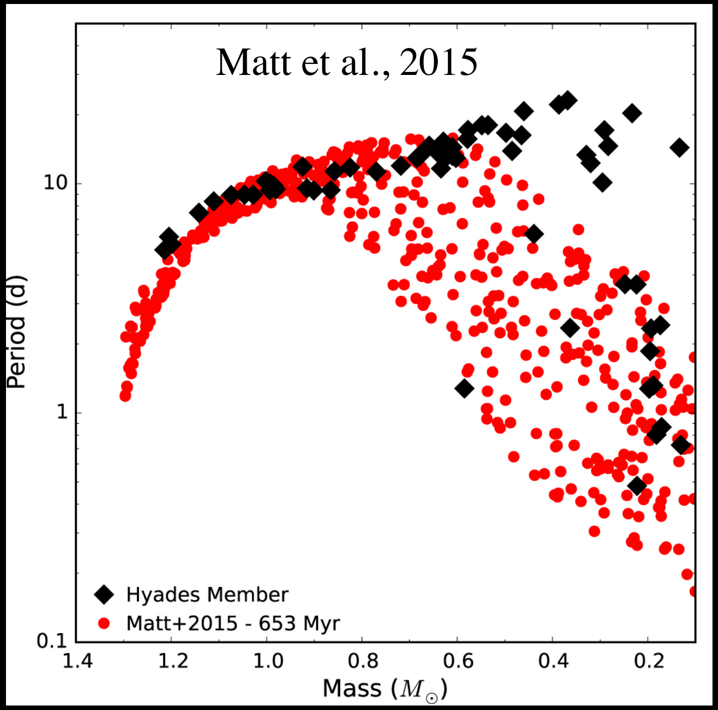
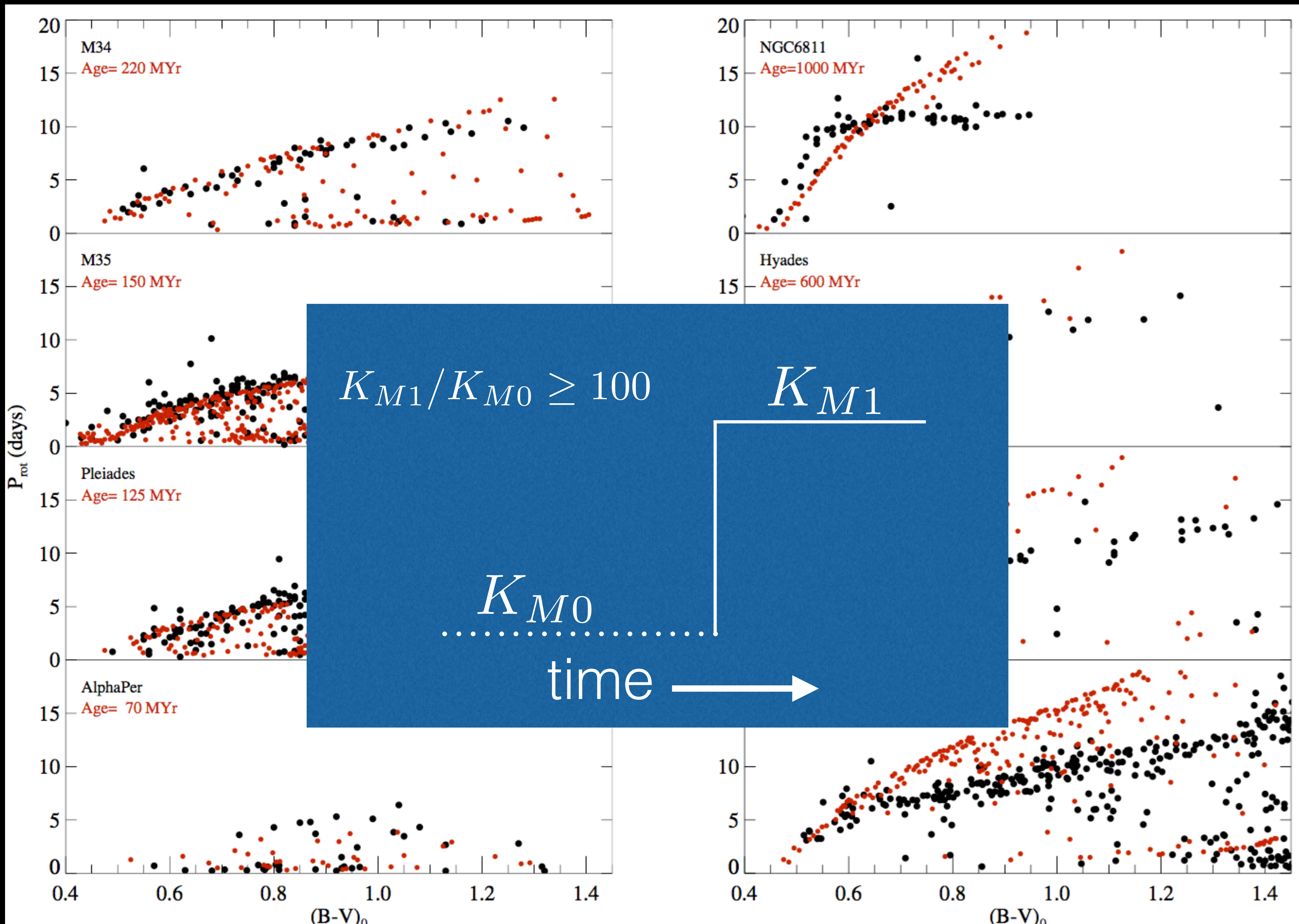


Figure from Douglas et al., 2016

$$I = \begin{cases} I_0, & \text{C - sequence} \\ I_1, & \text{I - sequence} \end{cases}$$

Spin-down models

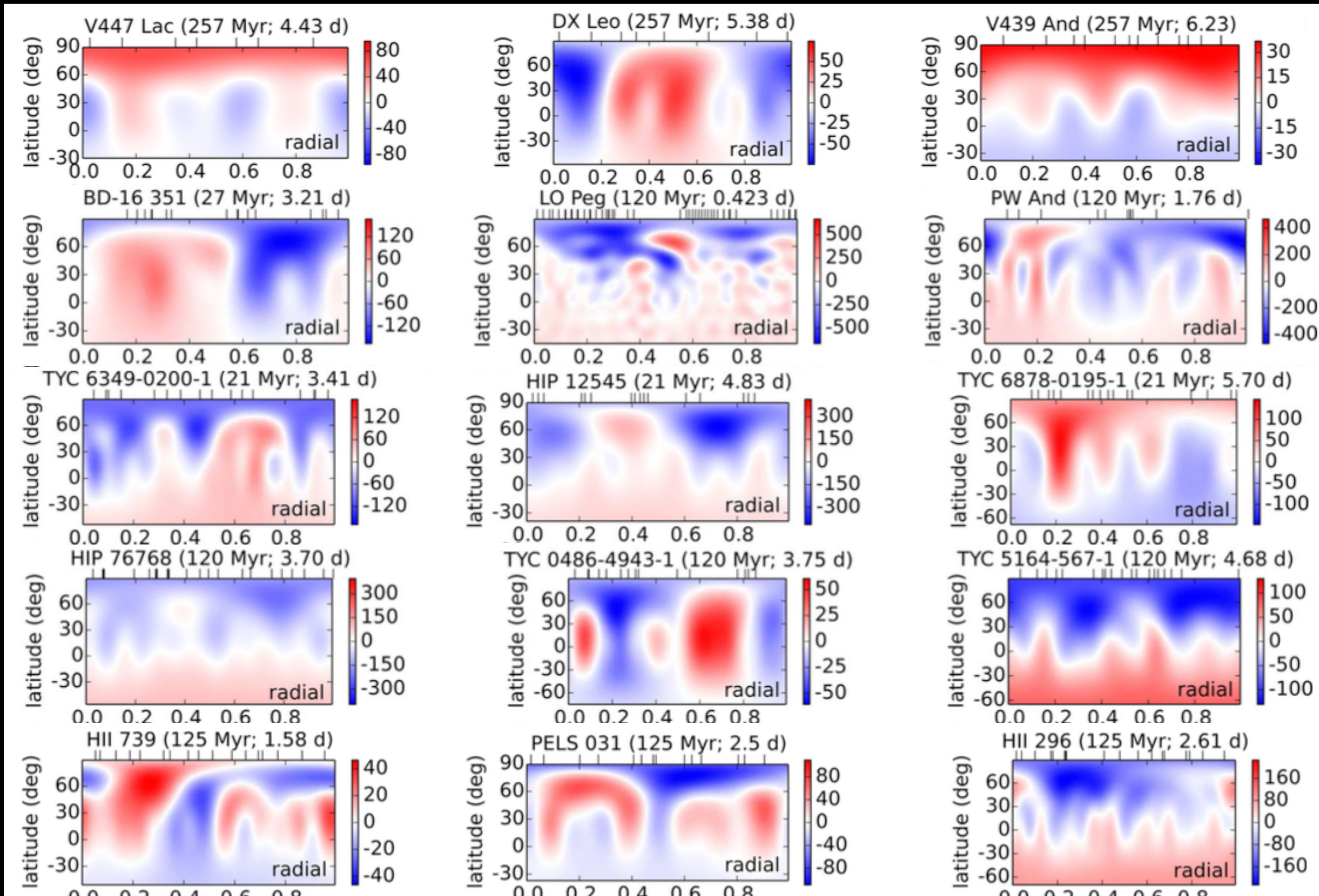
MDM, Brown 2014



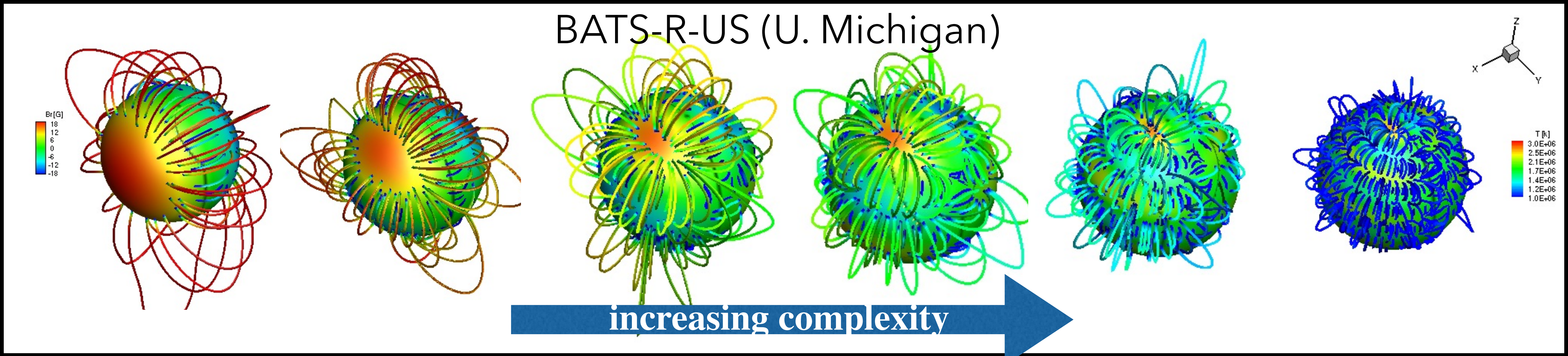
$$\Omega = J/I \longrightarrow dJ/dt = K_M \Omega^3 f^2(B-V)$$

Magnetic Activity Observations

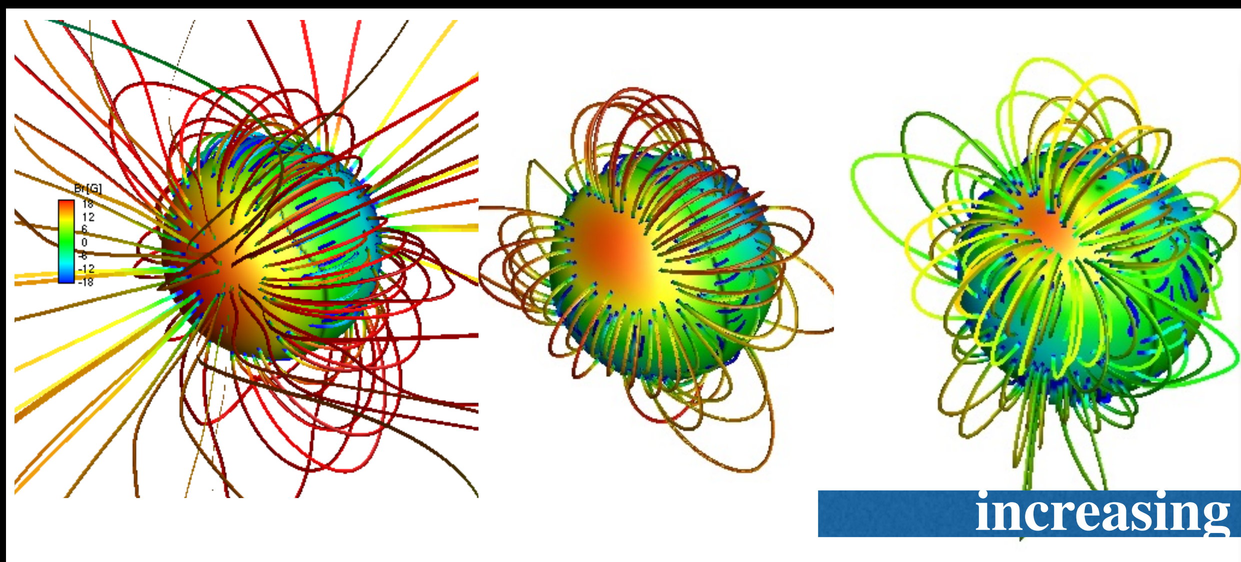
Folsom et al. 2016

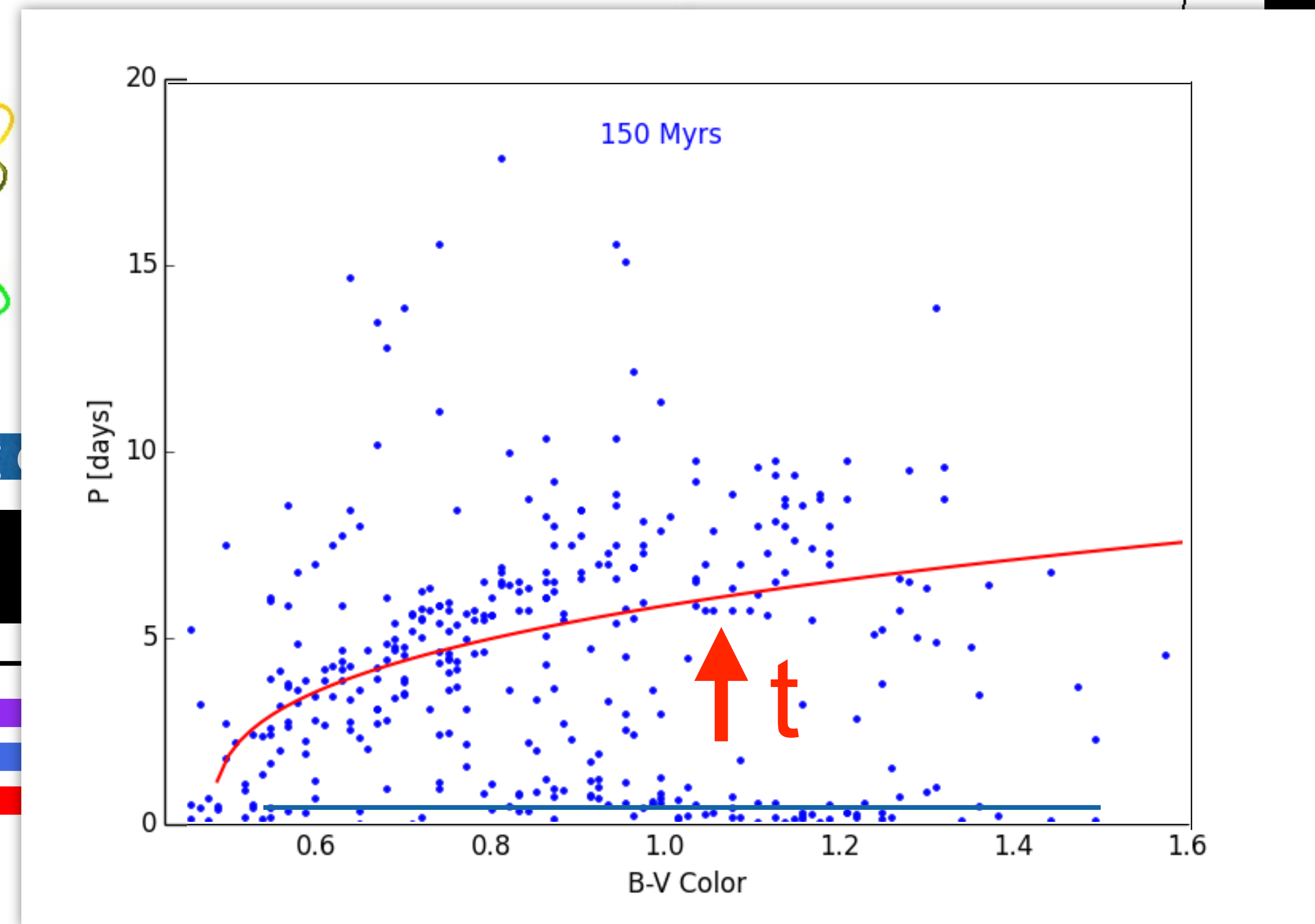


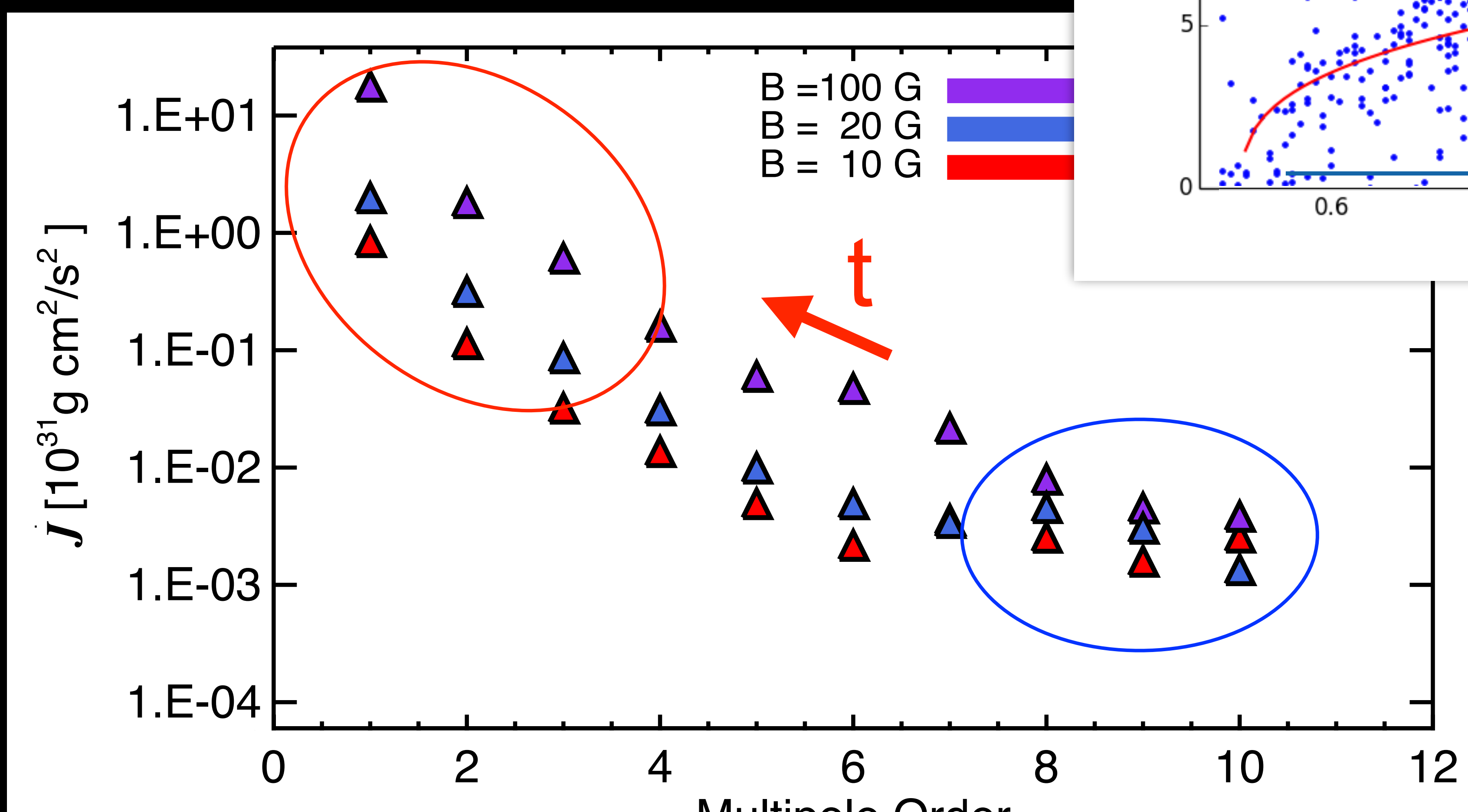
Magnetic Complexity



Magnetic Complexity







Garraffo et al., 2015

$$\dot{J} = \dot{J}_{Dip} Q_J(n)$$

$$Q_J(n) = 4.05\, e^{-1.4n}$$

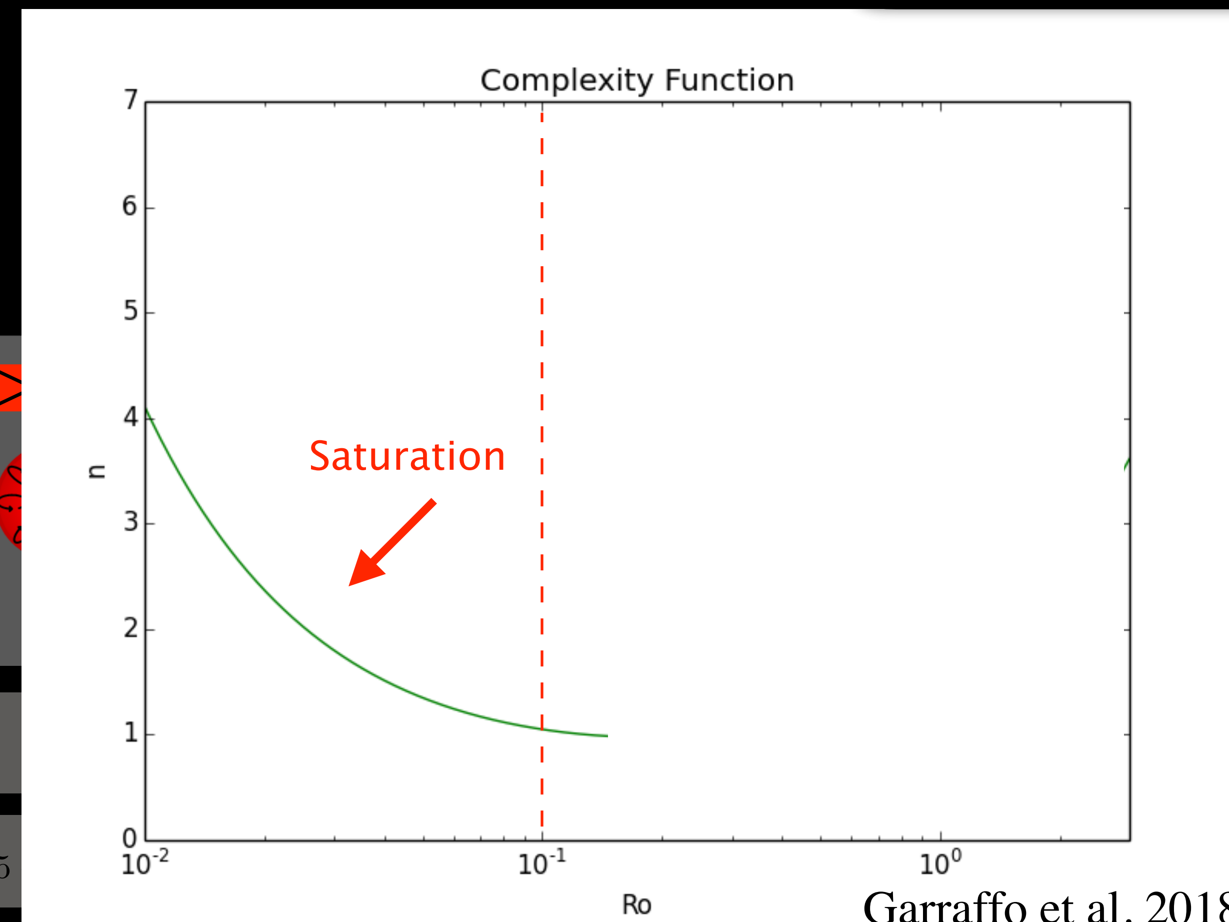
Garraffo et al., 2016

A Complete Spin-down Model

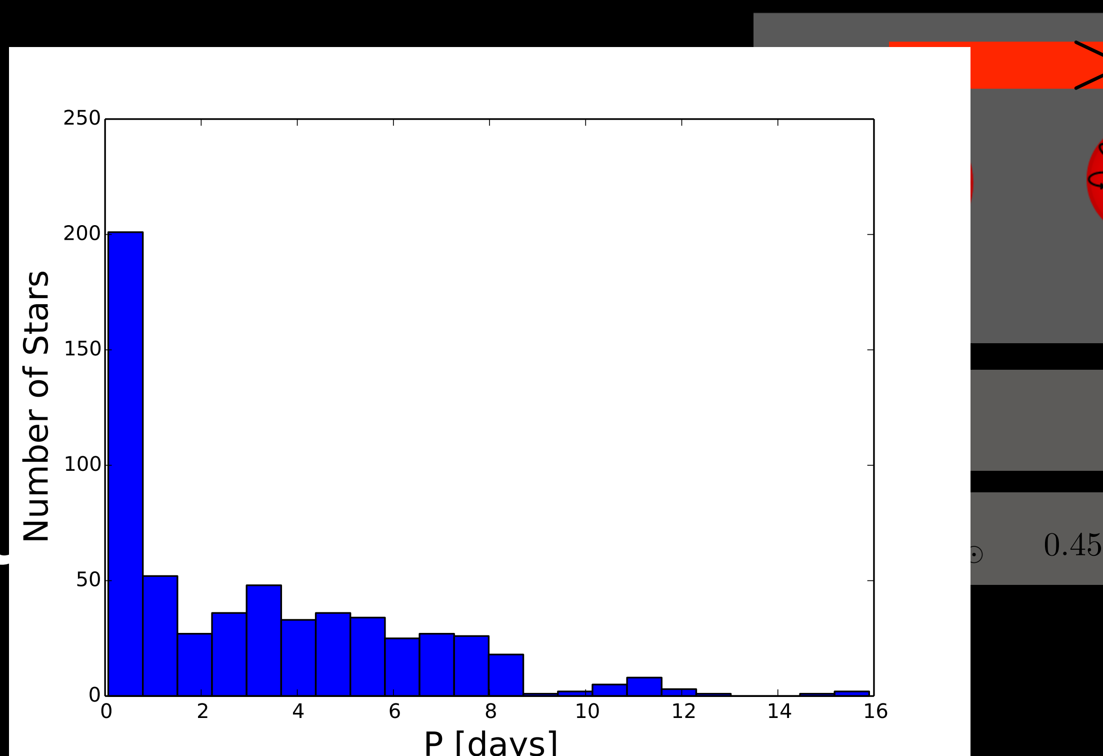
$$\dot{J} = \dot{J}_{Dip} Q_J(n)\ ,\ Q_J(n) = 4.05\, e^{-1.4n} \longrightarrow n = a/Ro + 2Ro + 1$$

Skumanich

$$\dot{J}_{Dip} = c\, \Omega^3 \tau$$



Popu

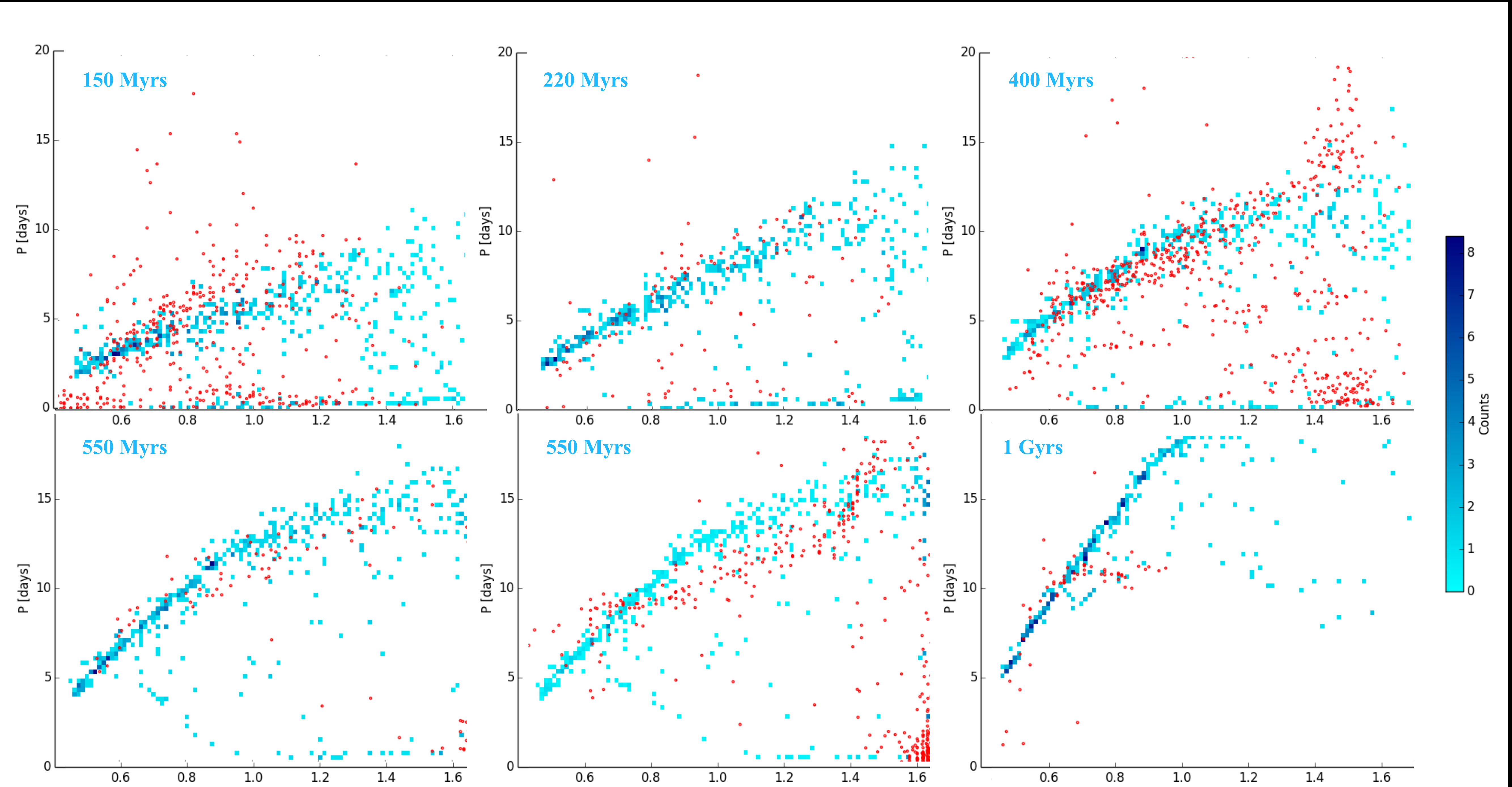


Initial rotation periods h Per, 13 Myrs old, after disk locking

$M, R, MoI, Teff, \tau$ evolutionary codes

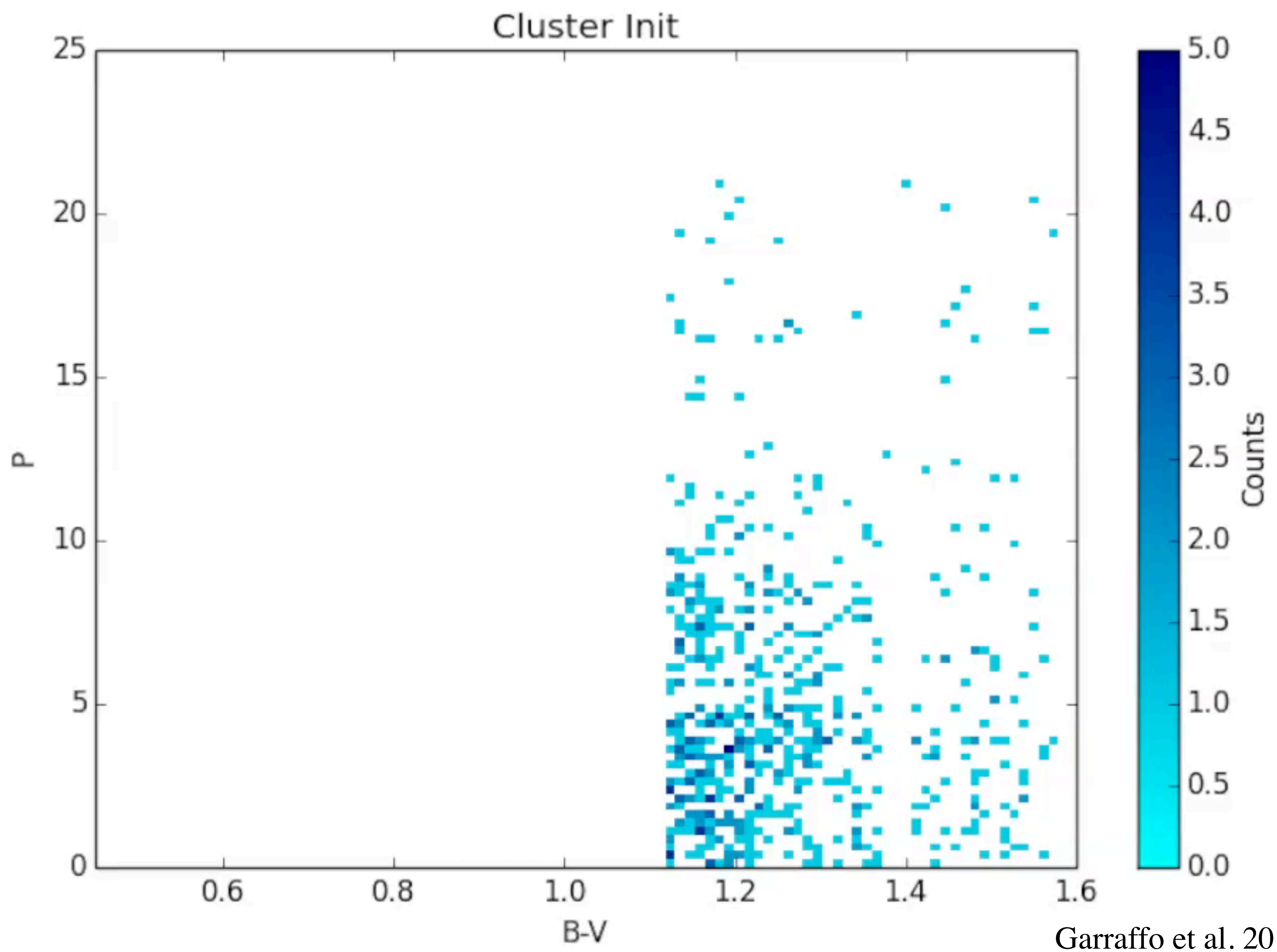
A Complete Spin-down Model

$$\dot{J} = \dot{J}_{Dip} Q_J(n)\ ,\ Q_J(n) = 4.05\, e^{-1.4n} \longrightarrow n = 0.02/Ro + 2Ro + 1$$



Garraffo et al. 2018

A Complete Spin-down Model

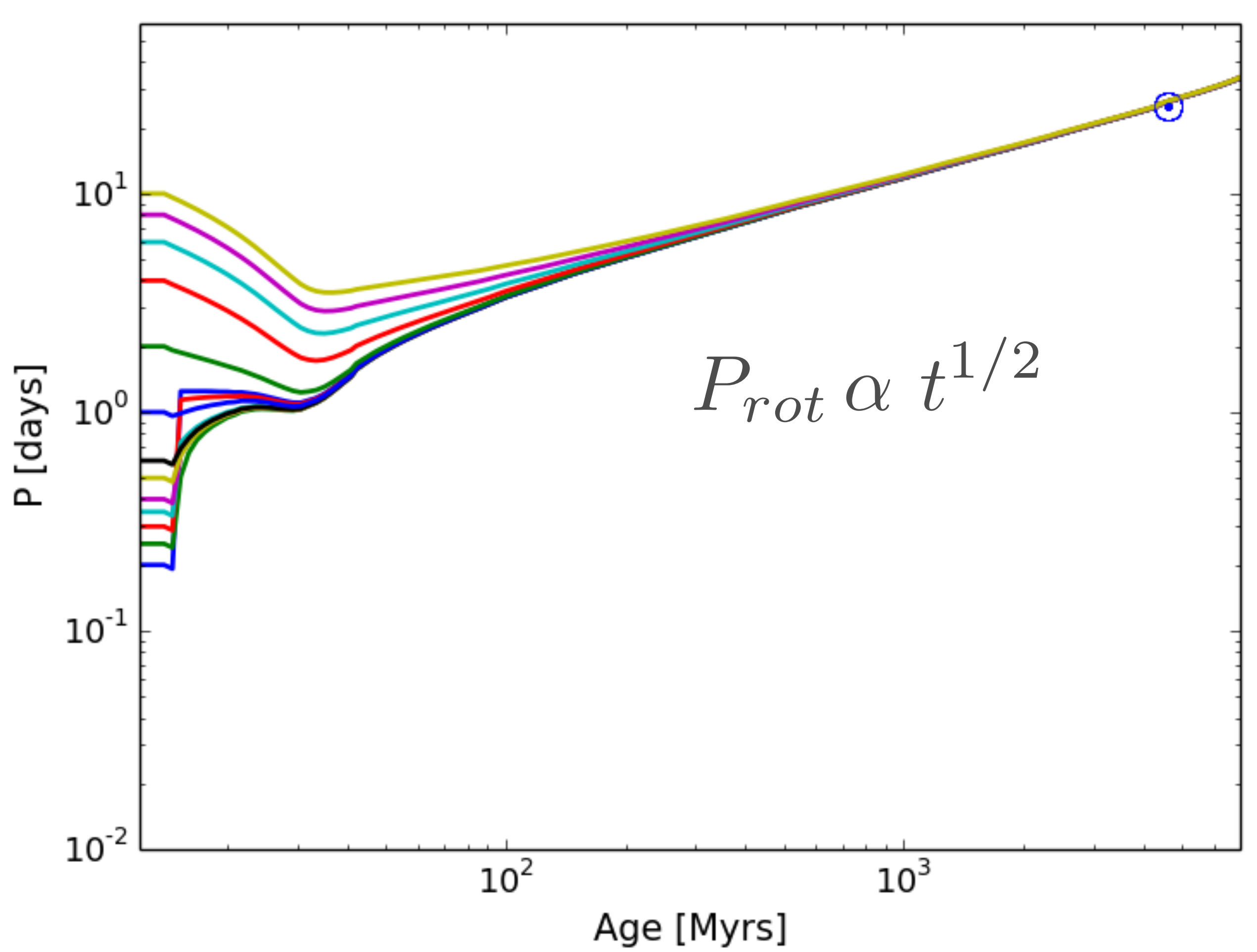


Garraffo et al. 2018

A Complete Spin-down Model

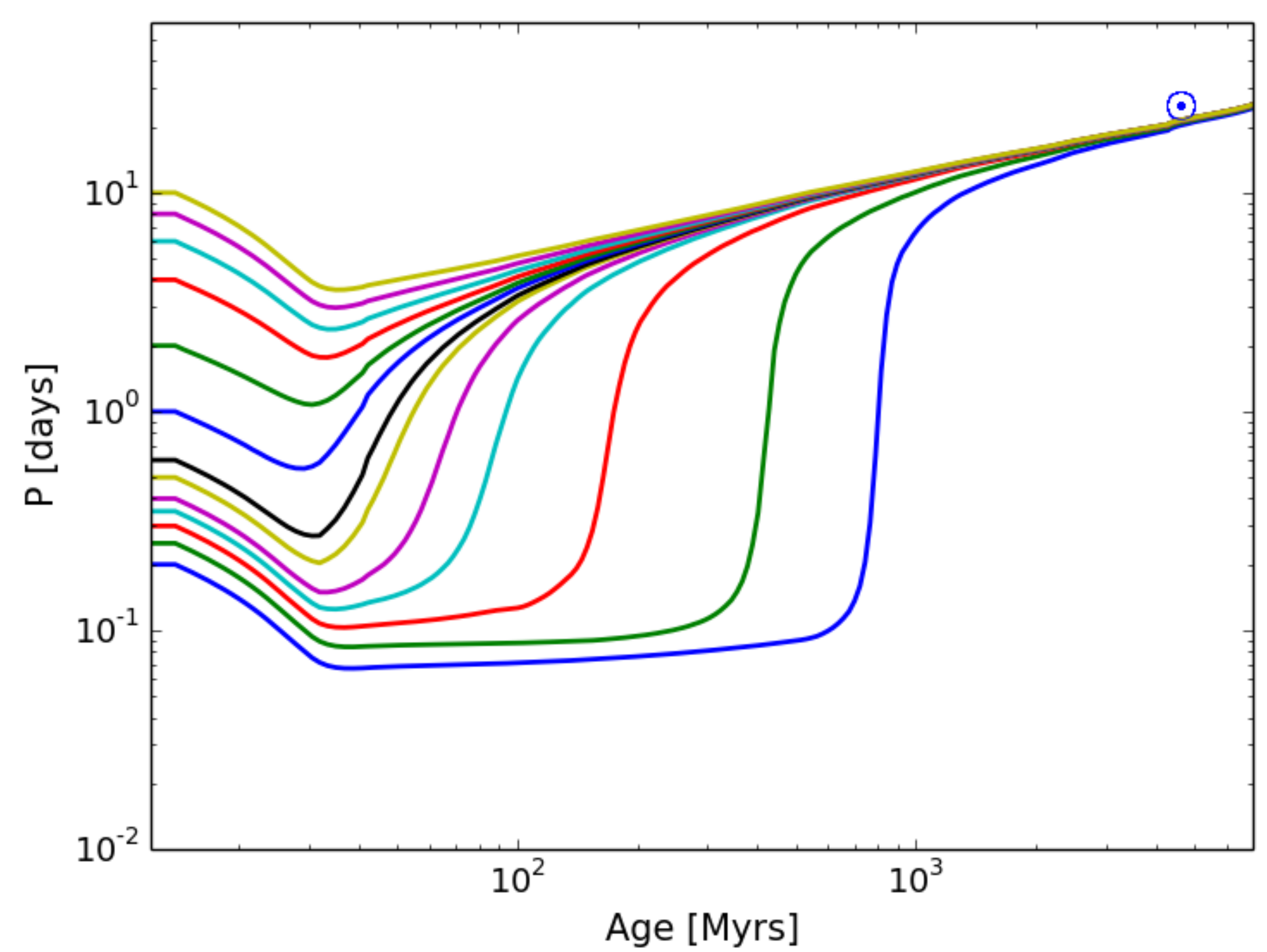
Just Skumanich

$$\dot{J} = \dot{J}_{Sku}$$

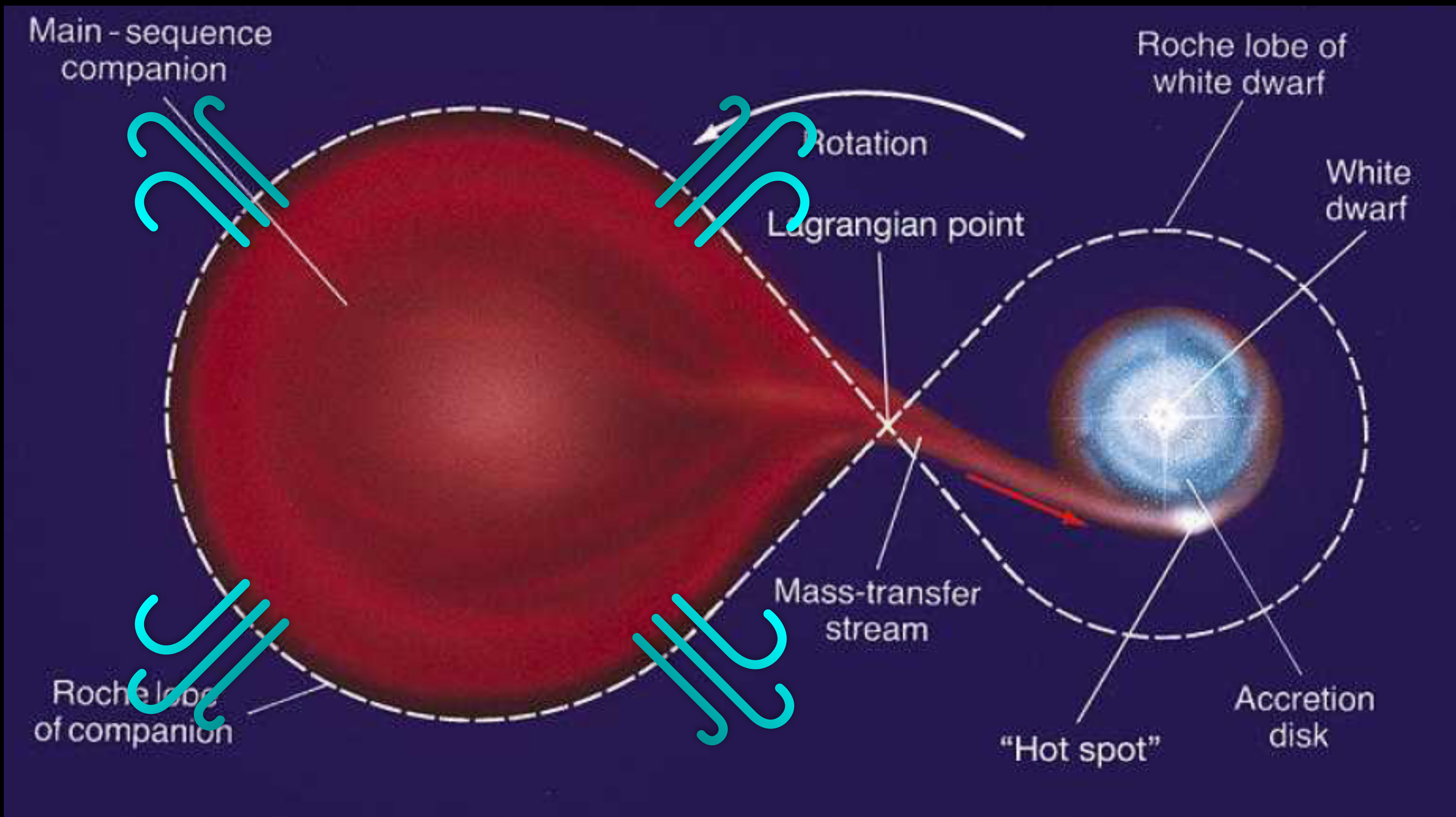


Including Complexity

$$\dot{J} = \dot{J}_{Sku} Q_J(n), \qquad Q_J(n) = 4.05e^{-1.4n}$$

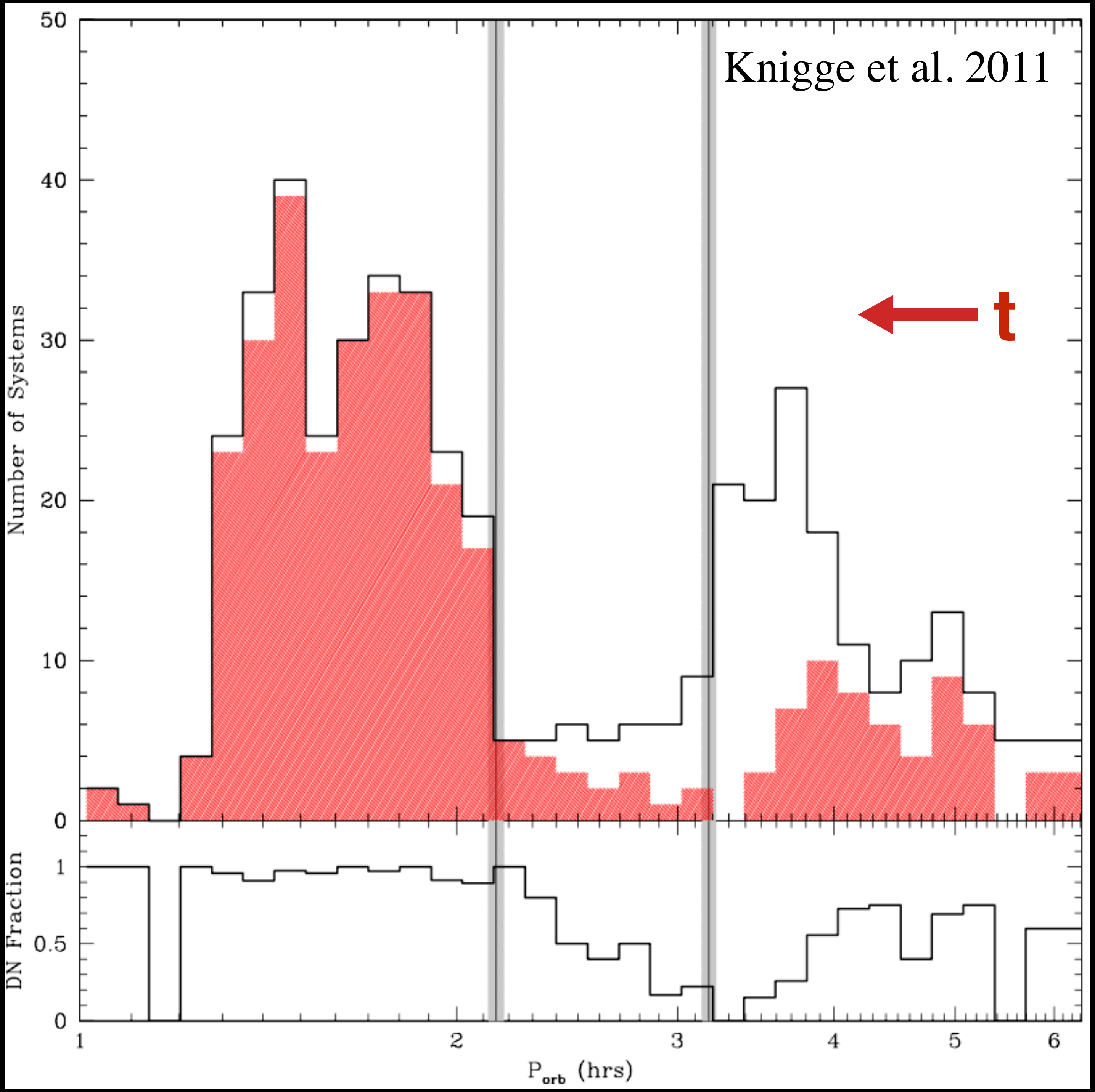


Orbital Evolution of Close Binaries



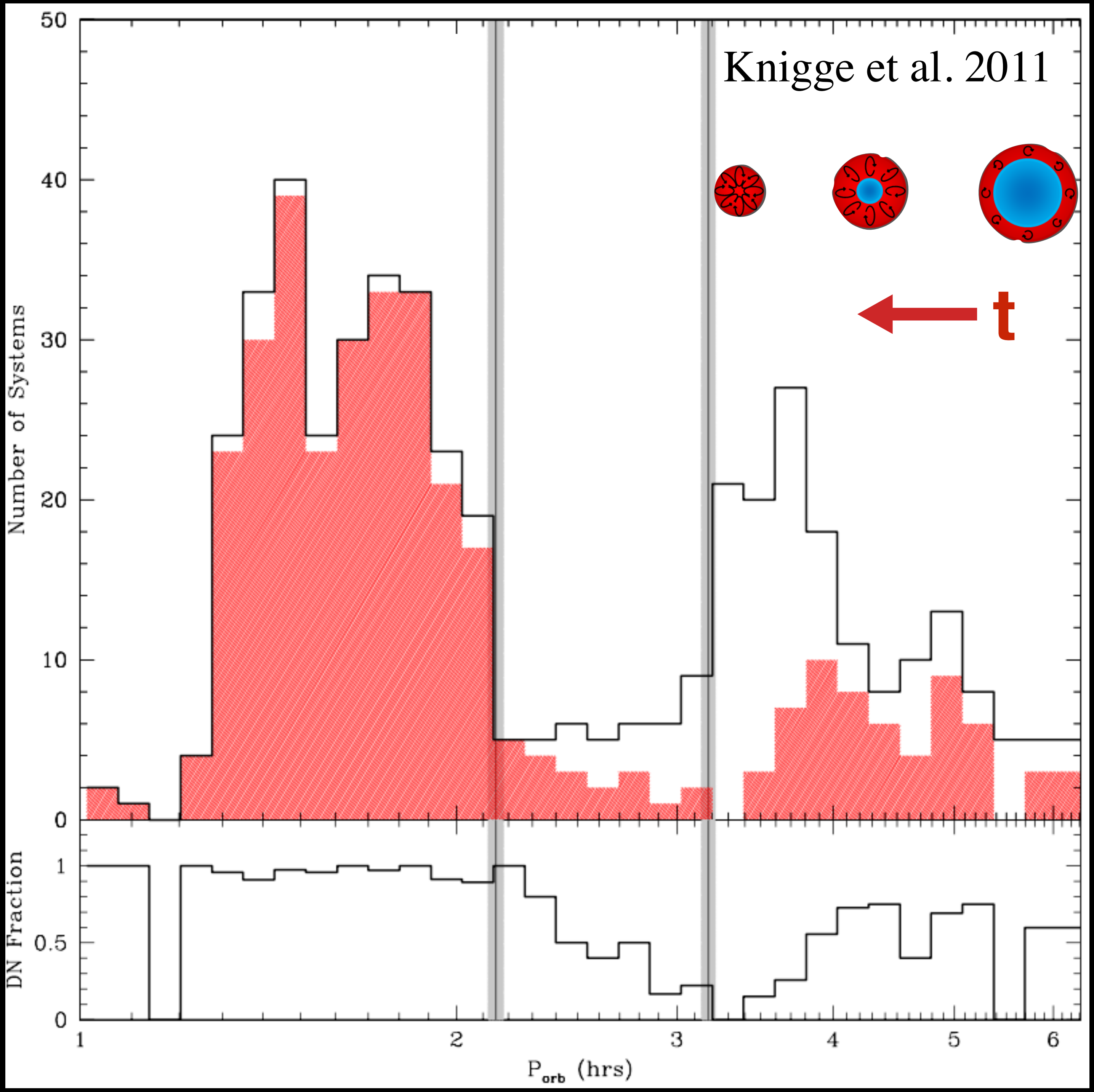
Orbital Evolution of Close Binaries

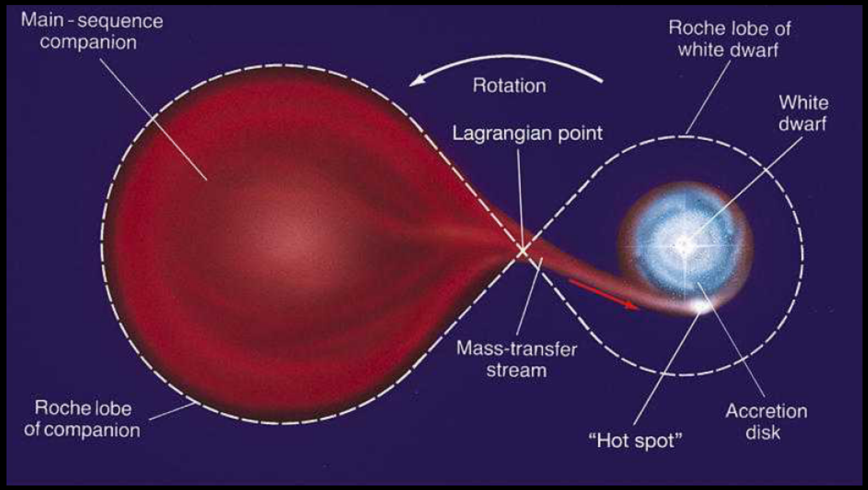
The Period Gap



Orbital Evolution of Close Binaries

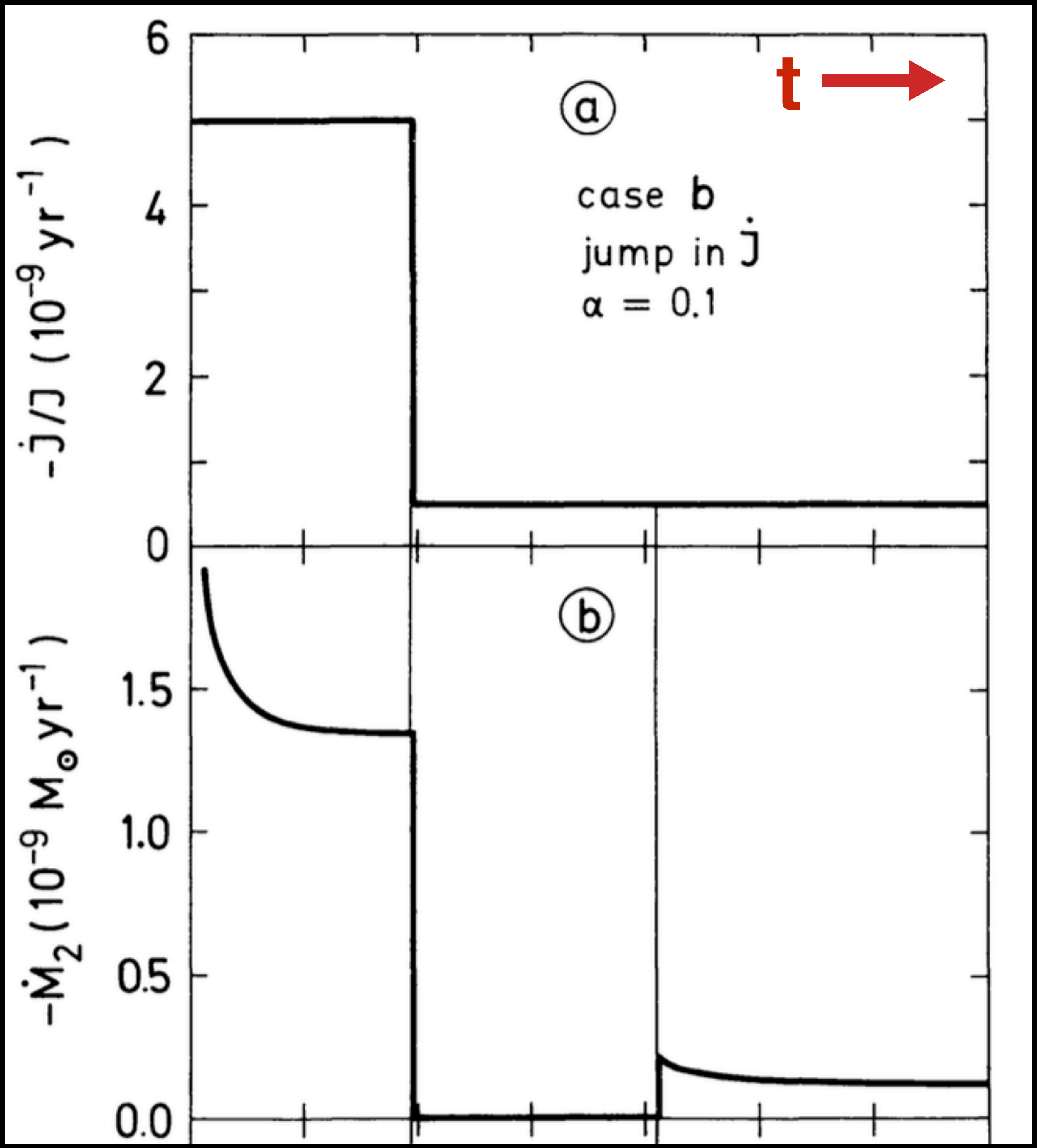
The Period Gap





Orbital Evolution of Close Binaries

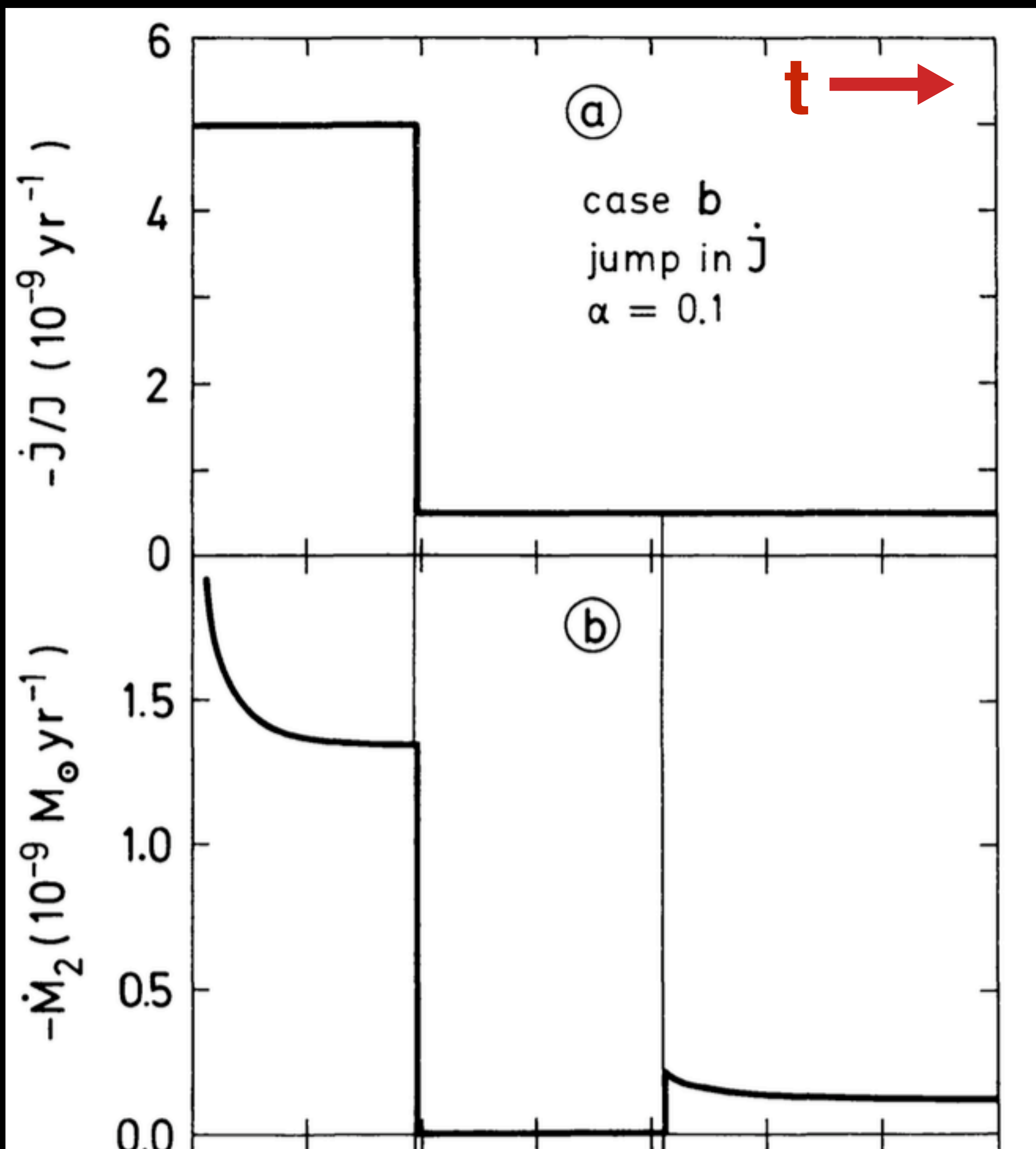
The Period Gap

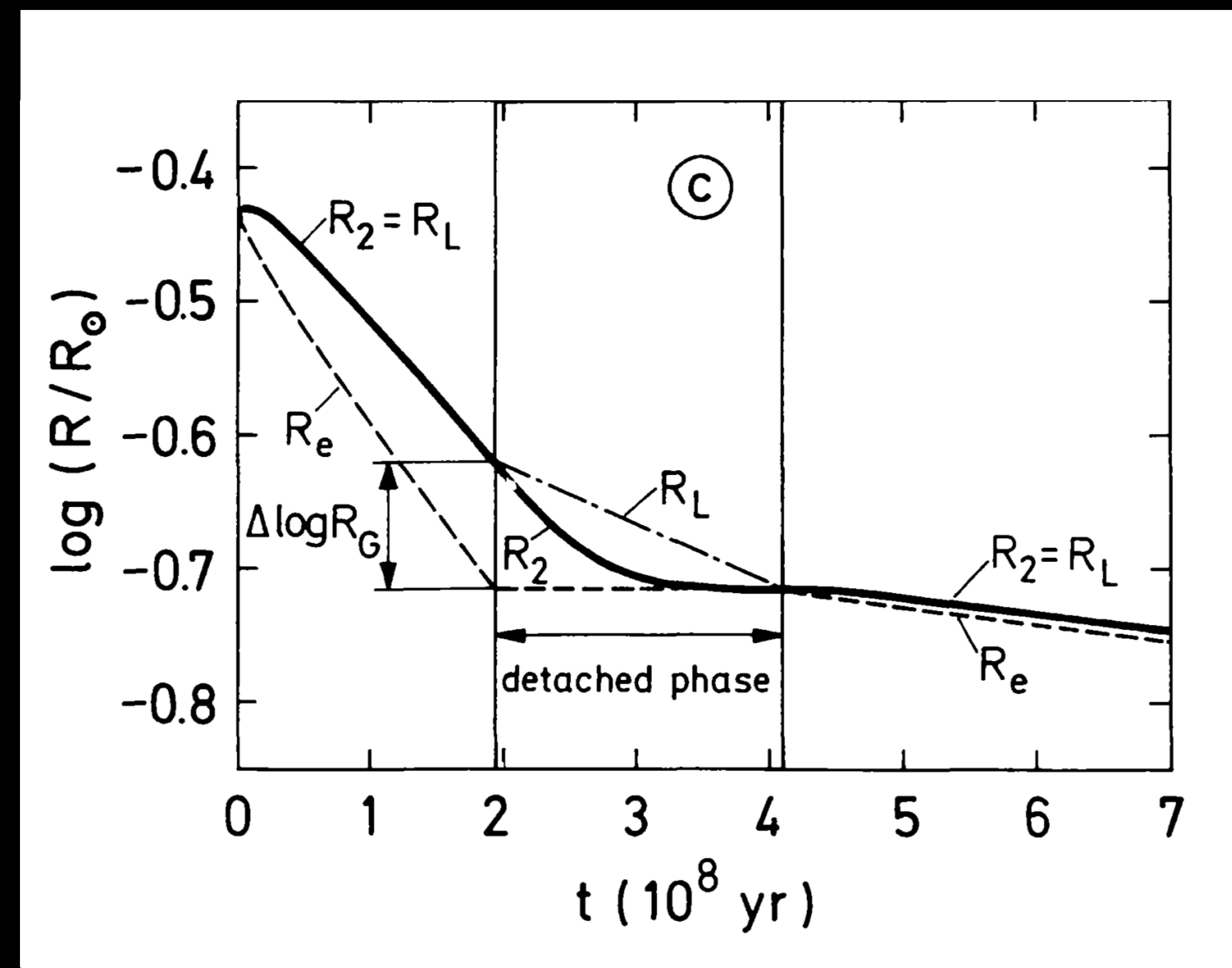


Spruit & Ritter 1983

Orbital Evolution of Close Binaries

The Period Gap

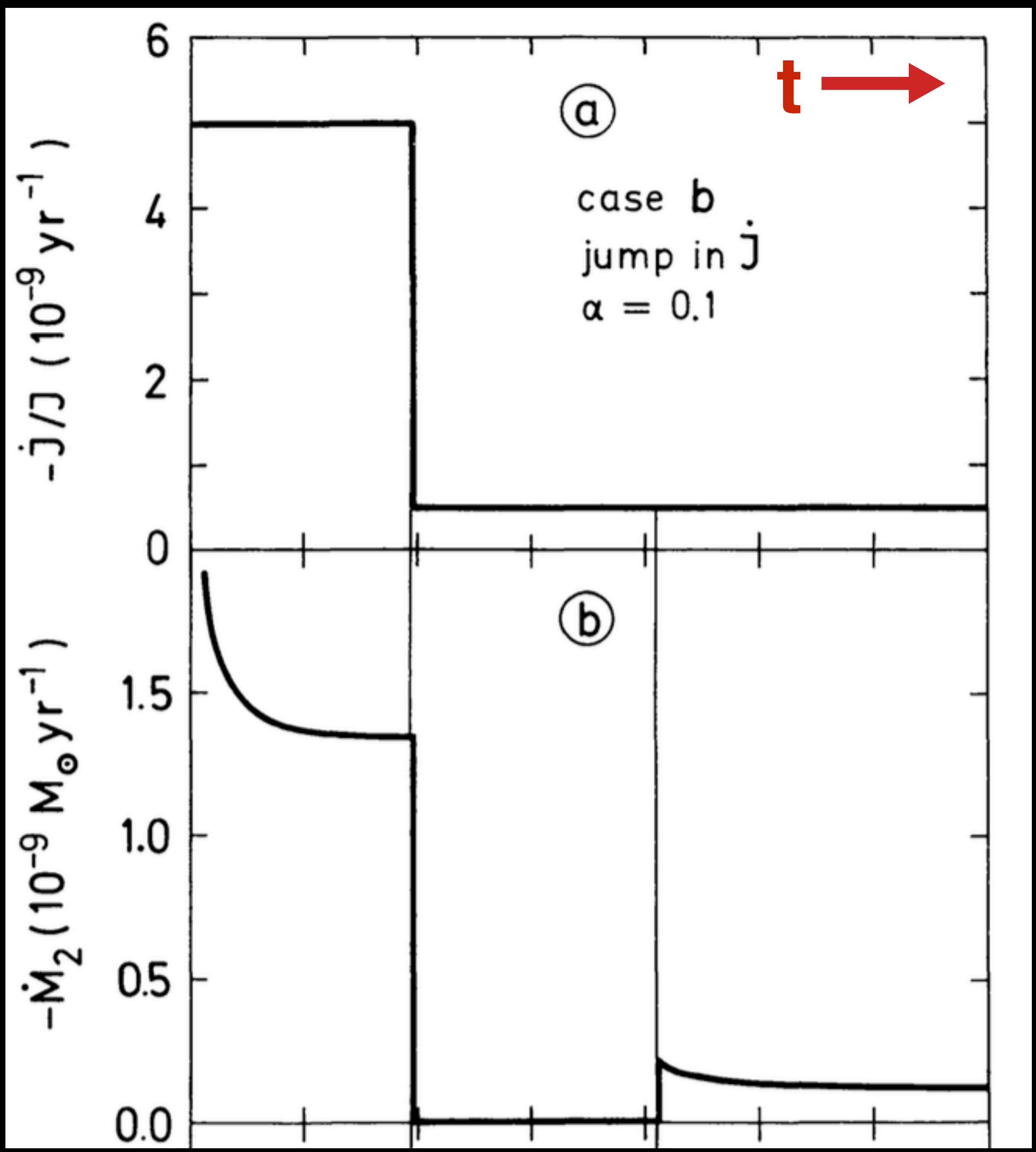




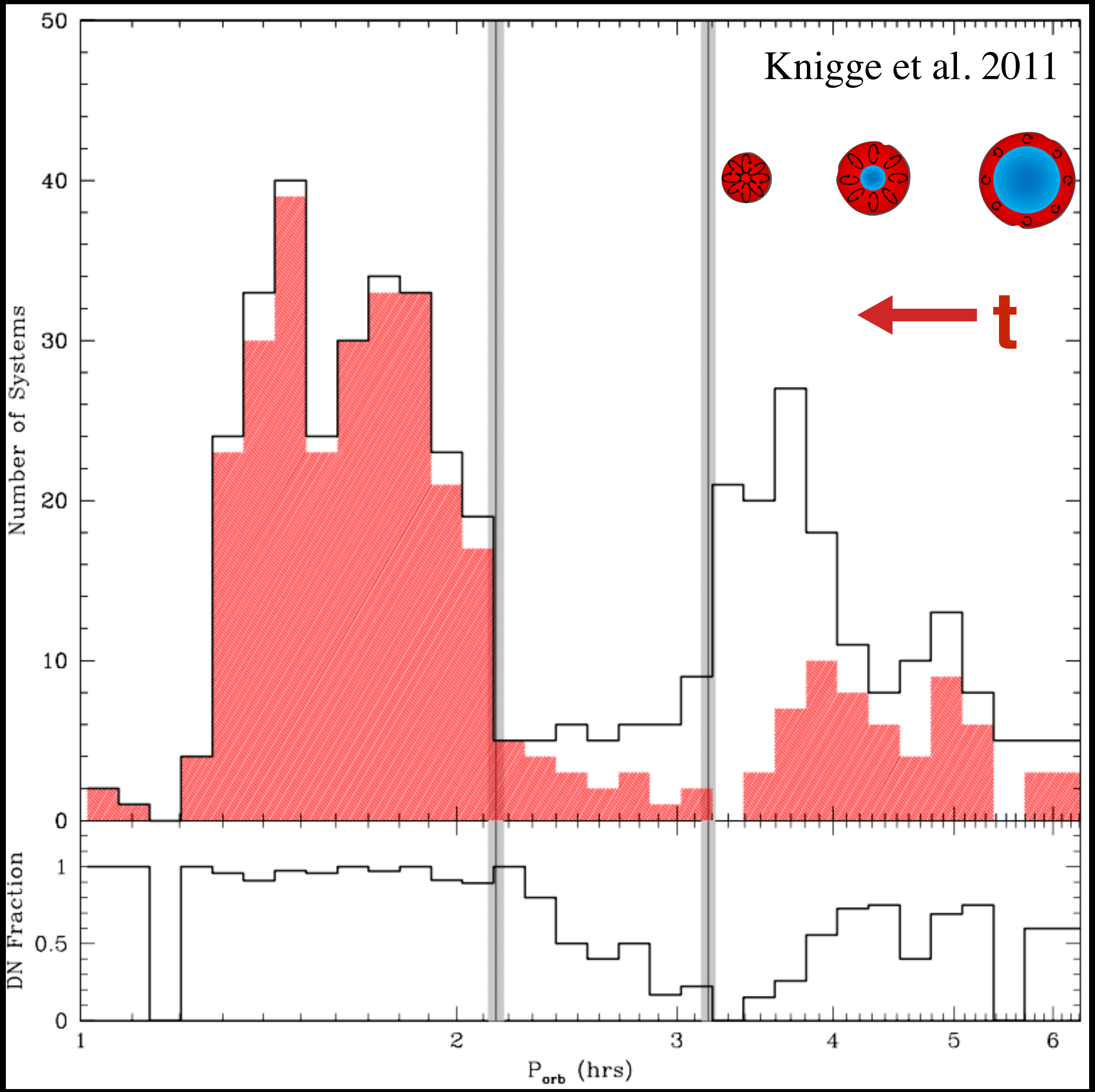
Spruit & Ritter 1983

Orbital Evolution of Close Binaries

The Period Gap

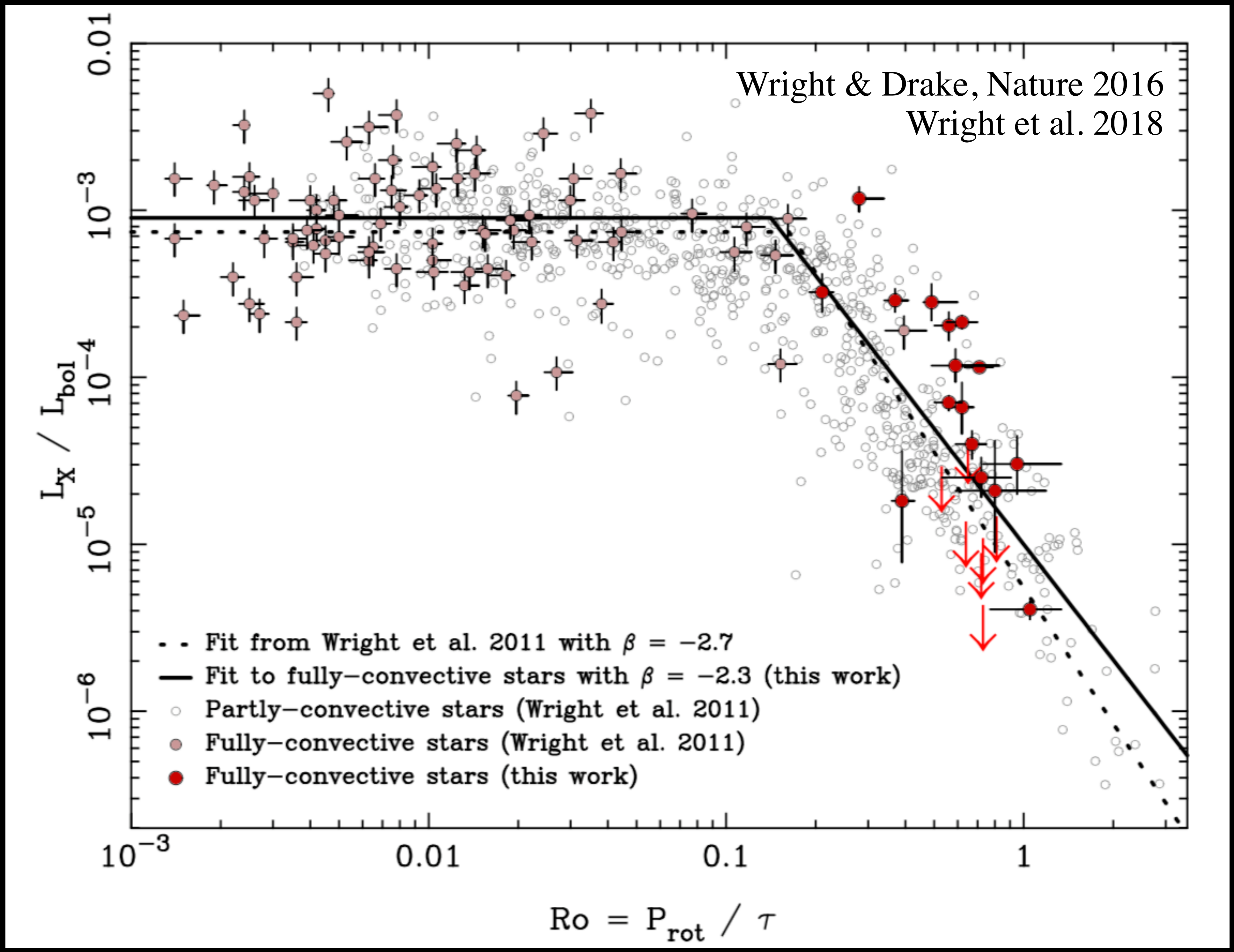


Spruit & Ritter 1983



Orbital Evolution of Close Binaries

The Period Gap

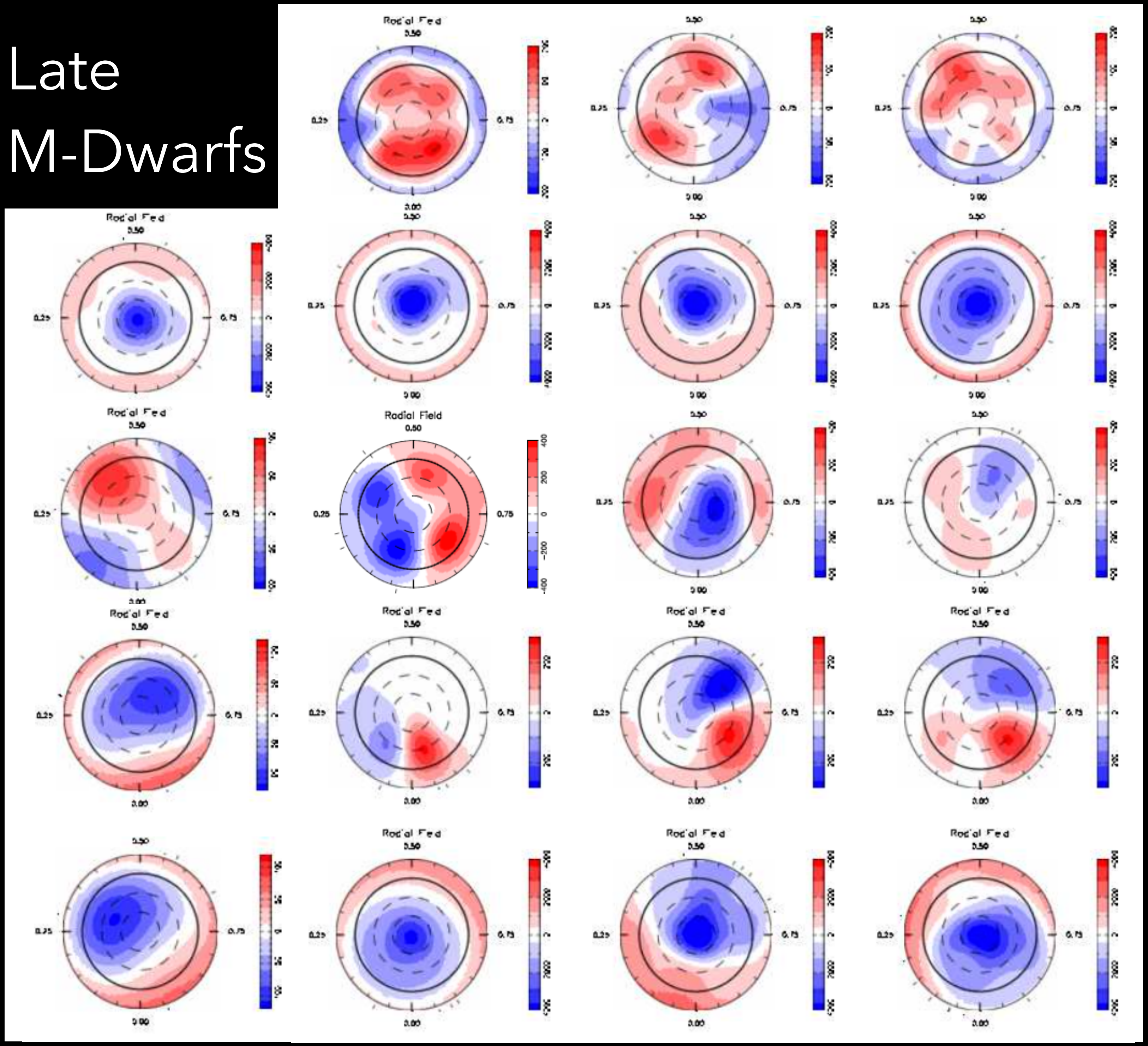


Orbital Evolution of Close Binaries

The Magnetic Nature of the Period Gap

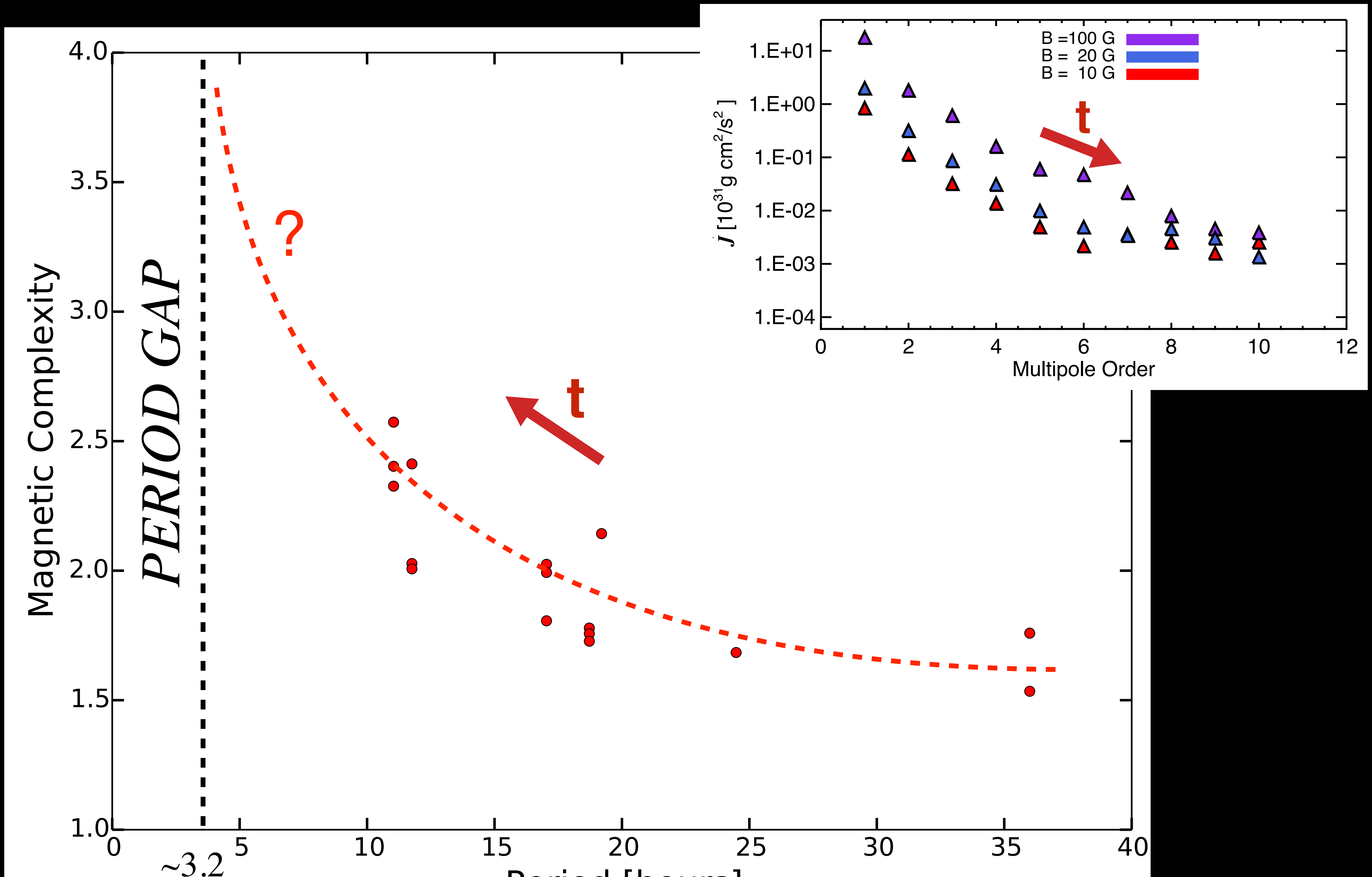
Morin et al. 2010

Late
M-Dwarfs



Orbital Evolution of Close Binaries

The Magnetic Nature of the Period Gap

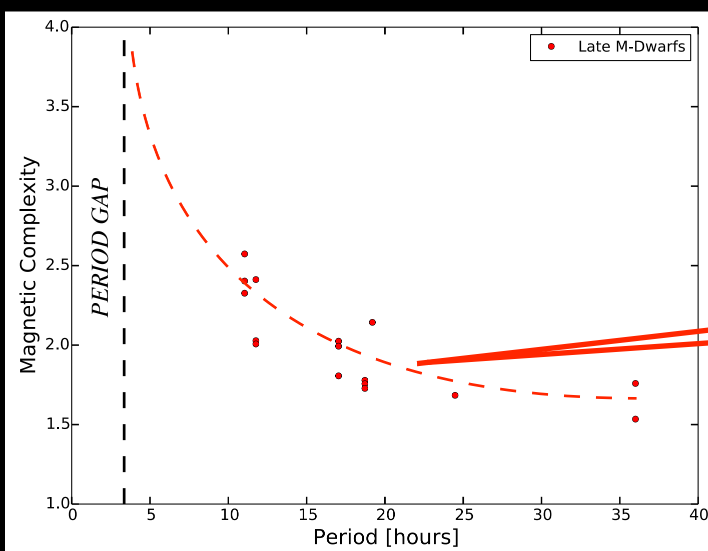


Garraffo et al. accepted to ApJ

Orbital Evolution of Close Binaries

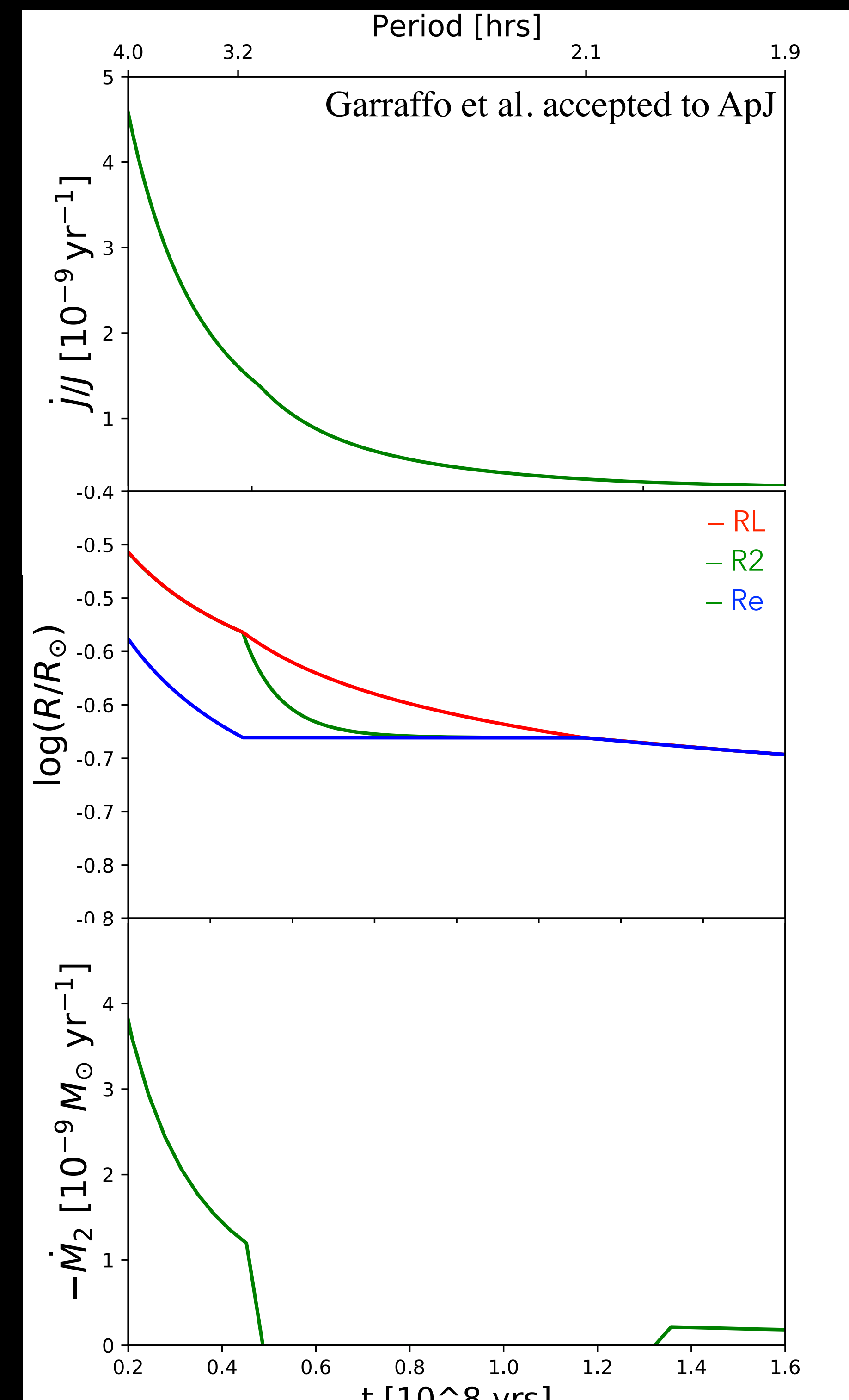
The Magnetic Nature of the Period Gap

Spin-Down model in single systems:



$$\dot{J} = \dot{J}_{Dip} Q_J(n)$$

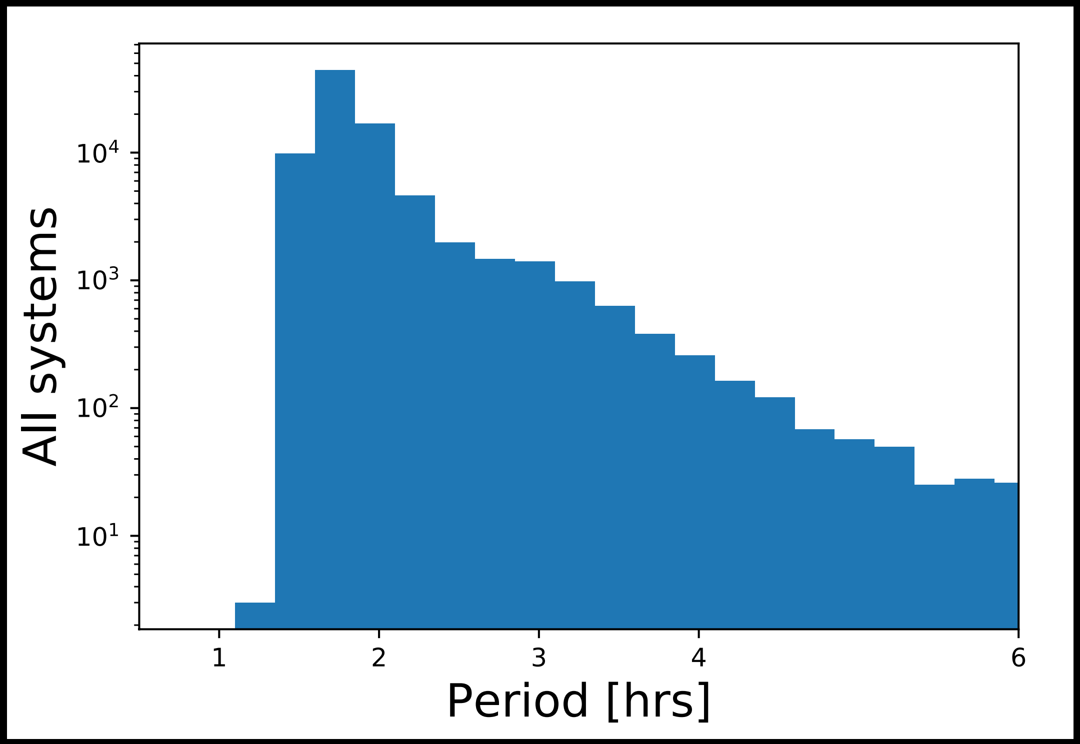
$$Q_J(n) = 4.05\, e^{-1.4n}$$

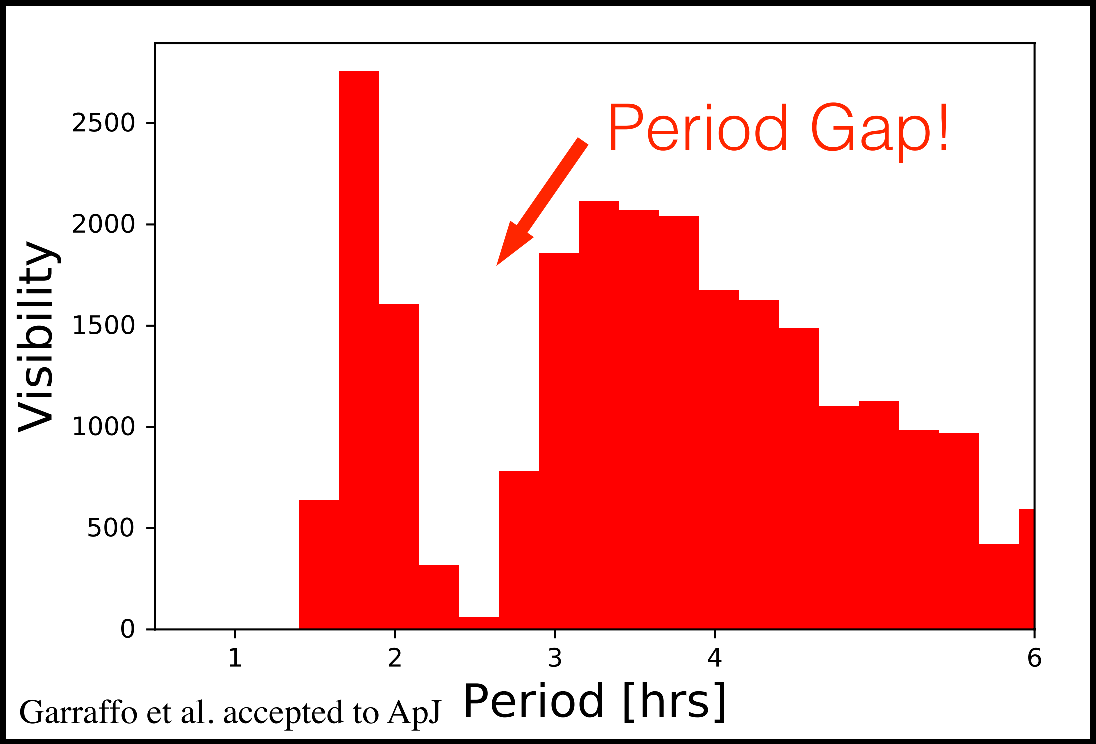


Orbital Evolution of Close Binaries

The Magnetic Nature of the Period Gap

Spin-Down model in synthetic populations:





$$L_{acc} \propto GM_1\dot{M}_2/R_1$$

Summary

- Magnetic complexity is the missing ingredient for a complete spin-down model
- The CV period gap is a consequence of stellar magnetic evolution
- The same single star spin-down prescription that reproduces the OC observations holds for close binary systems and explains the CV period gap.

"The answer is blowing in the wind..."

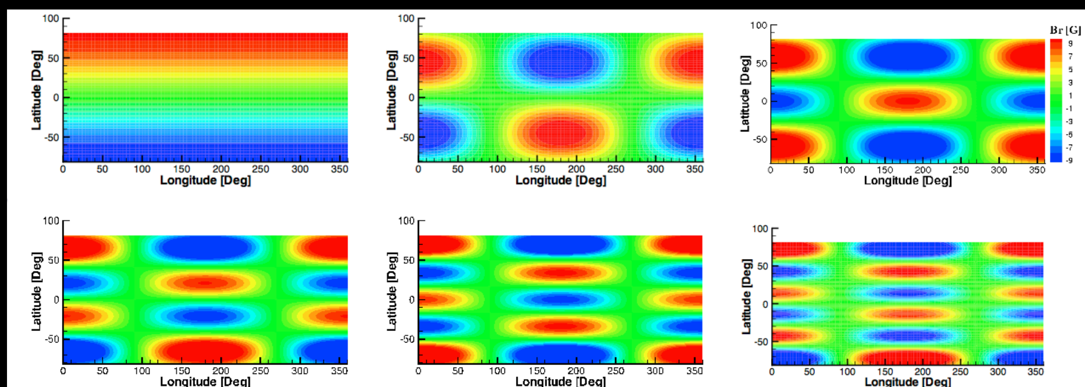
Thank you!

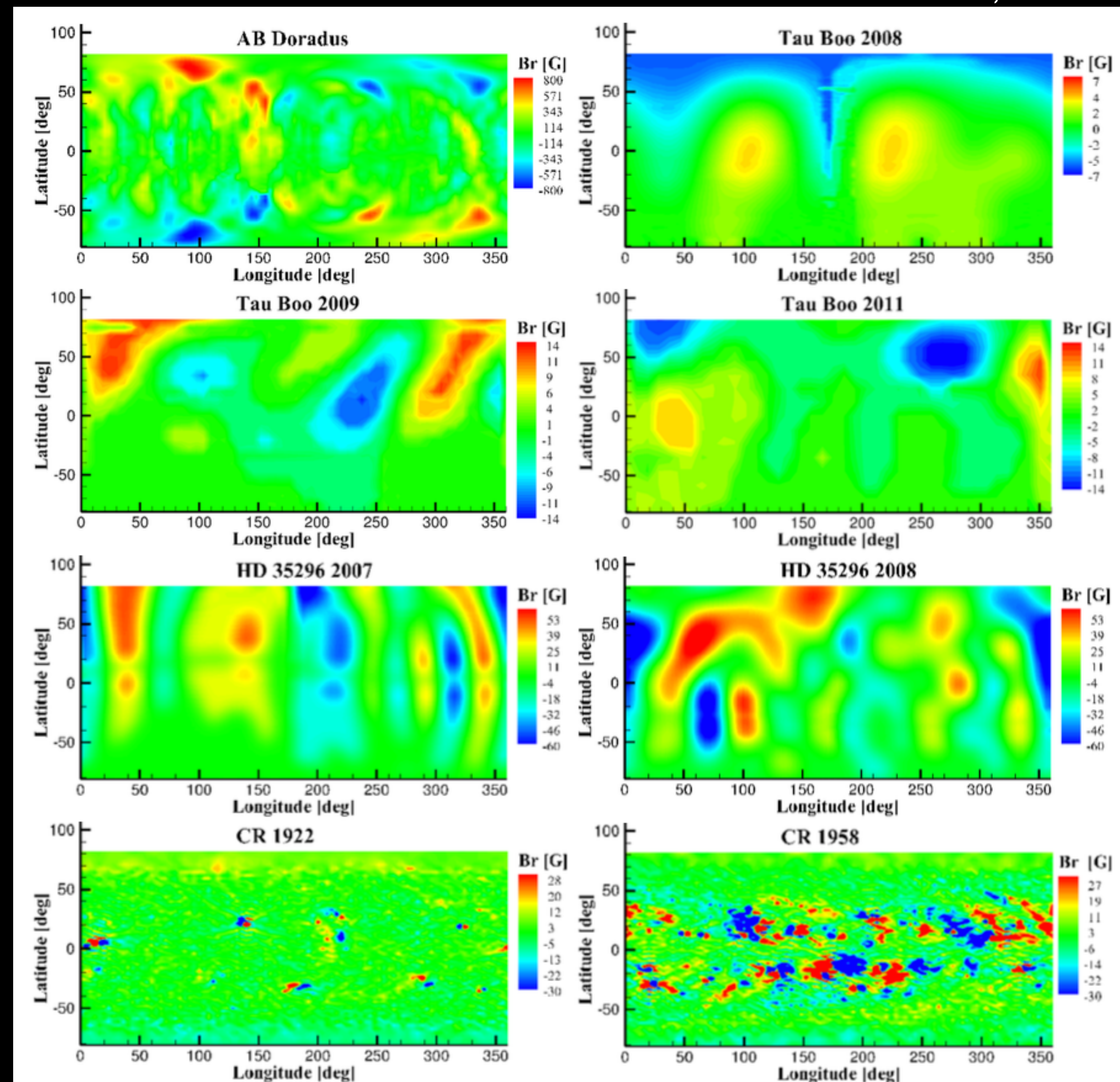
Backup Slides

Stellar Rotation

Application to Real Stars

Garraffo et al., 2016



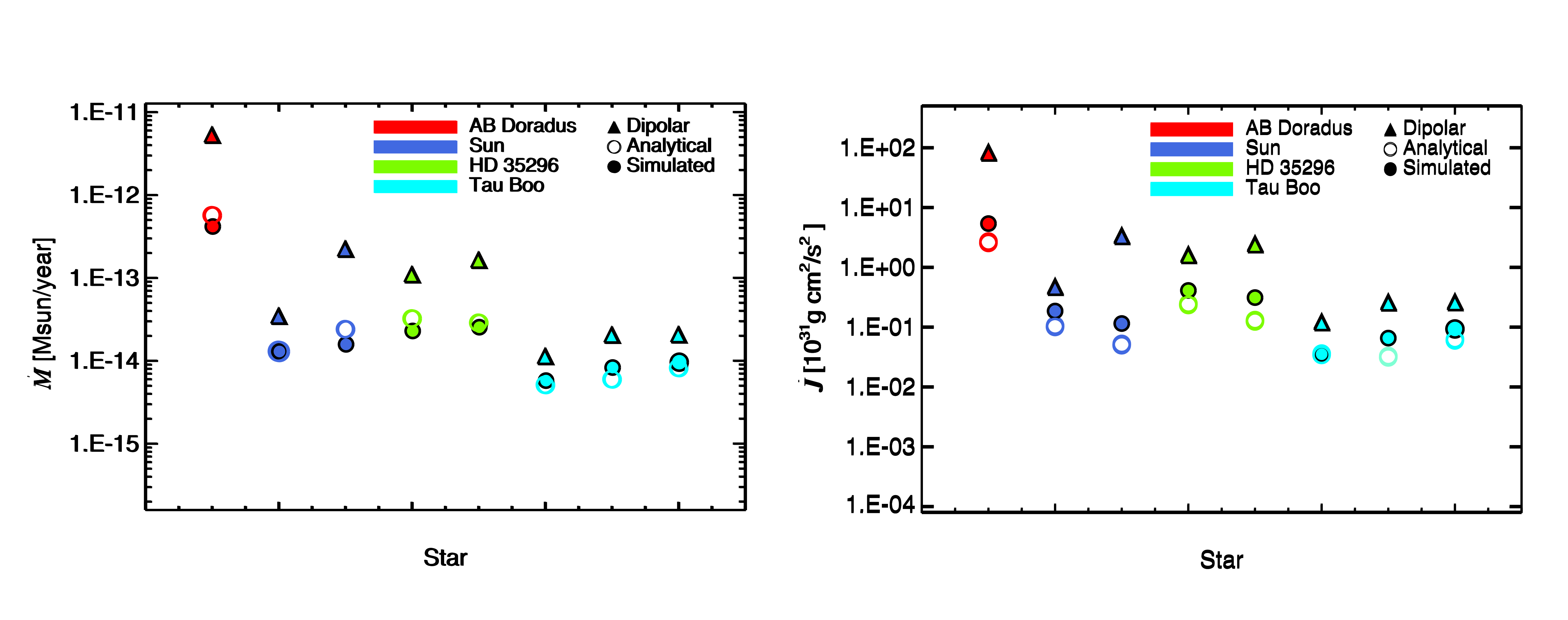


$$n = \sum_{l=0}^{l_{max}} \frac{l \, F_l}{F_T}$$

Stellar Rotation

Application to Real Stars

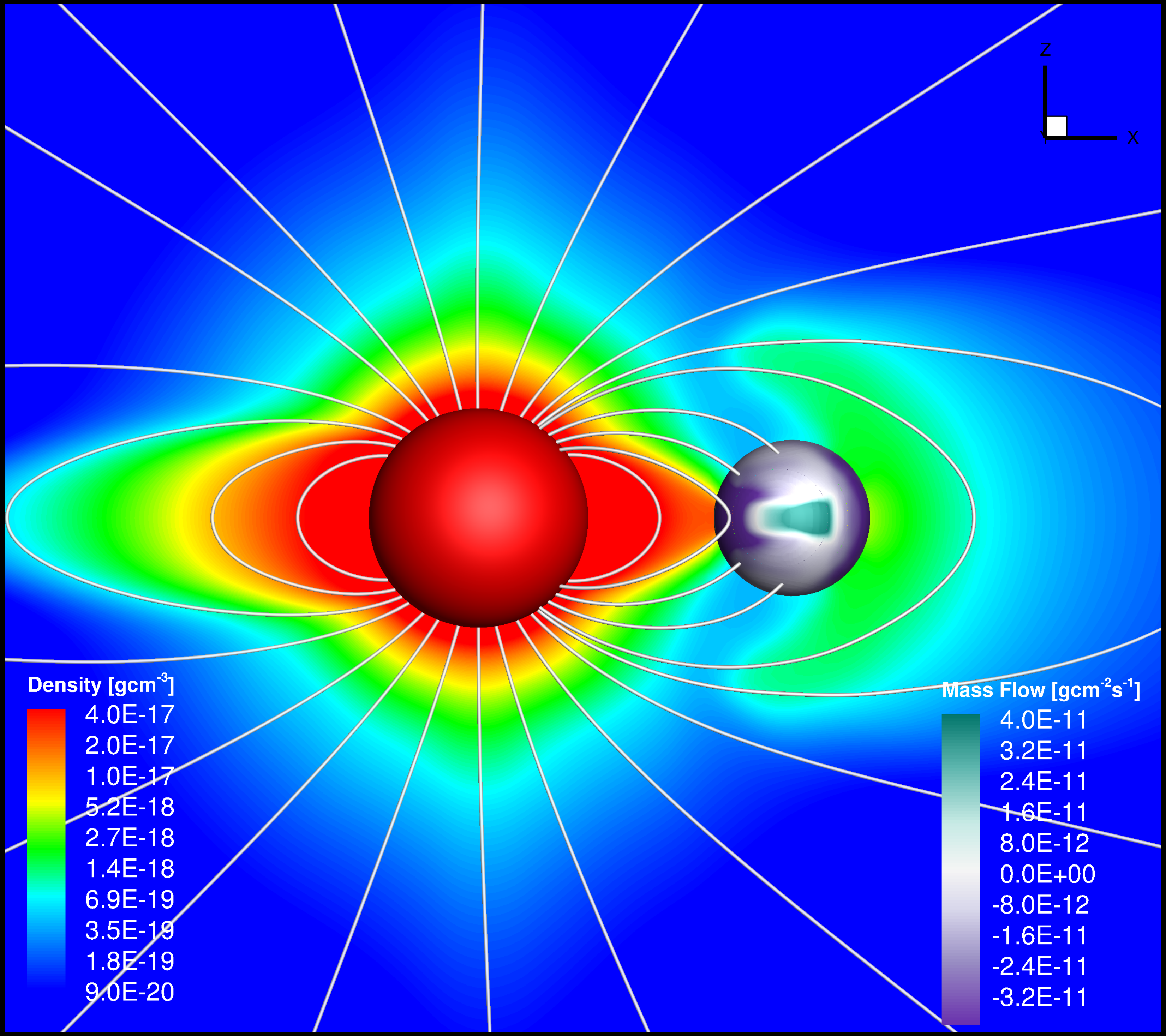
Garraffo et al., 2016



$$\dot{J} = \dot{J}_{Dip} Q_J(n) \qquad Q_J(n) = 4.05\, e^{-1.4n} + \frac{(n-1)}{(60\, n\, B)}$$

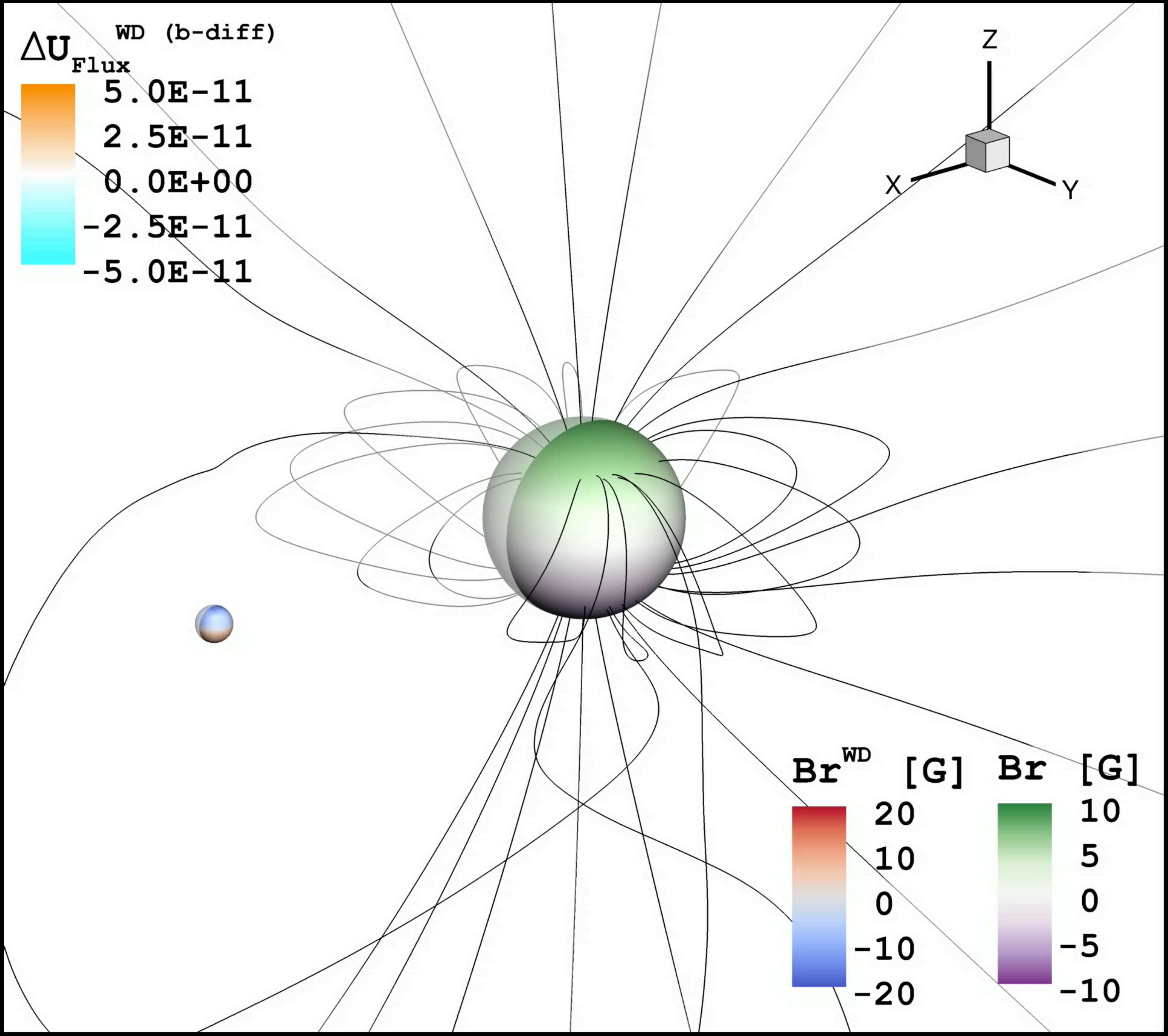
Wind Accretion in Pre-Cataclysmic Binaries

There is currently no way to **directly** detect the winds of late-type MS stars



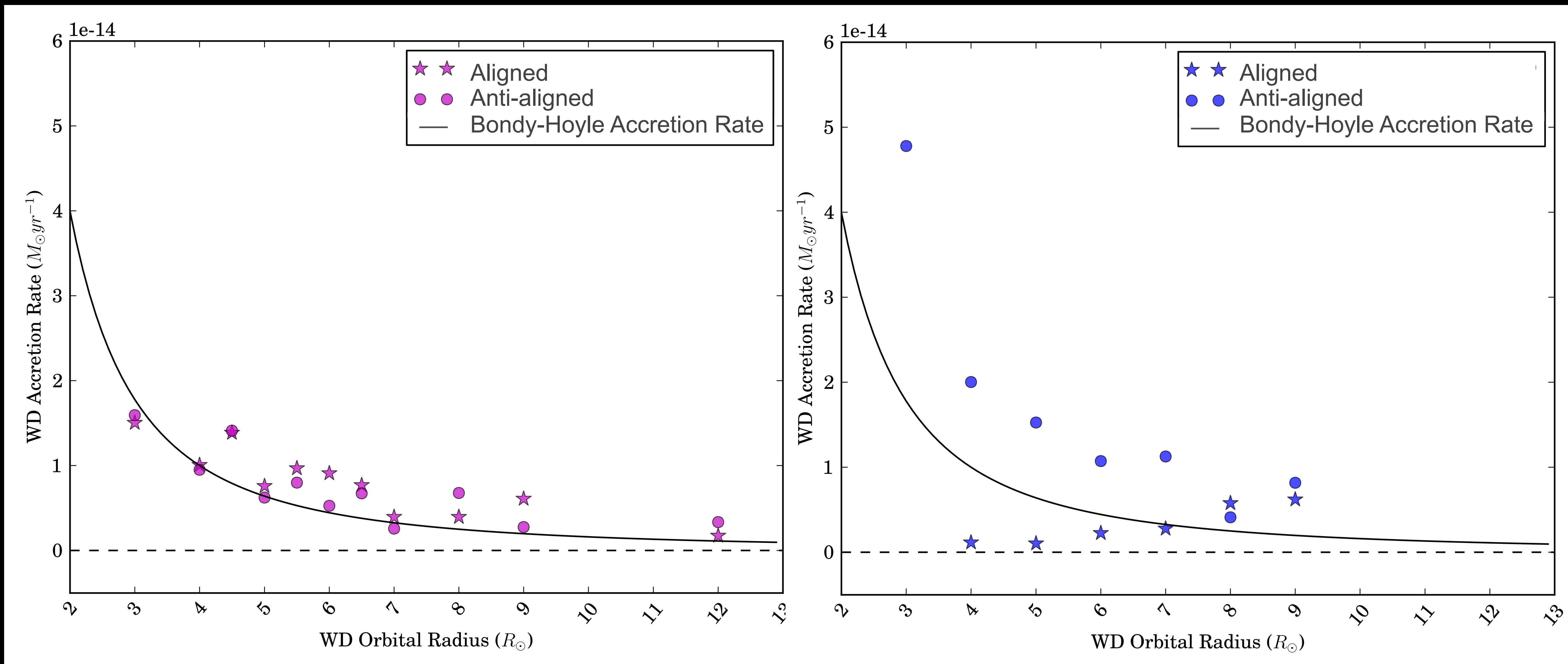
Lascelles, Garraffo + in prep

Wind Accretion in Pre-Cataclysmic Binaries



Lascelles, Garraffo + in prep

Wind Accretion in Pre-Cataclysmic Binaries



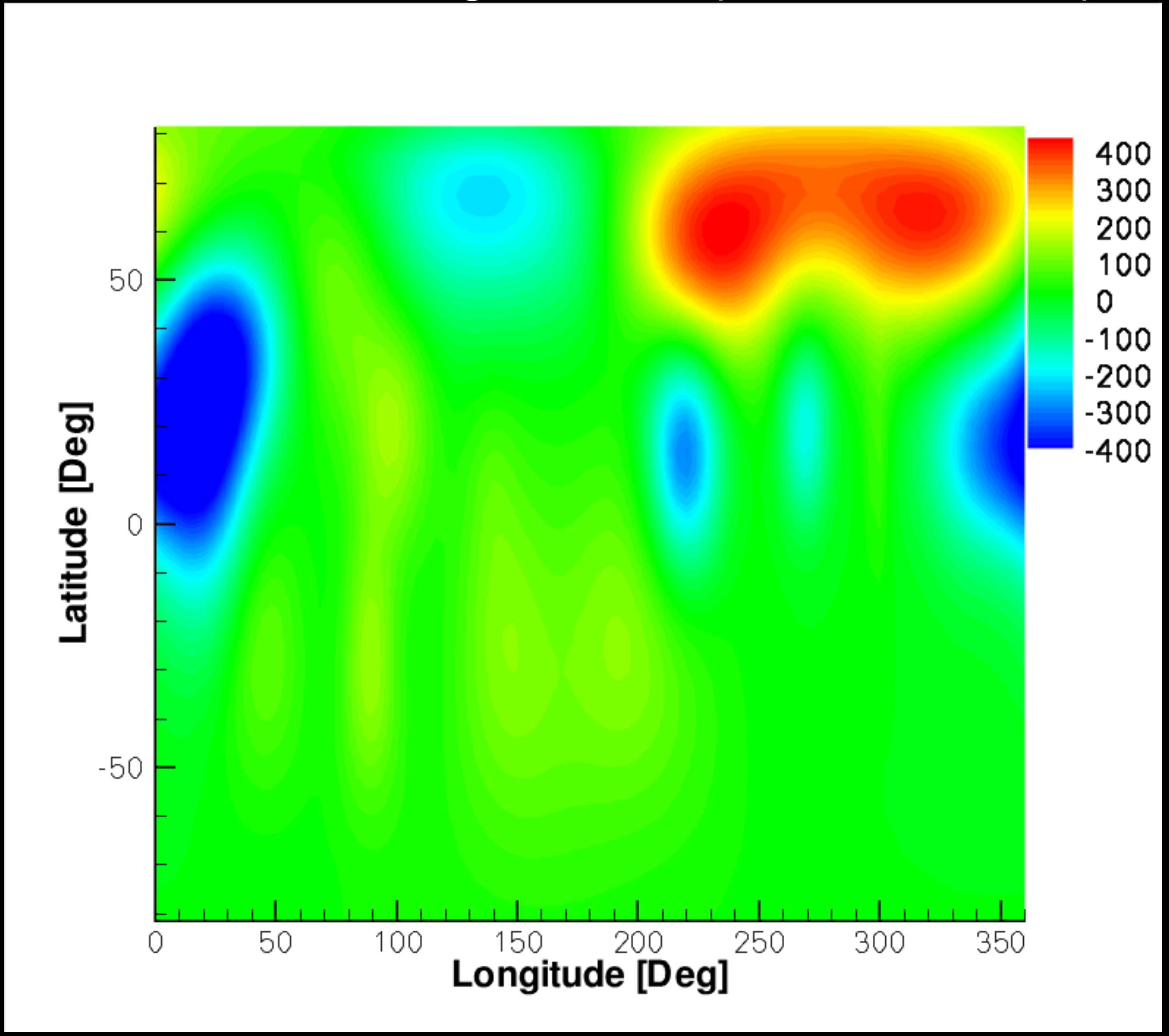
Lascelles, Garraffo + in prep

Stellar Rotation

We assume dipolar fields in our models, but observed magnetograms do not look dipolar.

1. How important is the missing the small scale?

ZDI magnetic map for V2129 Oph

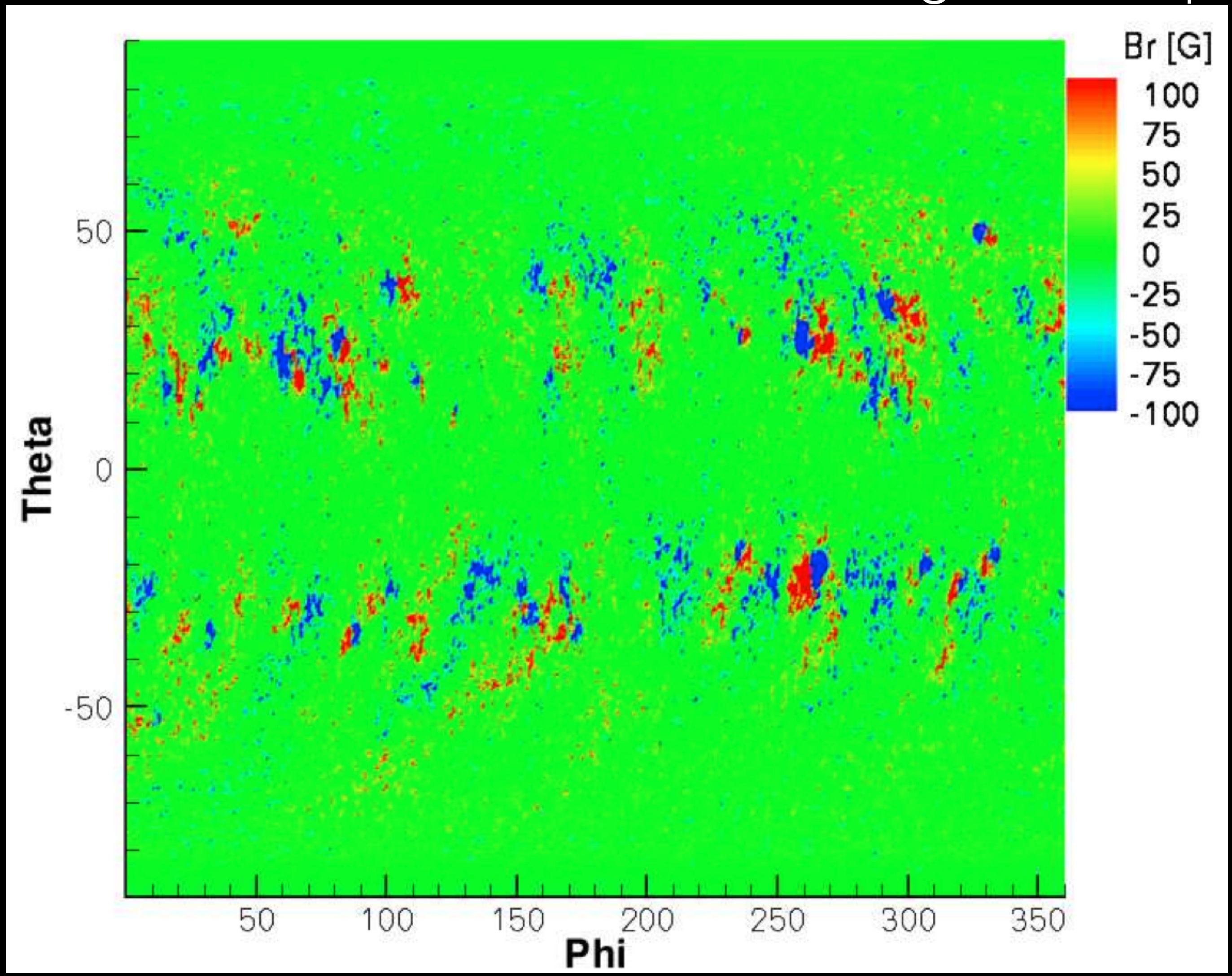


Stellar Rotation

We assume dipolar fields in our models, but observed magnetograms do not look dipolar.

1. How important is the missing the small scale?
2. Do active regions affect angular momentum loss?

Solar magnetic map

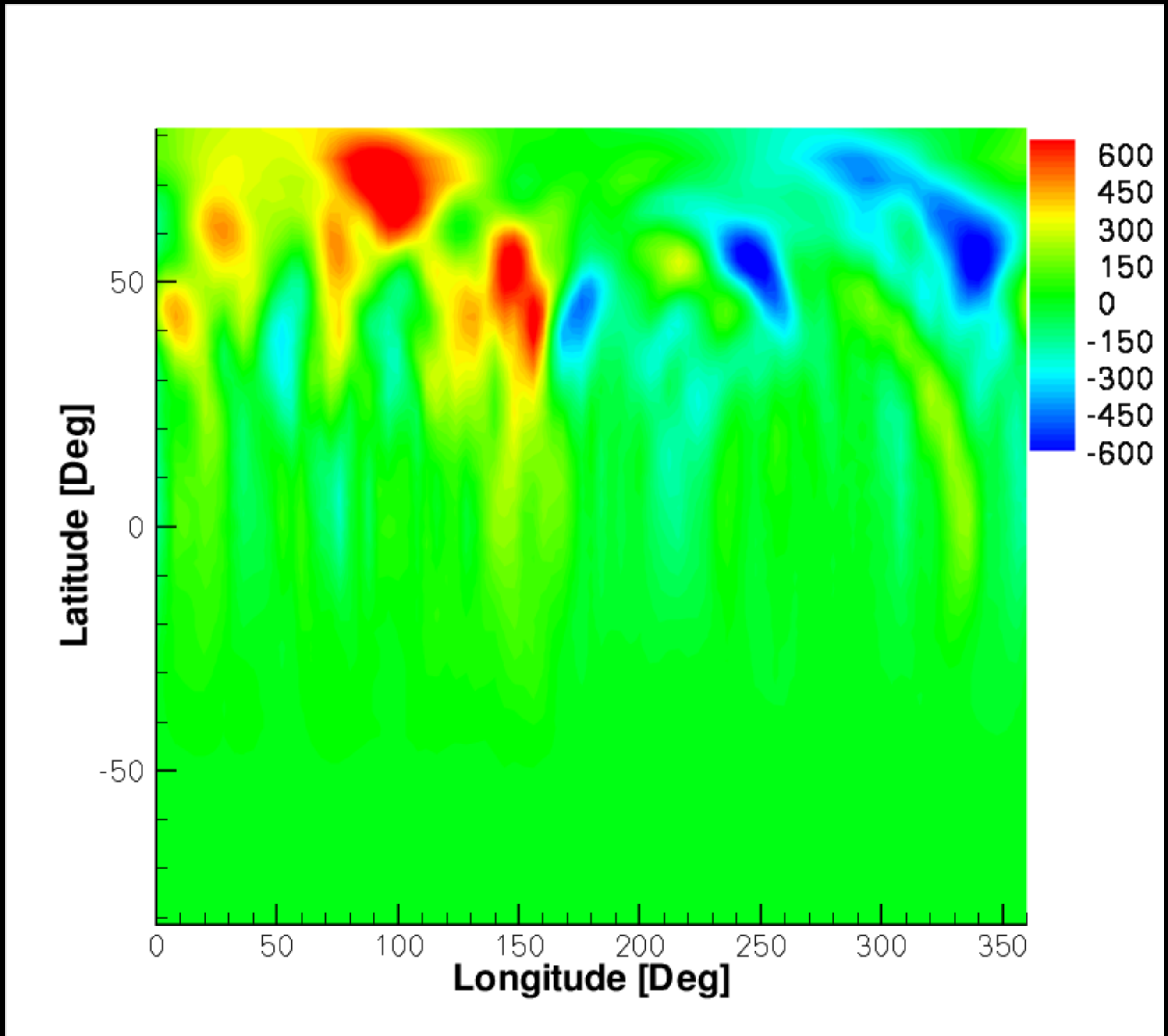


Stellar Rotation

We assume dipolar fields in our models, but observed magnetograms do not look dipolar.

AB Doradus

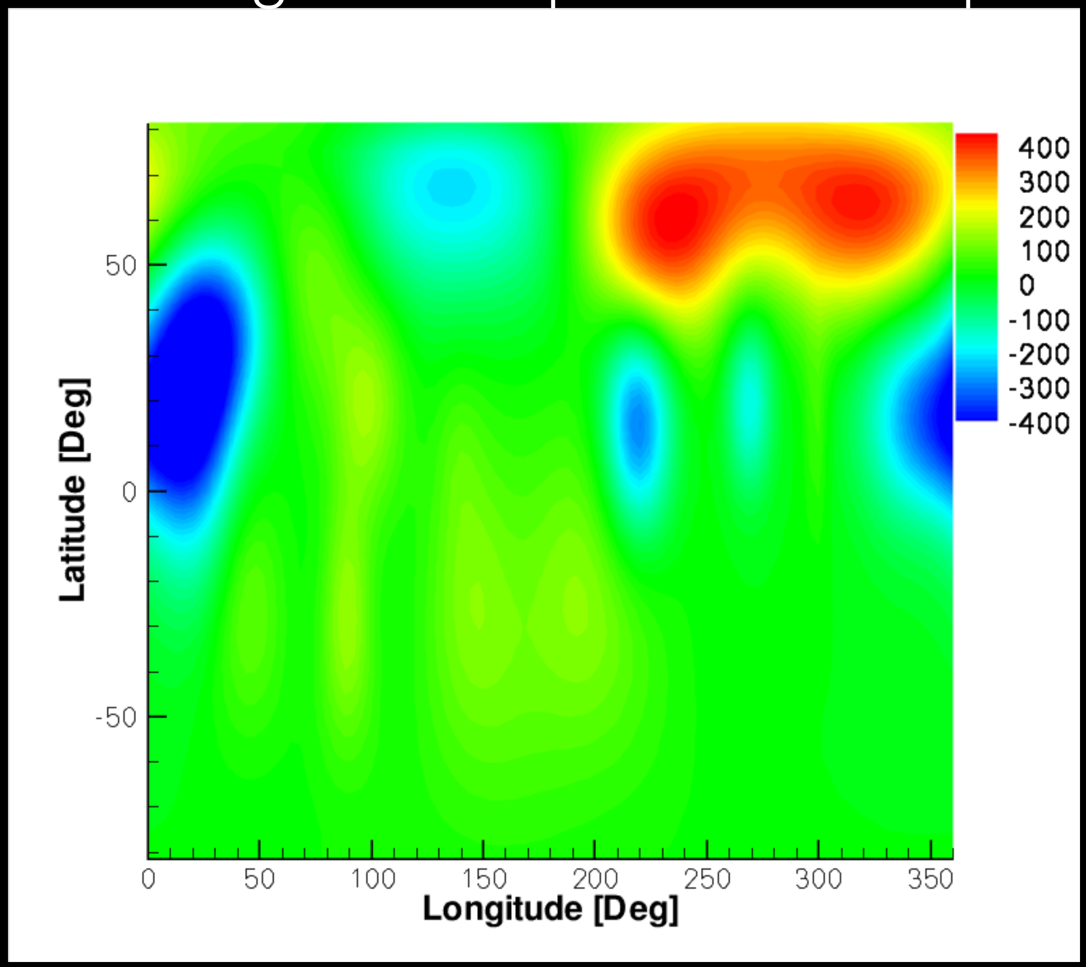
1. How important is the missing the small scale?
2. Do active regions affect angular momentum loss?
3. How much does large scale morphology matter?



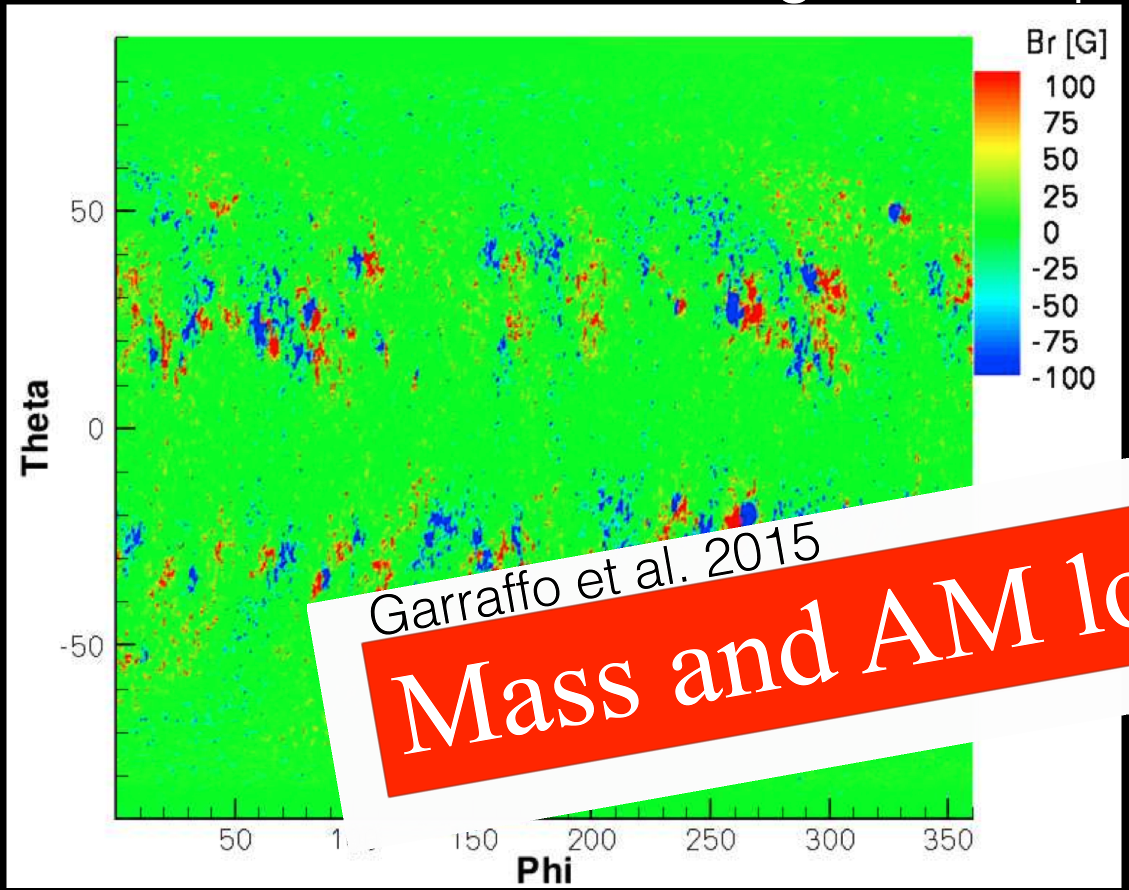
Stellar Rotation

How important is the missing the small scale?

ZDI magnetic map for V2129 Oph



Solar magnetic map



Garraffo et al. 2015

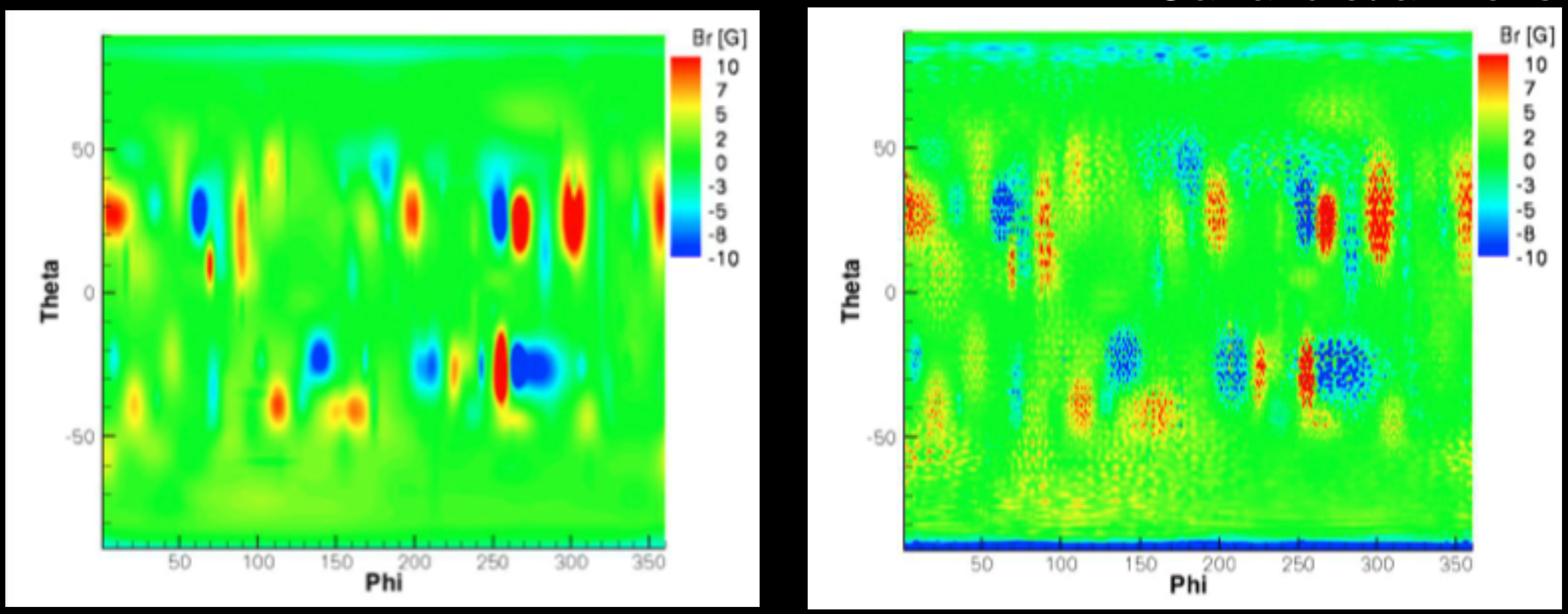
Mass and AM loss rates change by a few

…momentum loss?

Stellar Rotation

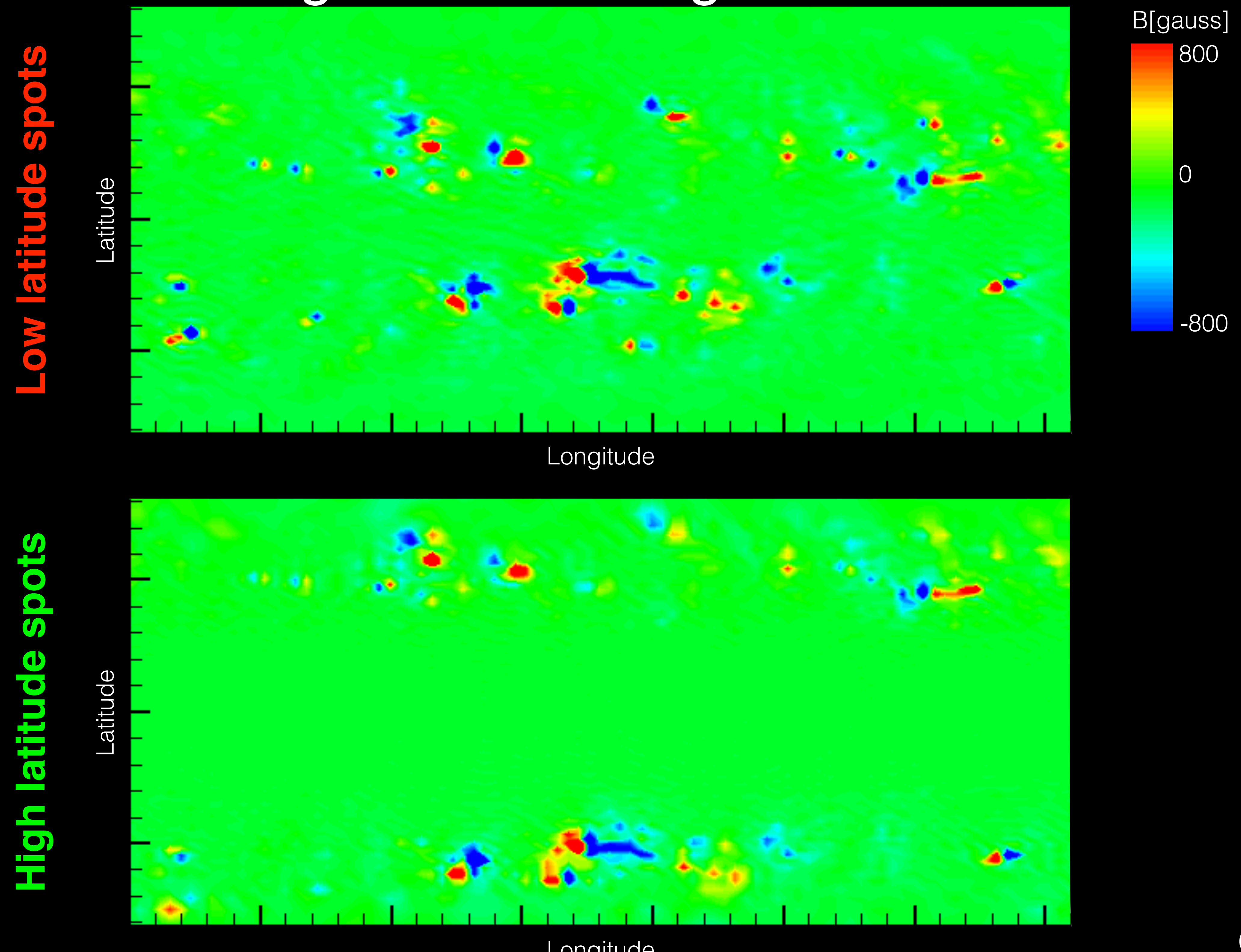
1. How important is the missing the small scale?

Garraffo et al. 2013



Stellar Rotation

2. Do active regions affect angular momentum loss?



Stellar Rotation

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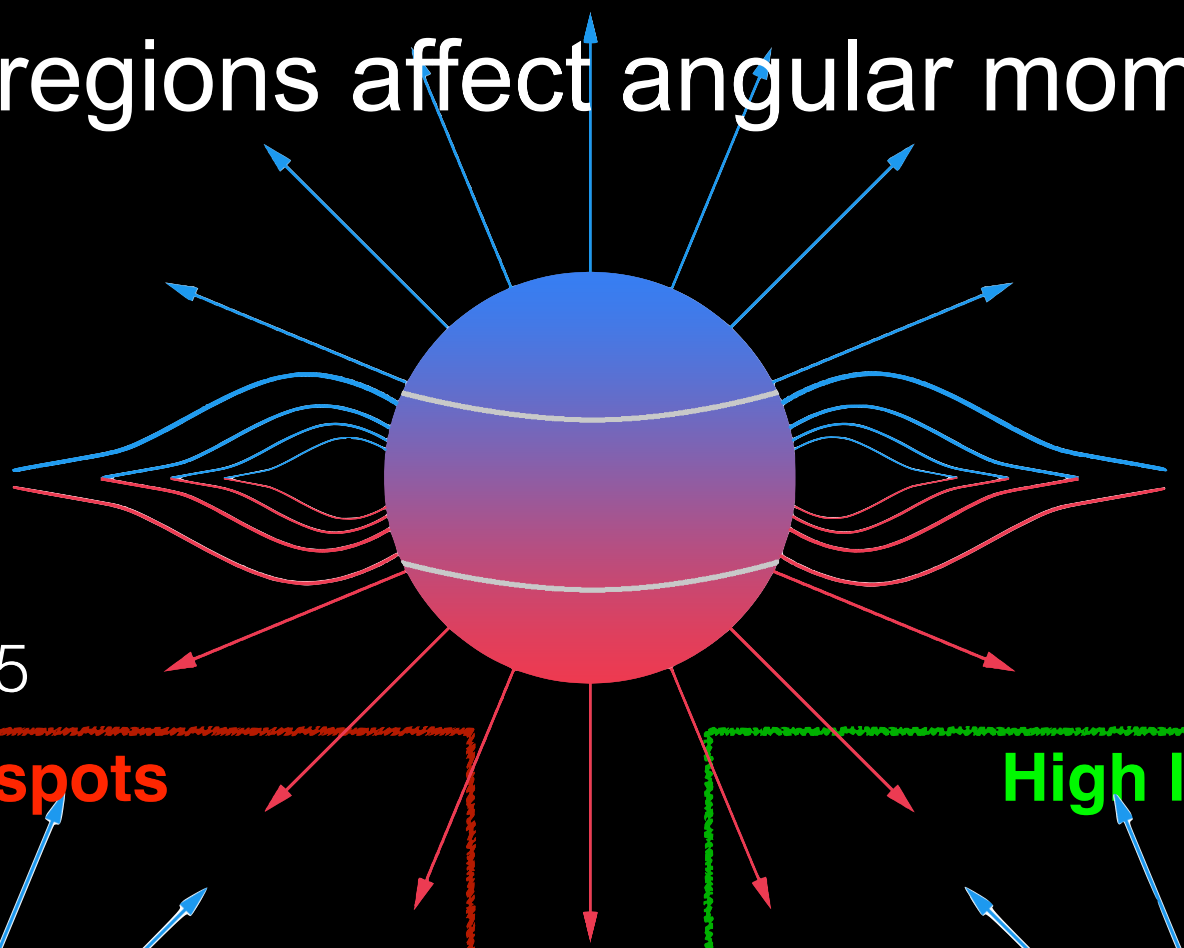
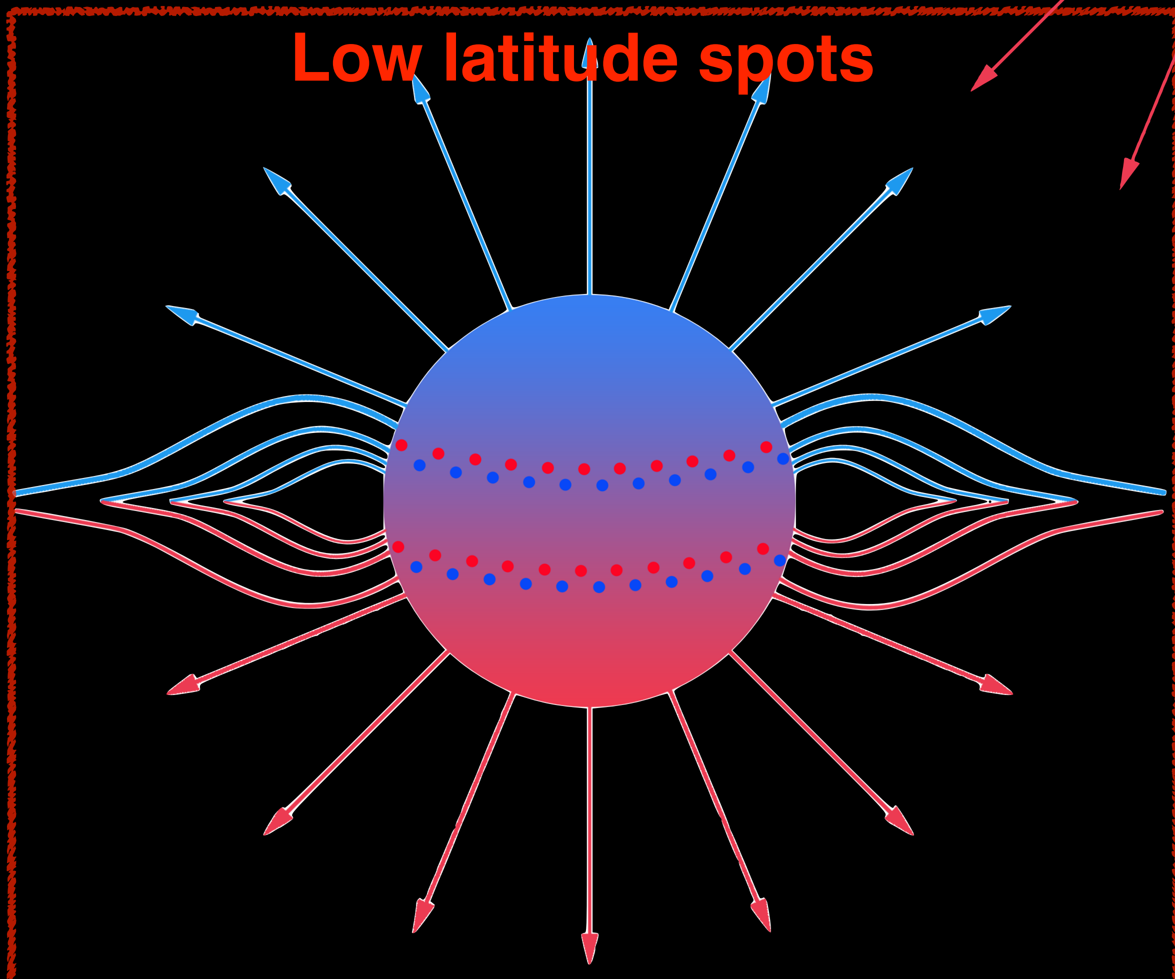
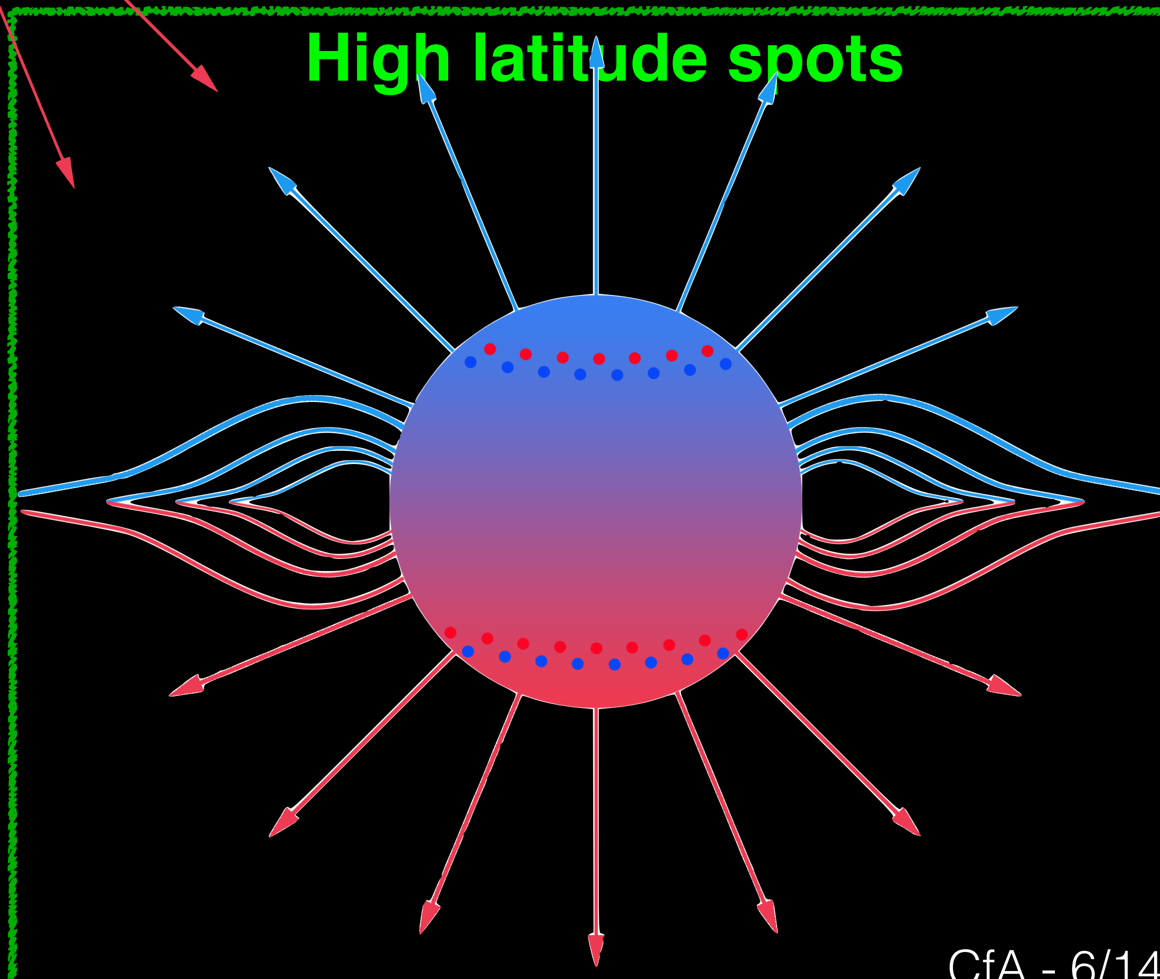


Garraffo et al. ApJ 2015

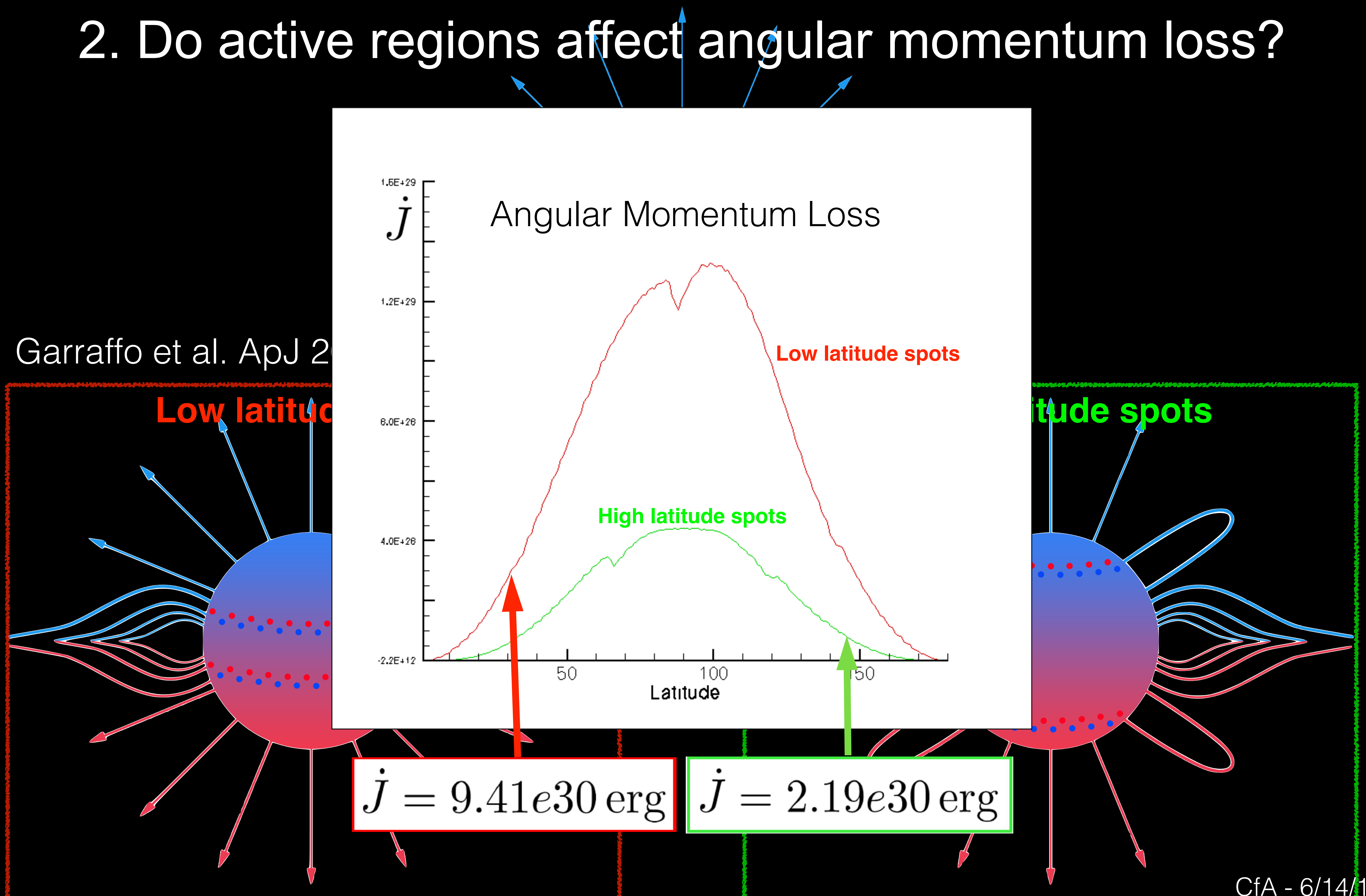




Stellar Rotation

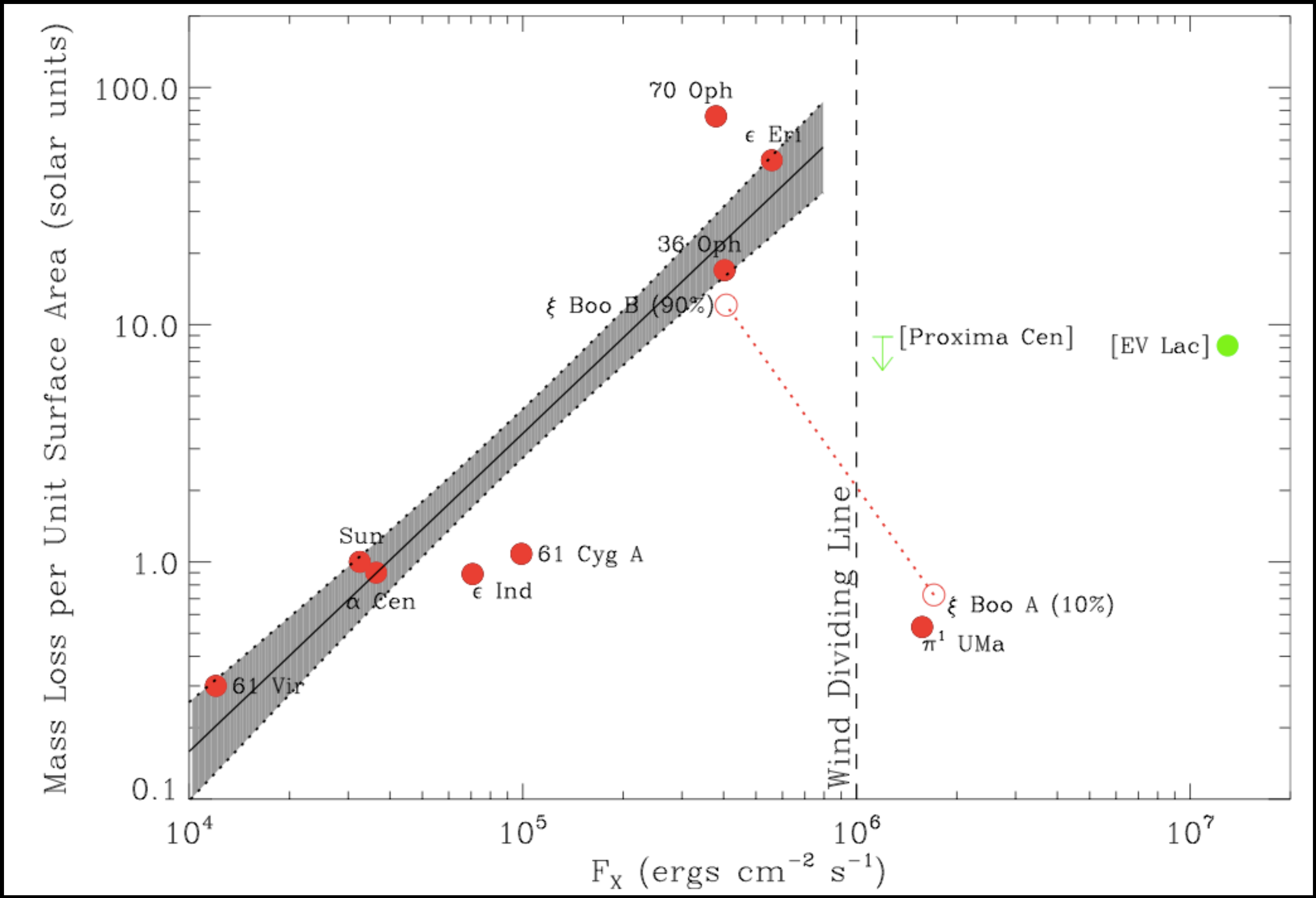
2. Do active regions affect angular momentum loss?

Garraffo et al. ApJ 2



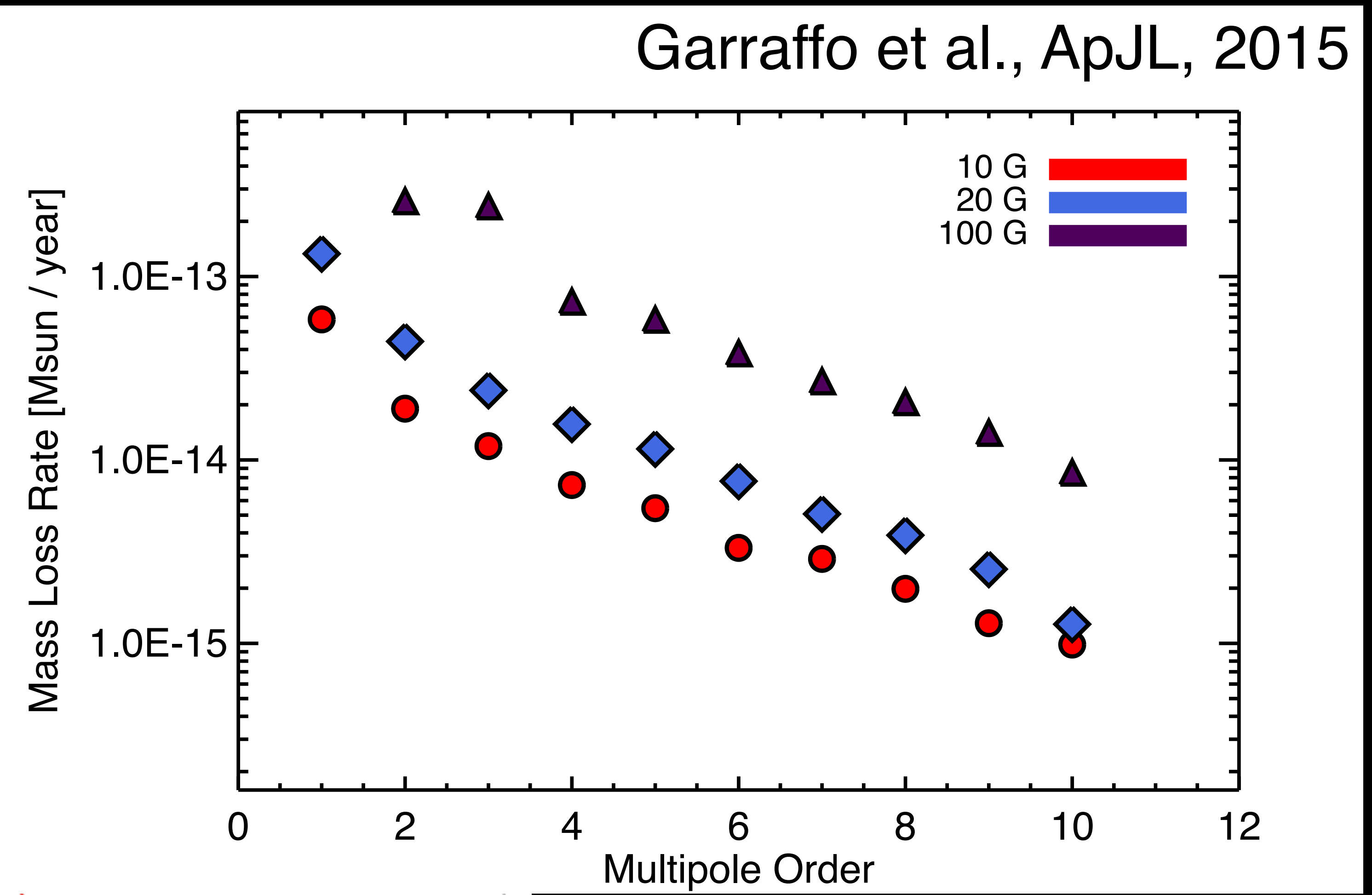
Stellar Rotation

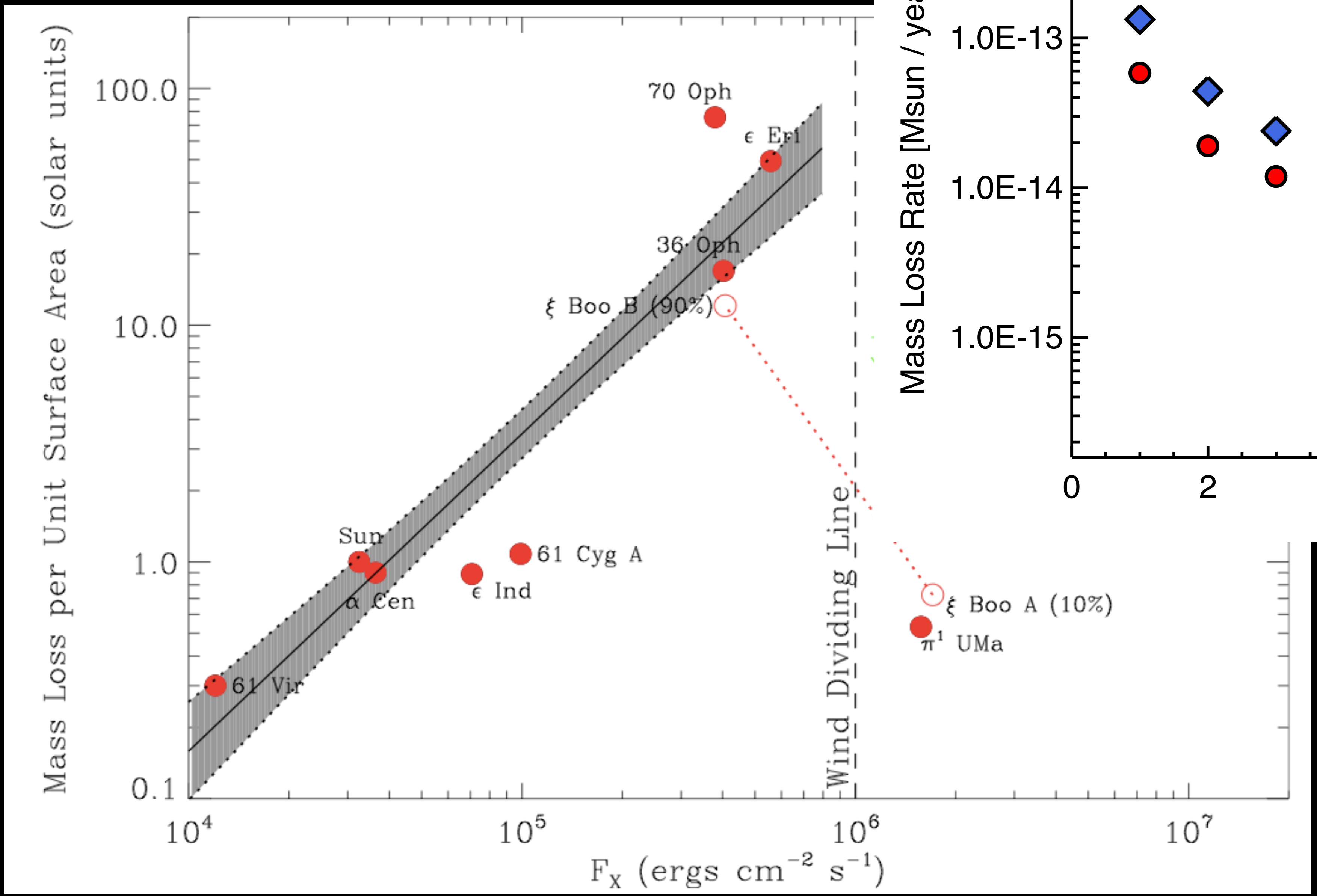
3. How much does morphology matter?



Wood et al., 2014

Stellar Rotation
3. How much does morphology matter?





Wood et al., 2014