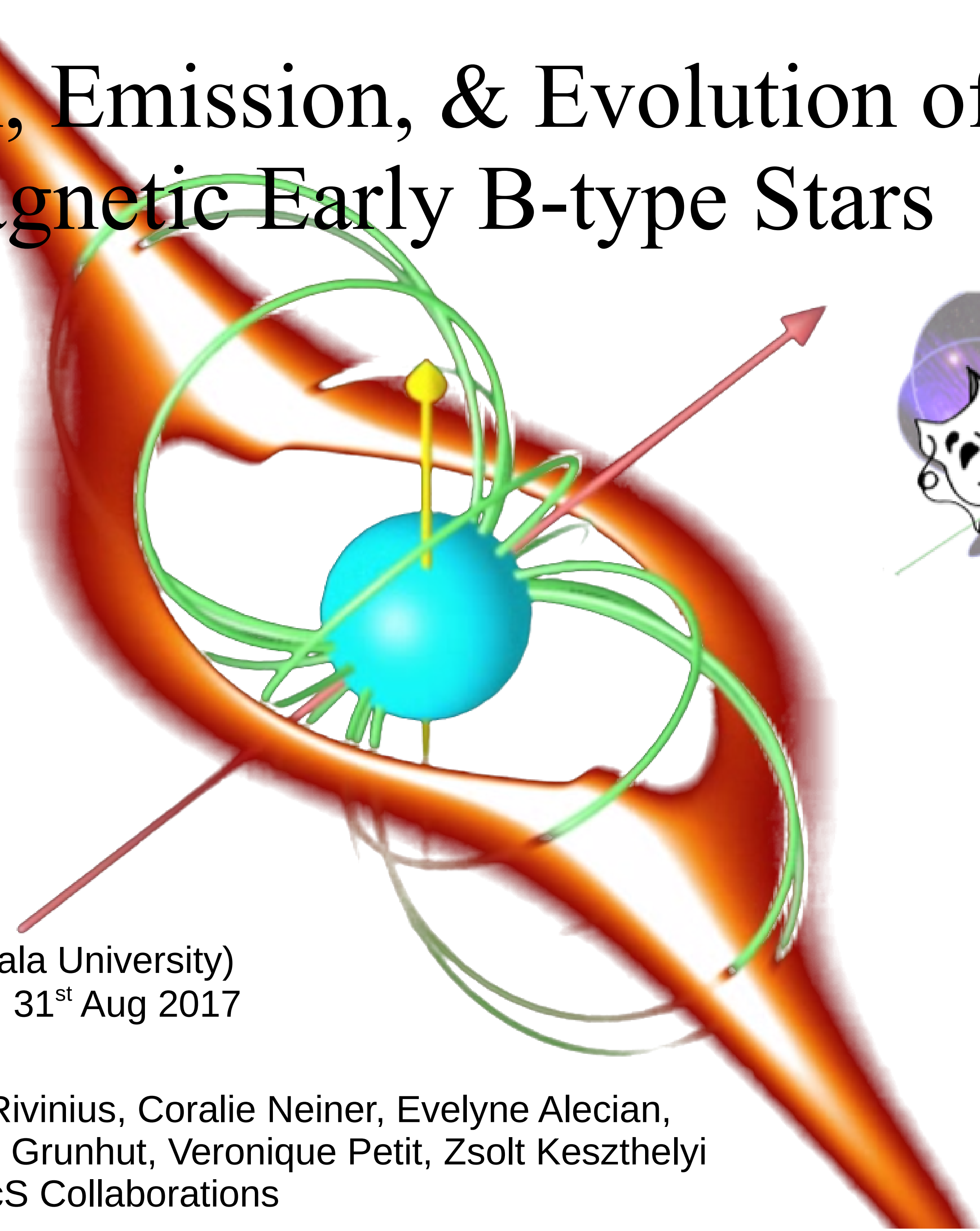
# Rotation, Emission, & Evolution of the Magnetic Early B-type Stars



Matthew Shultz (Uppsala University)
Brno, Czech Republic, 31st Aug 2017

In Collaboration With:
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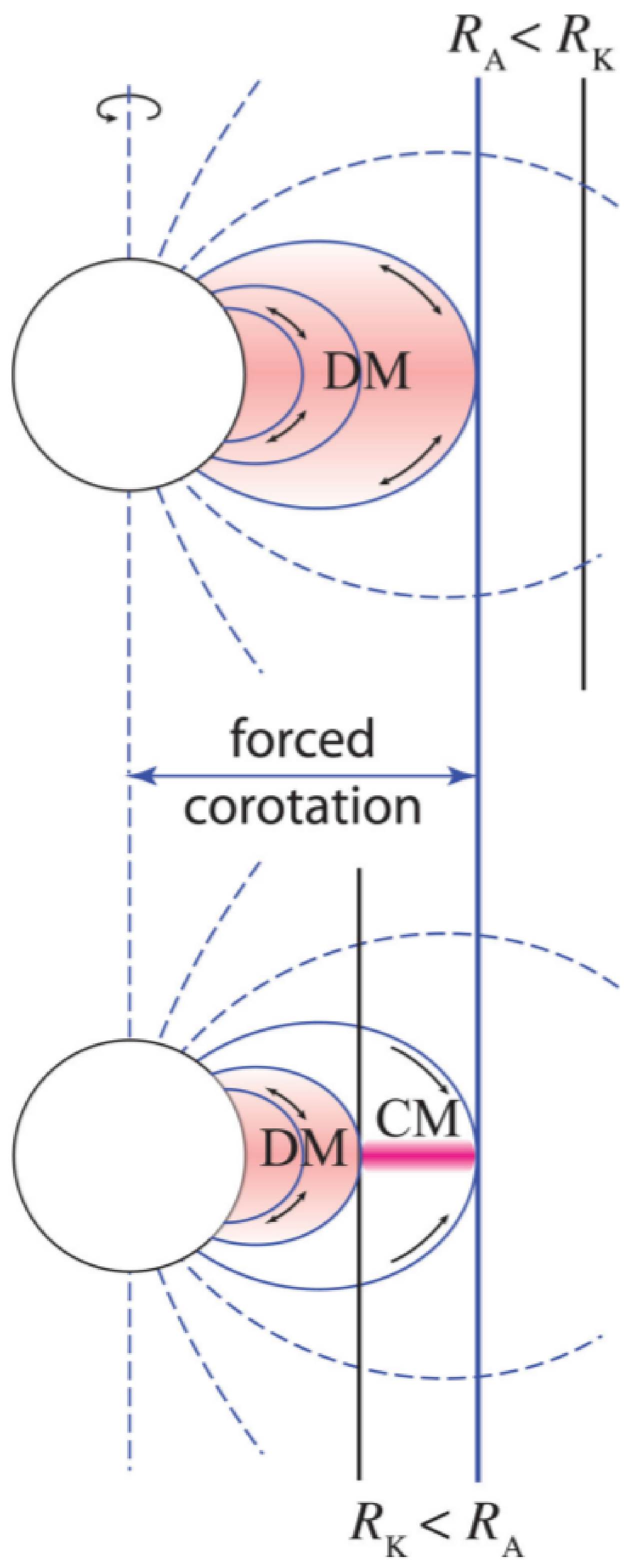
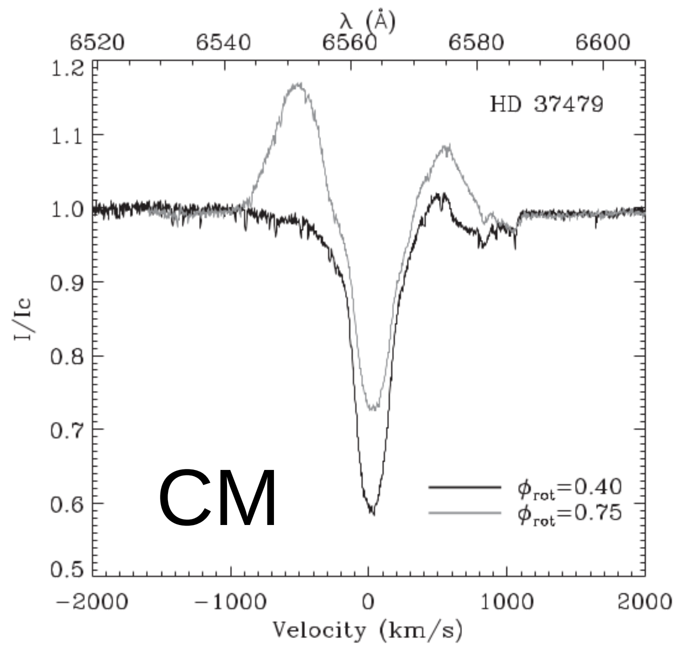
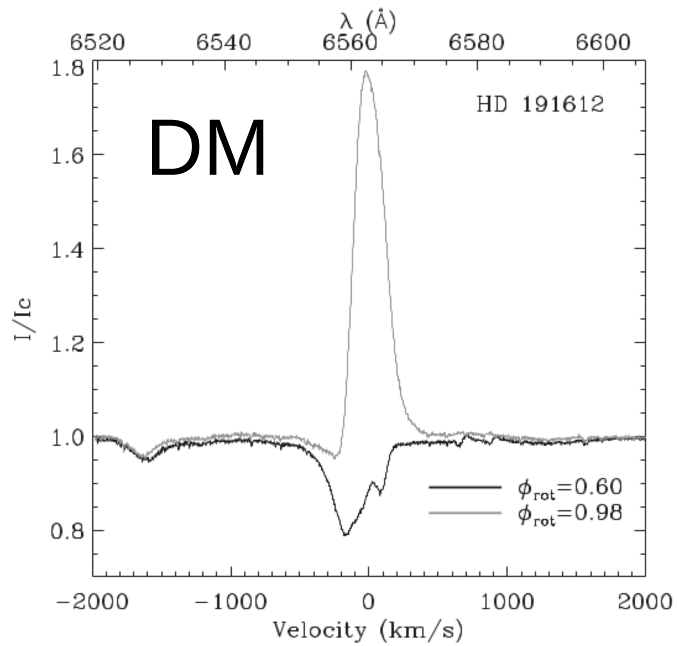
# Magnetic wind confinement leads to different kinds of emission signatures, depending on rotation.



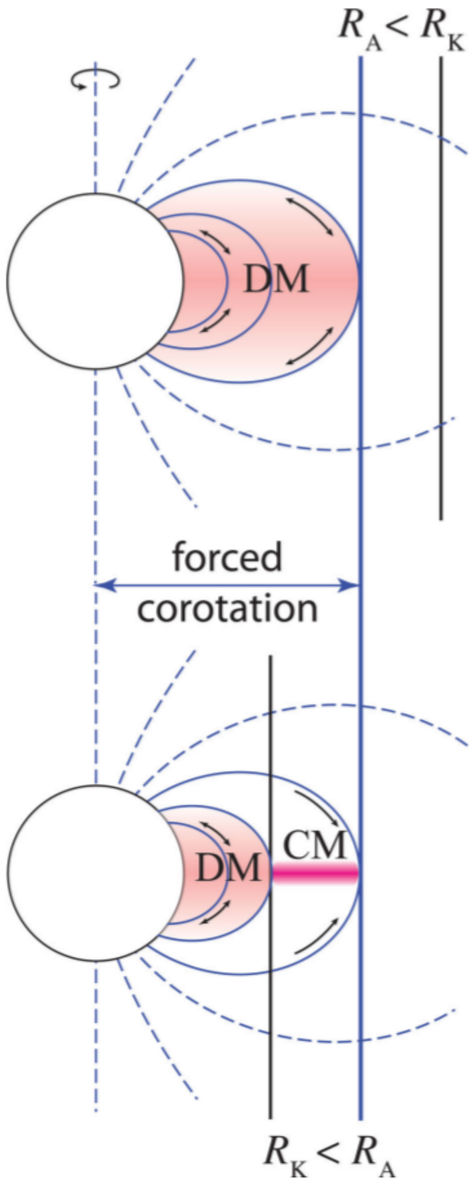



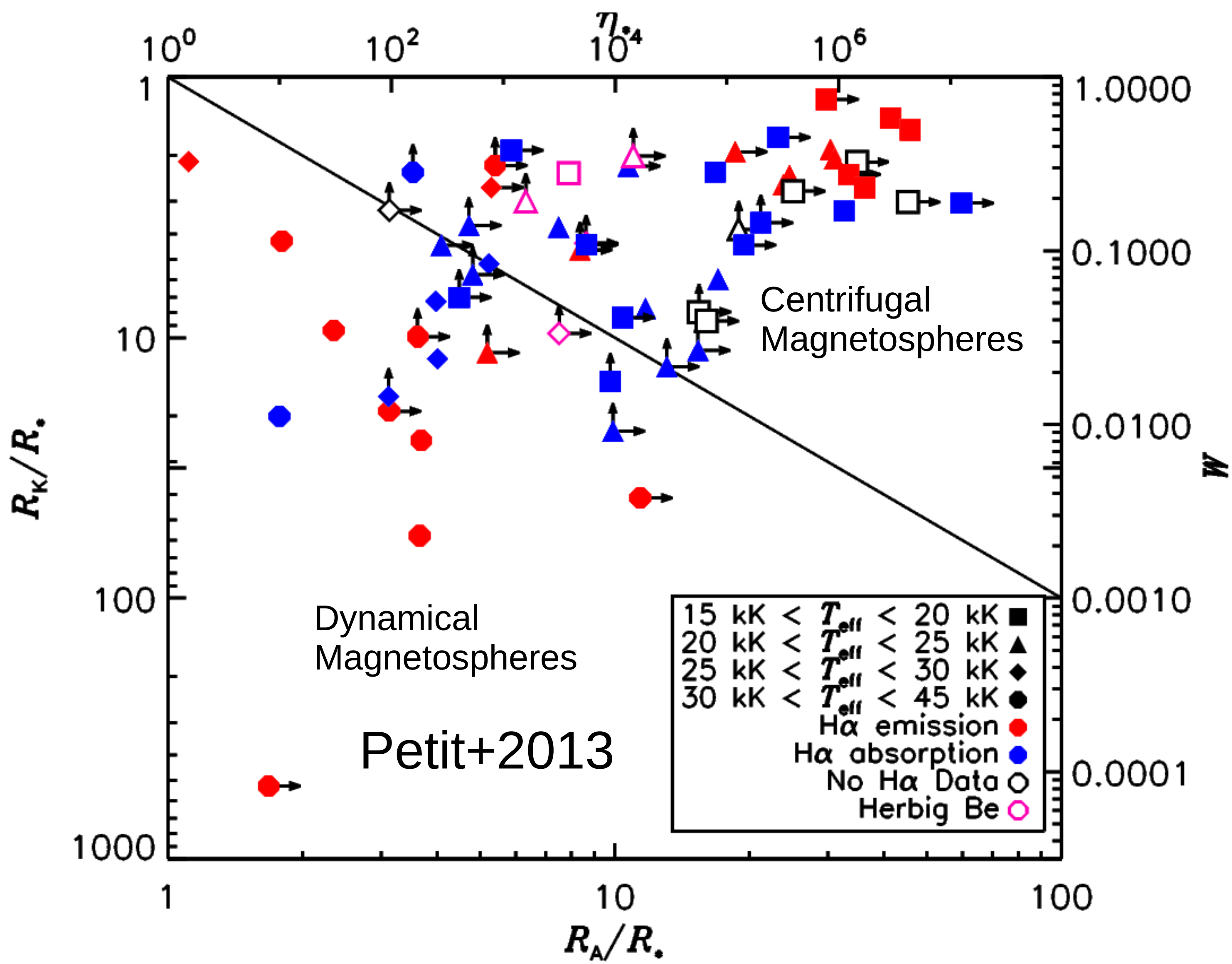




ud-Doula+2002
Townsend+2005

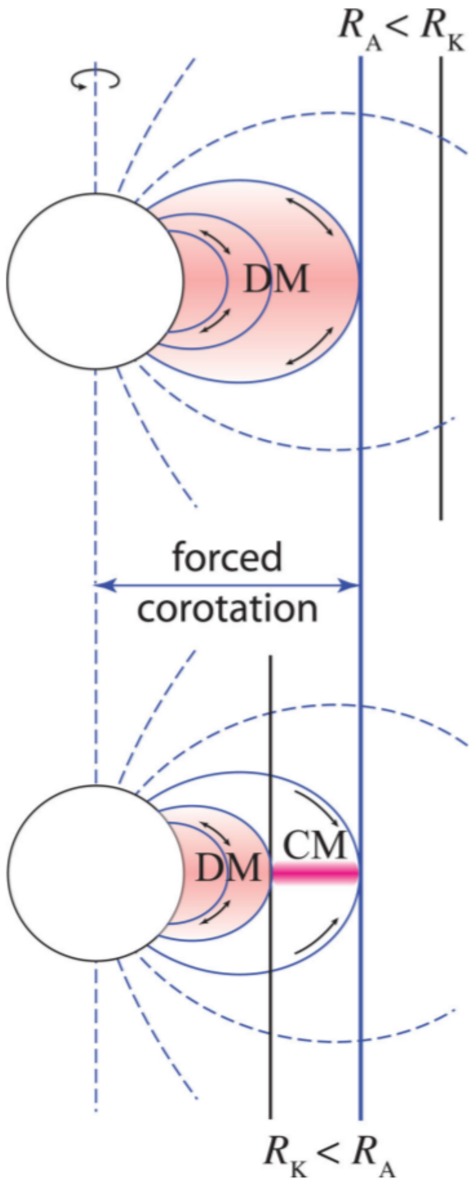
Petit+2013

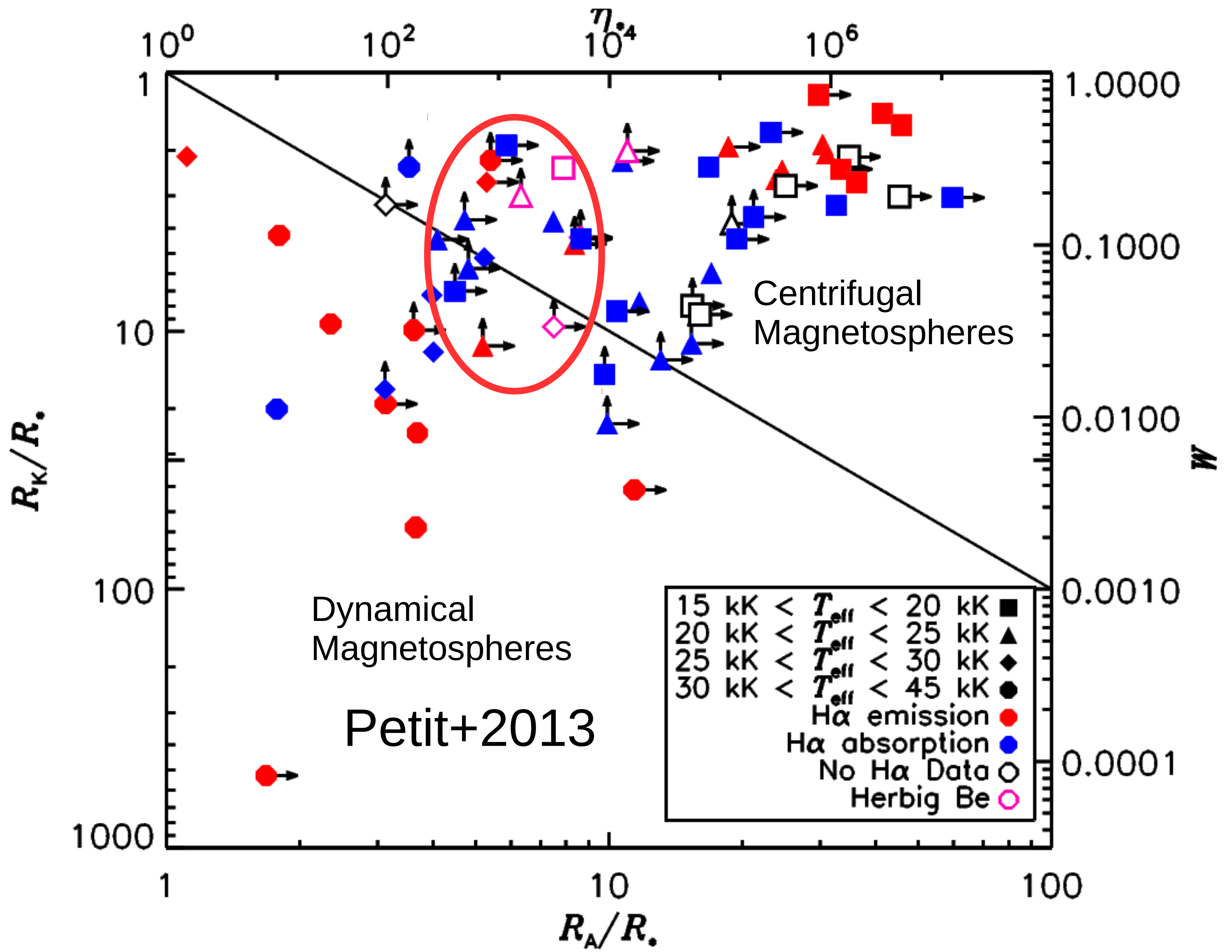
# The Rotation-Magnetic Confinement Diagram (RMCD) organizes stars with/out emission.



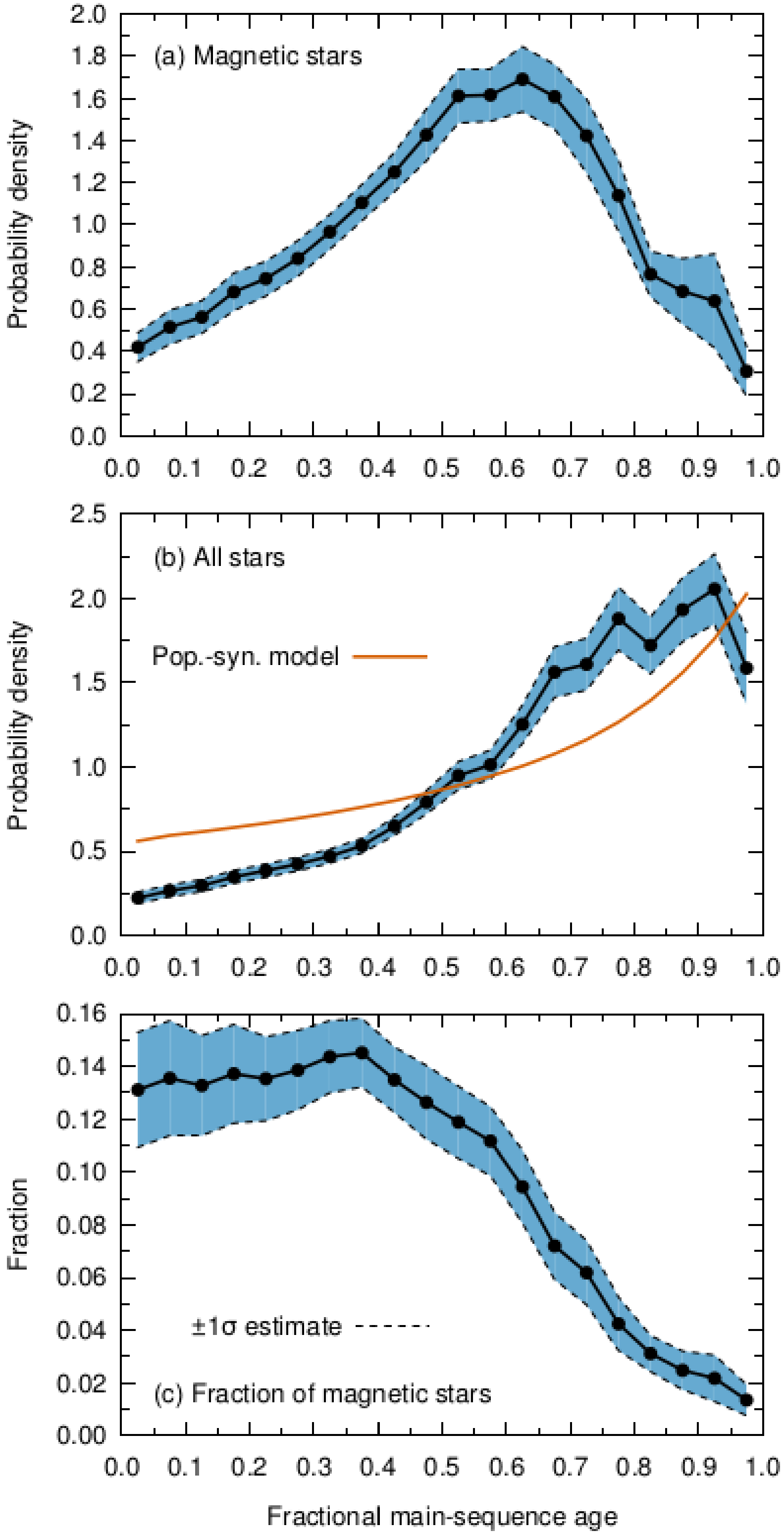



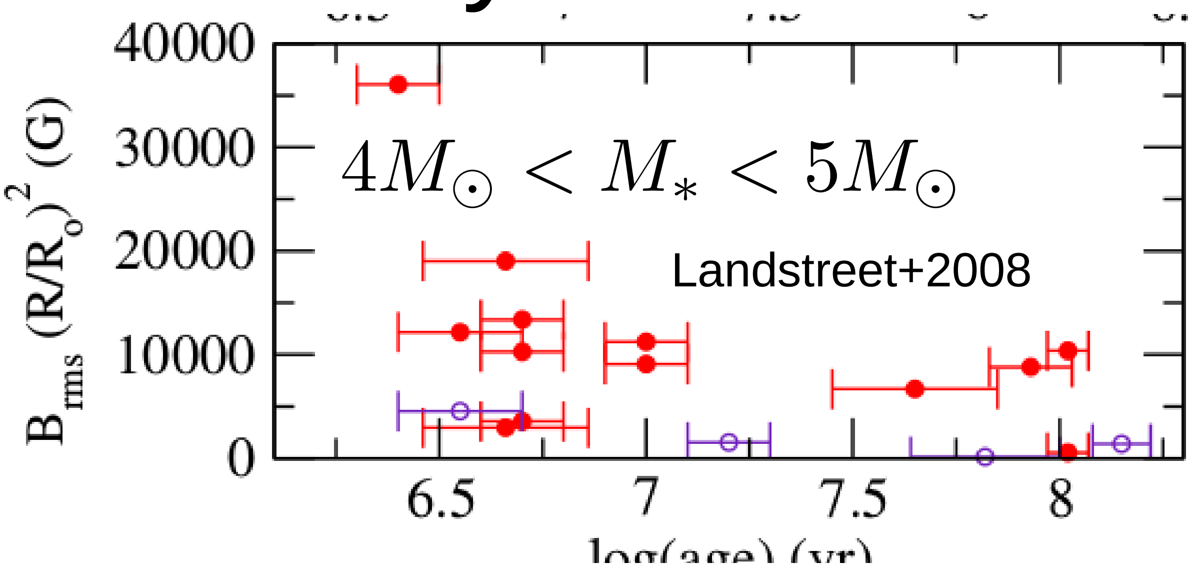
# The Rotation-Magnetic Confinement Diagram (RMCD) *roughly* organizes stars with/out emission.

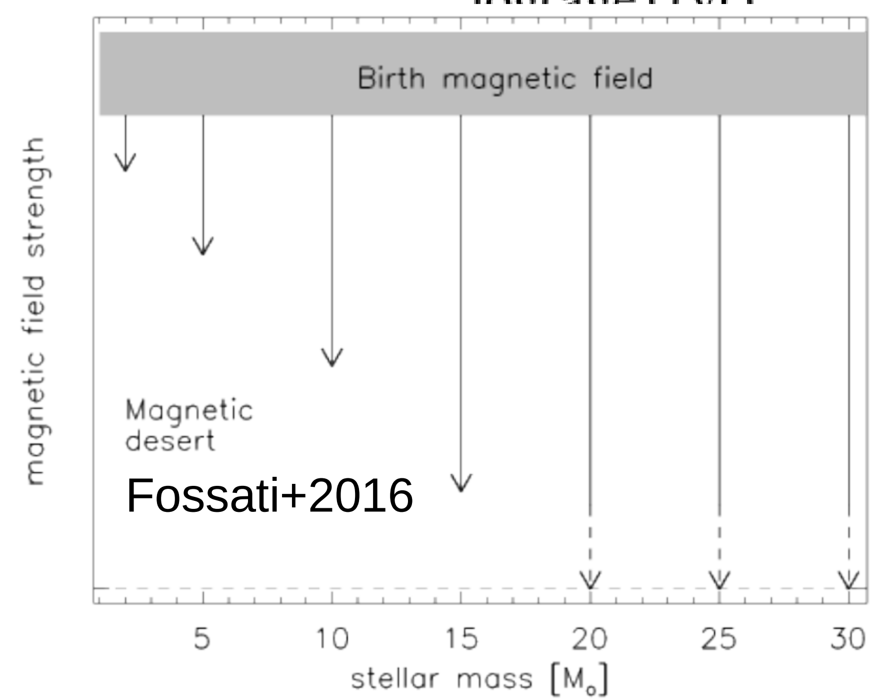


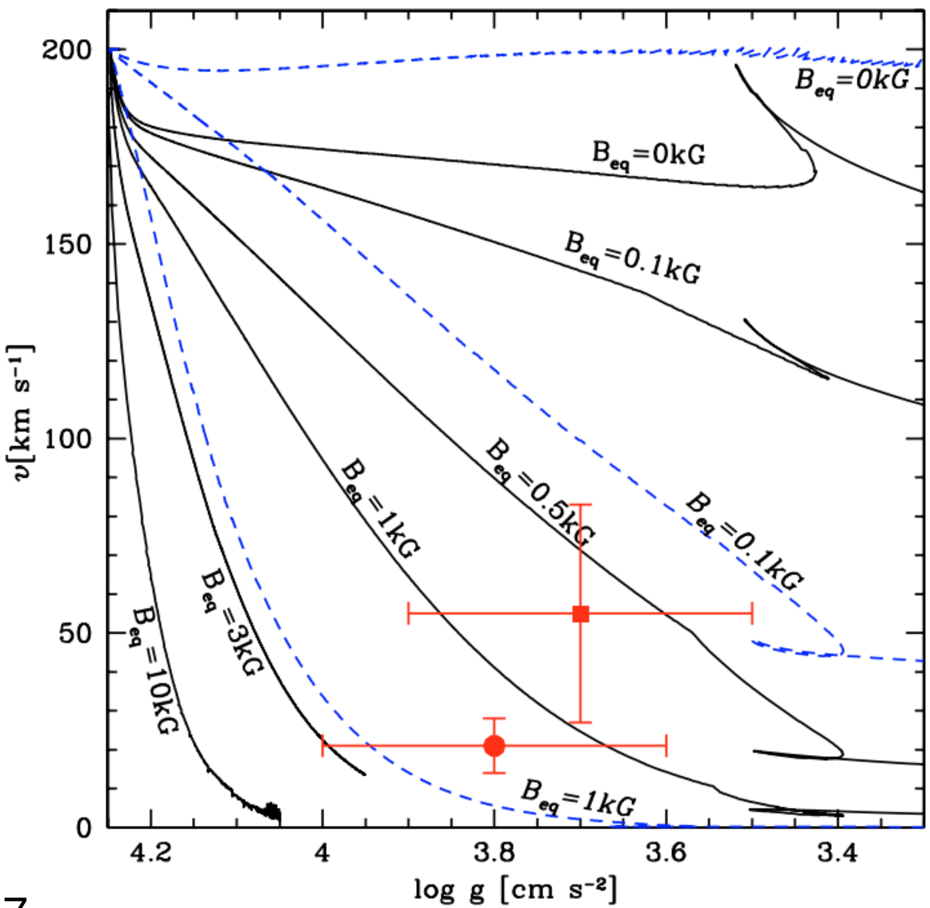
# Does fossil magnetic flux decay?



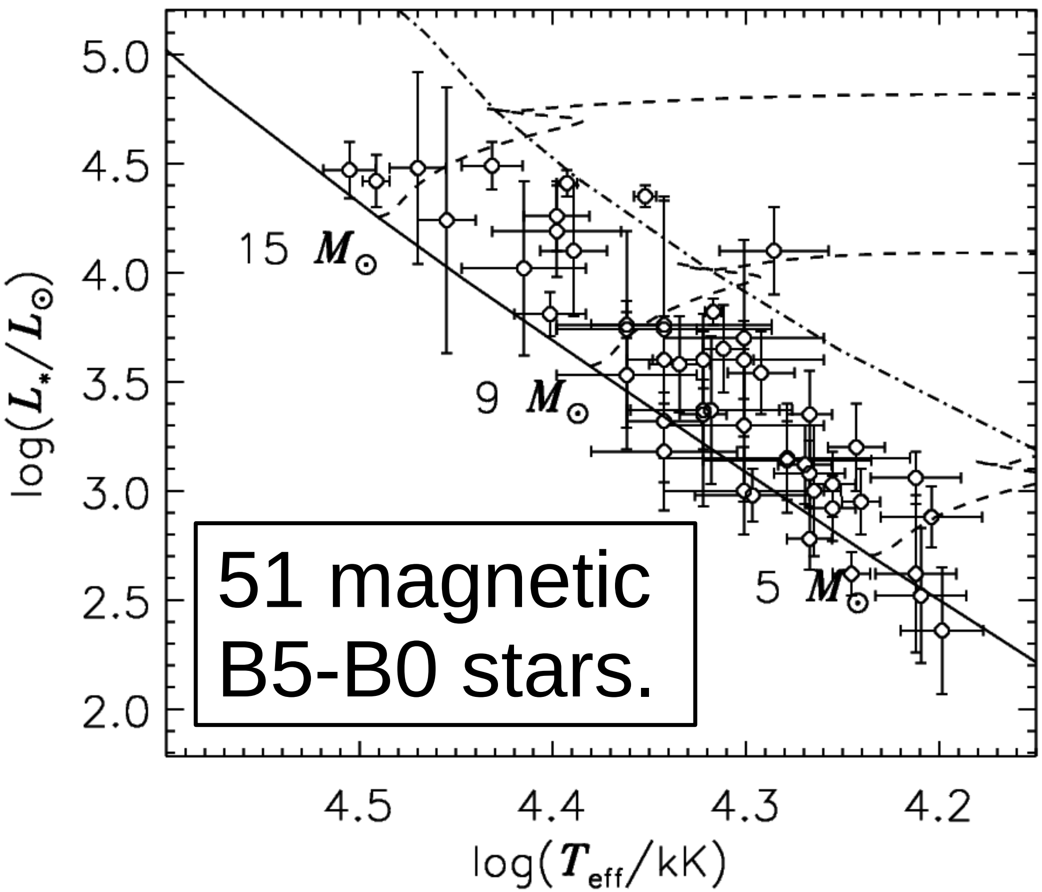
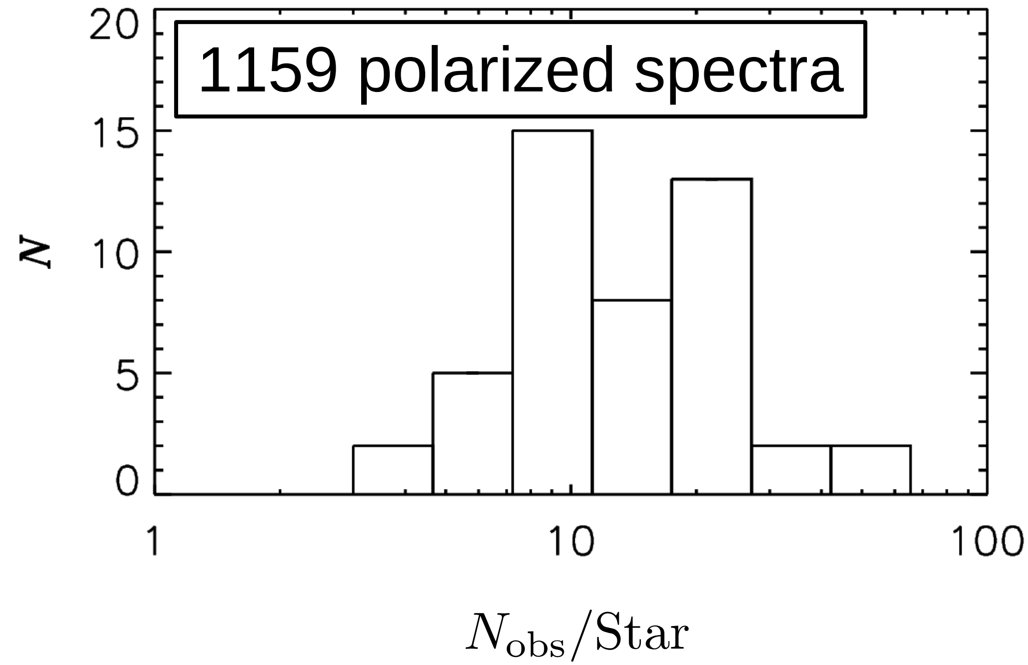
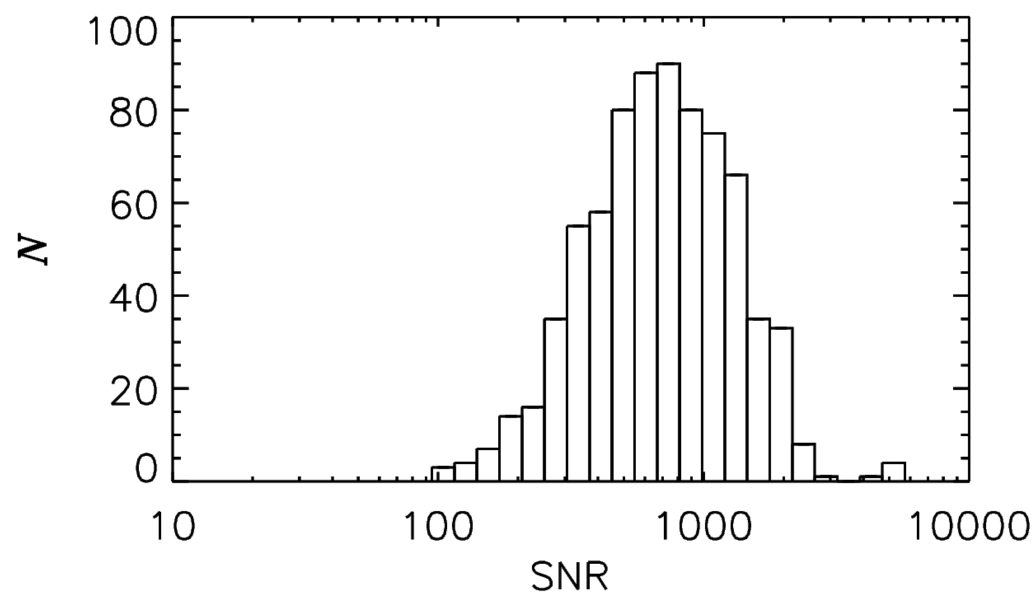



# Magnetic braking causes rapid spindown ... but how rapid?

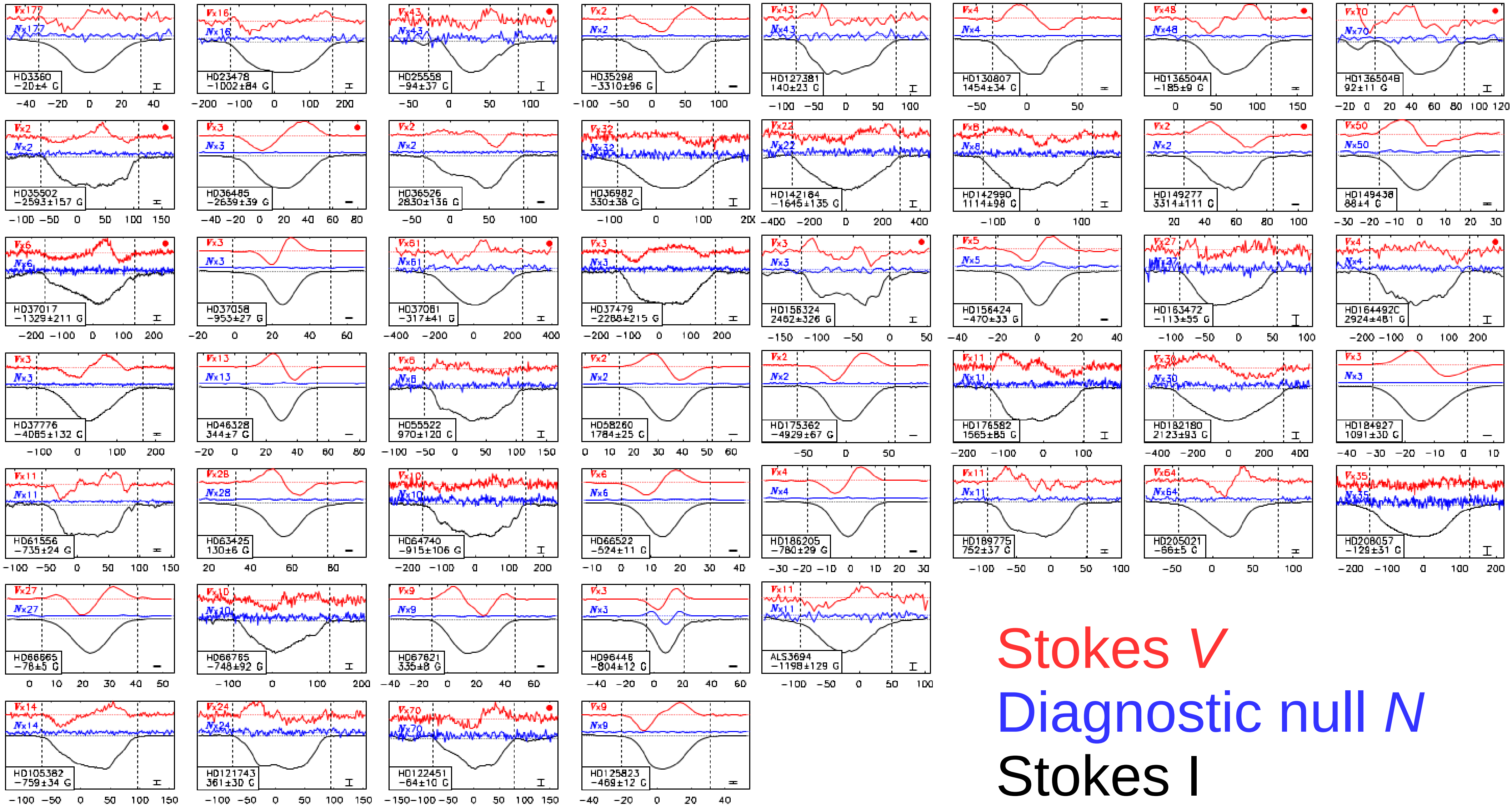



Weber & Davis 1967
ud-Doula+2008

Meynet+2011


51 magnetic B5-B0 stars.
15 $M_\odot$
9 $M_\odot$
5 $M_\odot$
$\log(L_*/L_\odot)$
$\log(T_{\rm eff}/{\rm kK})$
5.0
4.5
4.0
3.5
3.0
2.5
2.0
4.5
4.4
4.3
4.2

1159 polarized spectra
$N$
$N_{\rm obs}/{\rm Star}$
20
15
10
5
0
1
10
100

$N$
SNR
100
80
60
40
20
0
10
100
1000
10000

# Least Squares Deconvolution (LSD) was used to measure $<B_z>$.

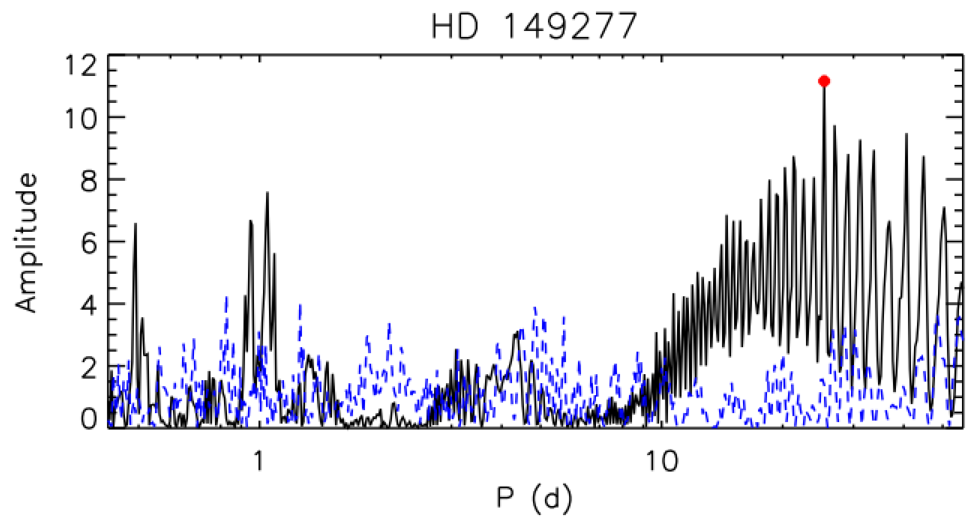


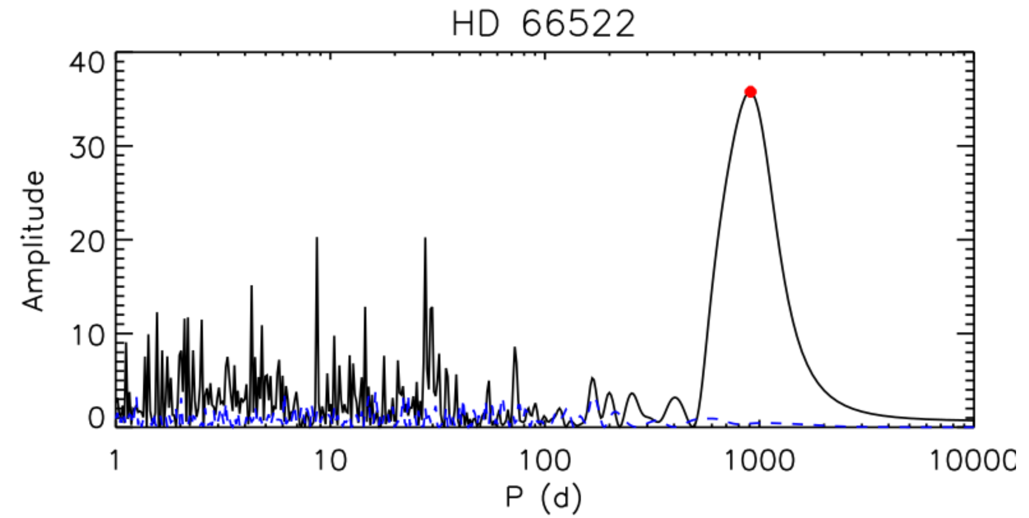

Stokes *V*

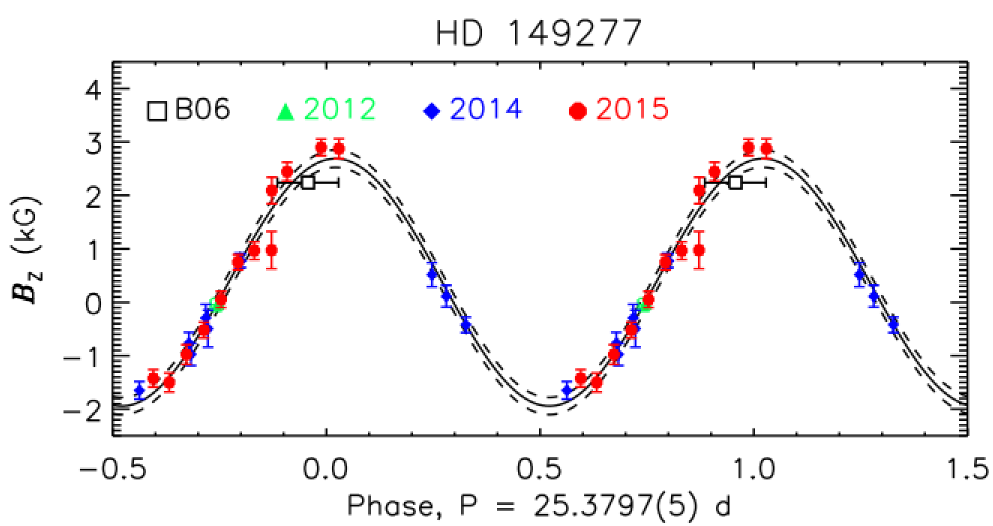
Diagnostic null *N*

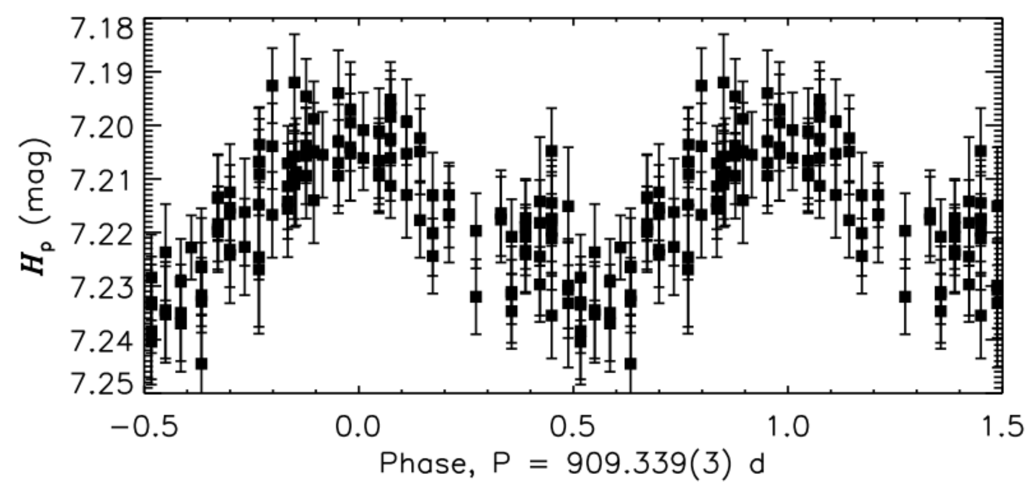
Stokes I

# $P_{rot}$ was determined for 15/18 stars for which it was unknown using <$B_z$>, spectroscopy, & photometry.



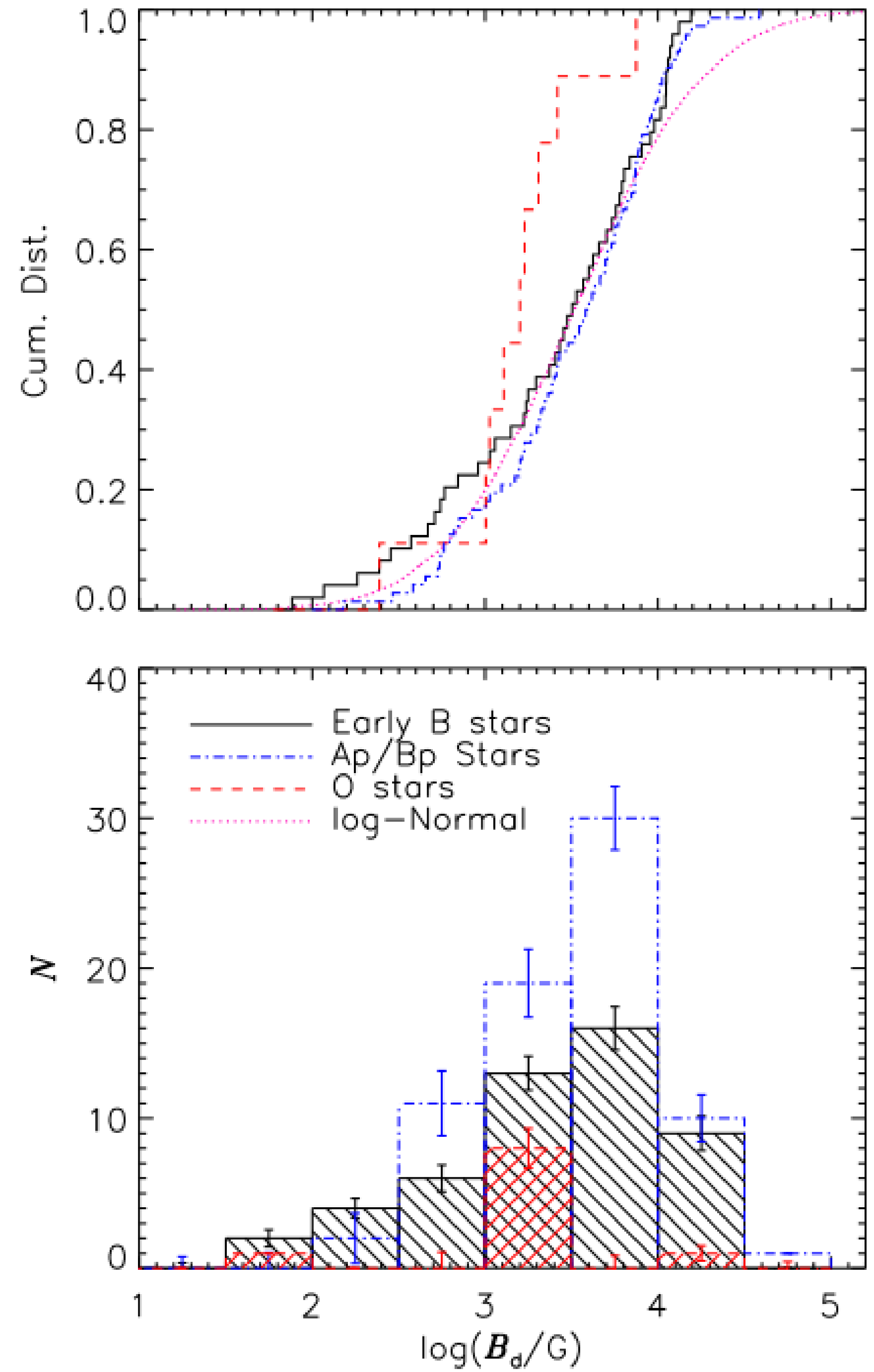



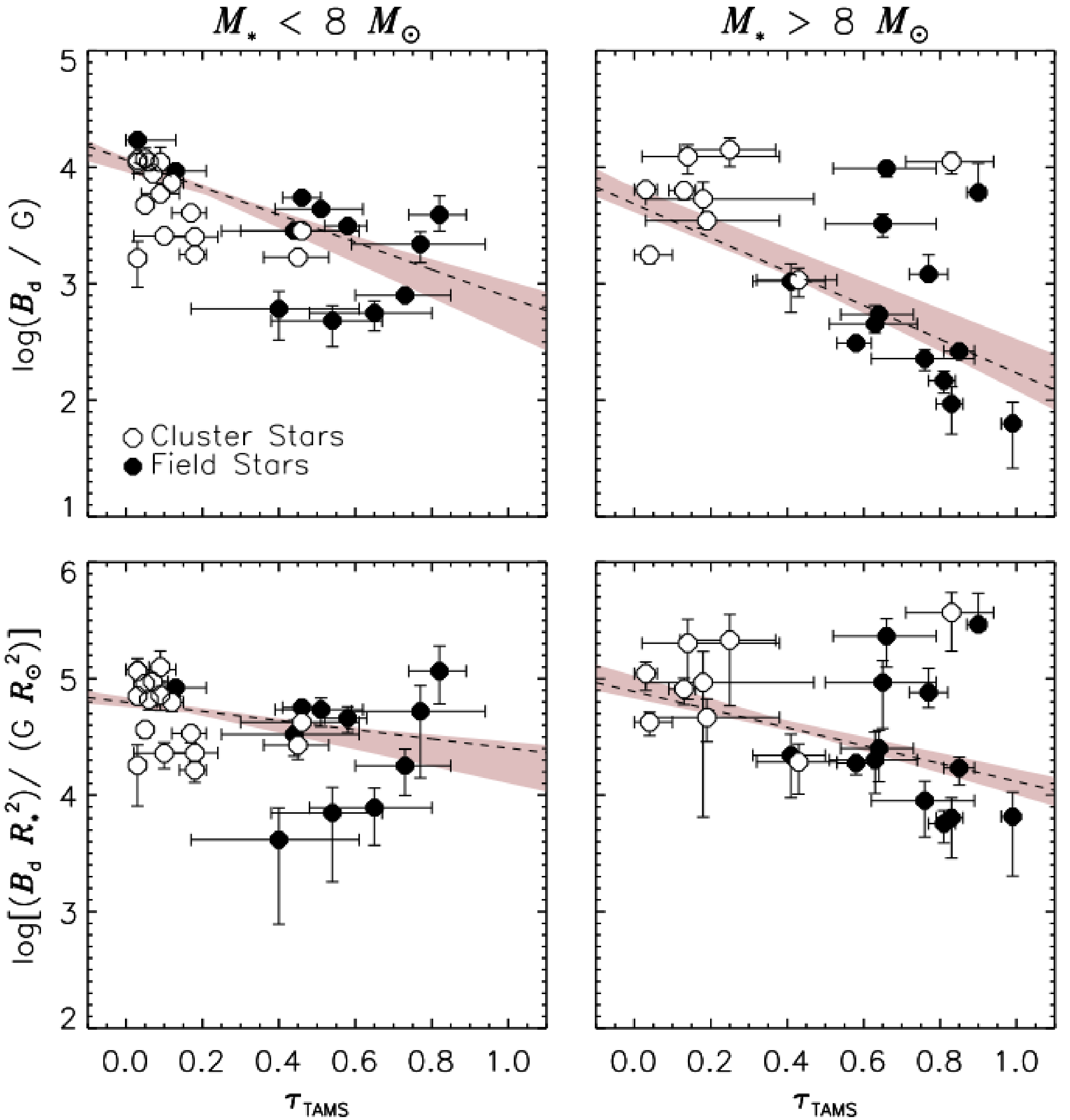
$B_d$ is approximately log-normal, and is similar to Ap stars, but perhaps a bit stronger than O-type stars.

Ap Stars:
Landstreet & Mathys 2000
Hubrig+2007
Auriere+2007
Power 2007

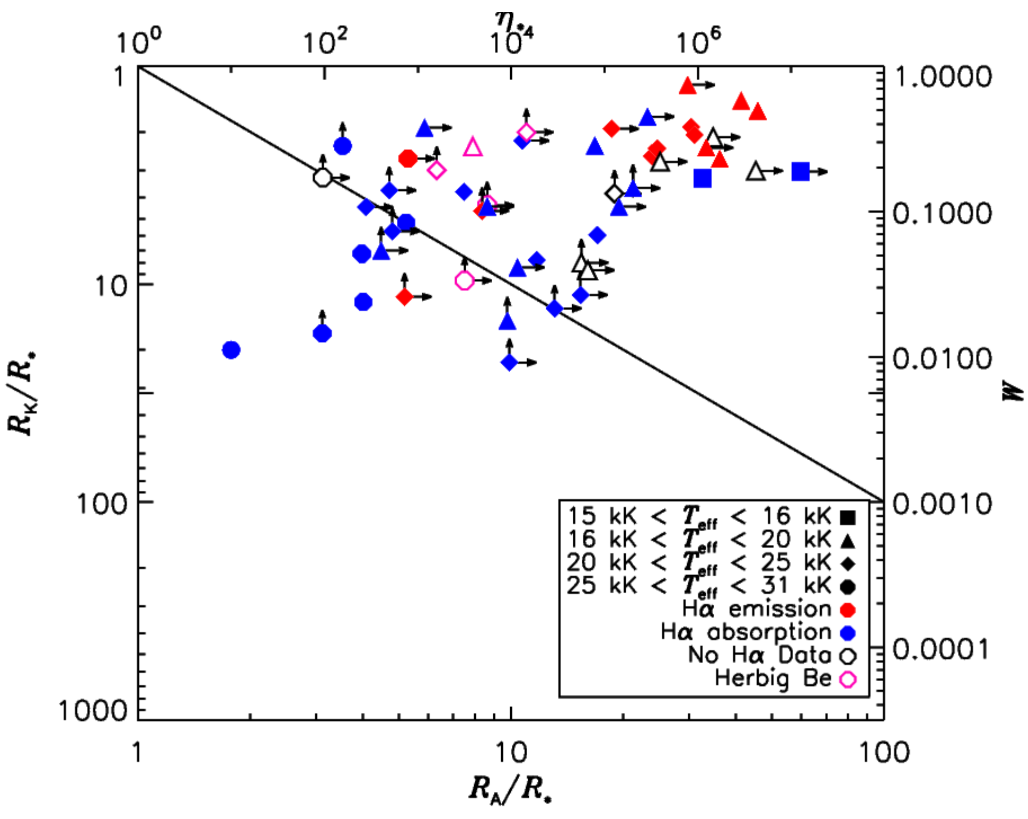
O stars: Petit+2013

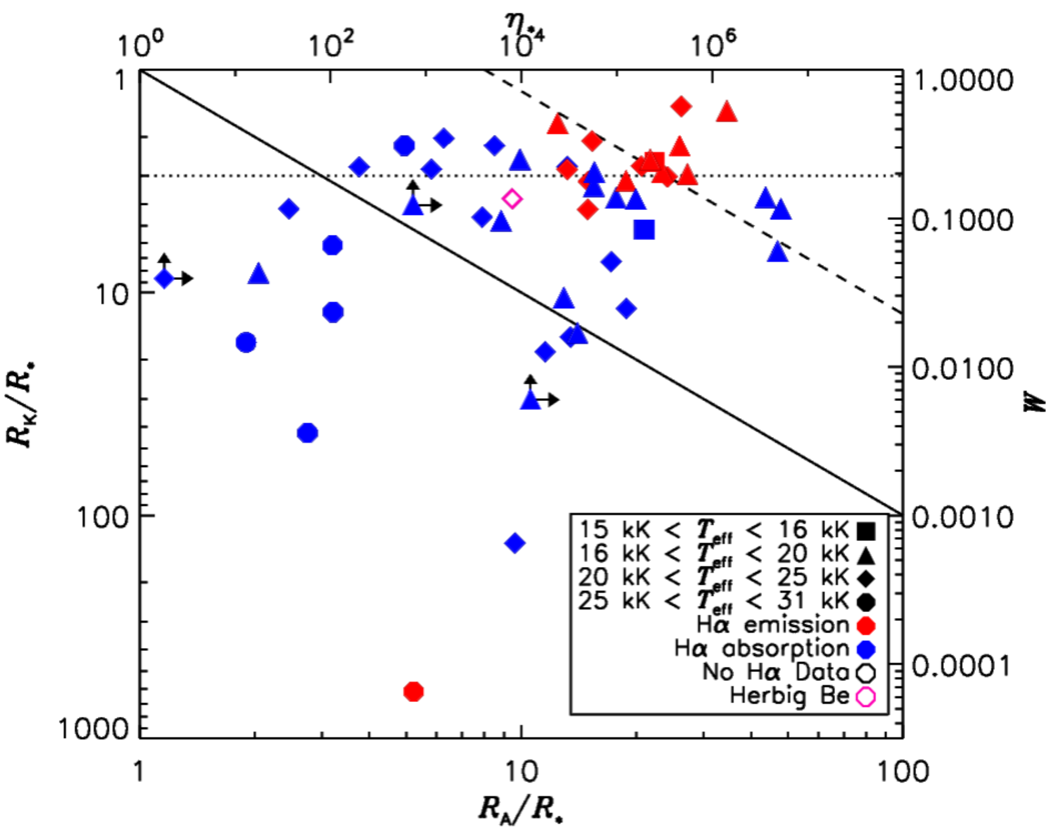


# $B_d$ gets weaker over time ... but does flux decay?



# New magnetospheric parameters result in a much cleaner RMCD.



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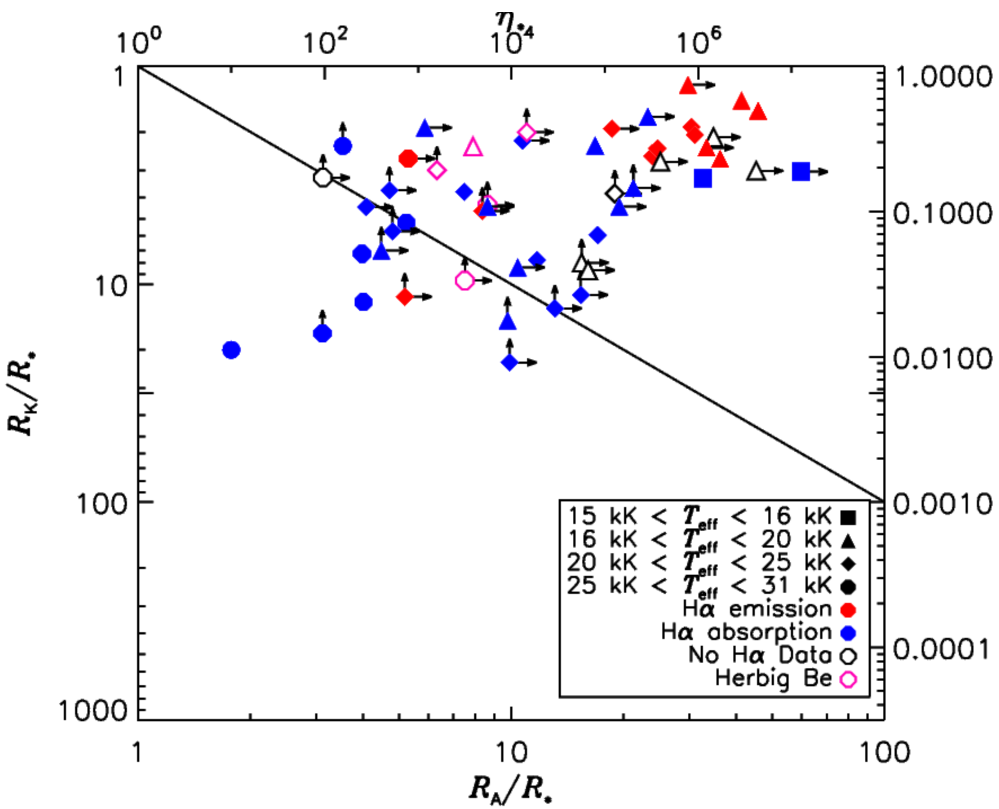
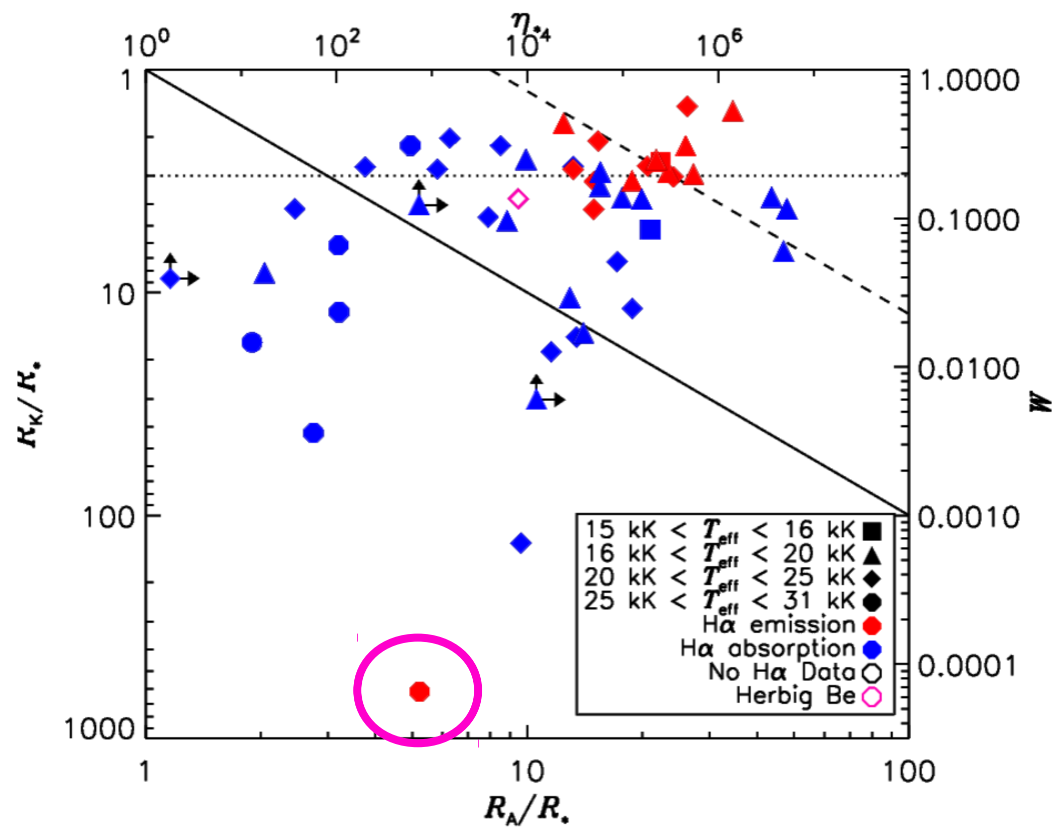
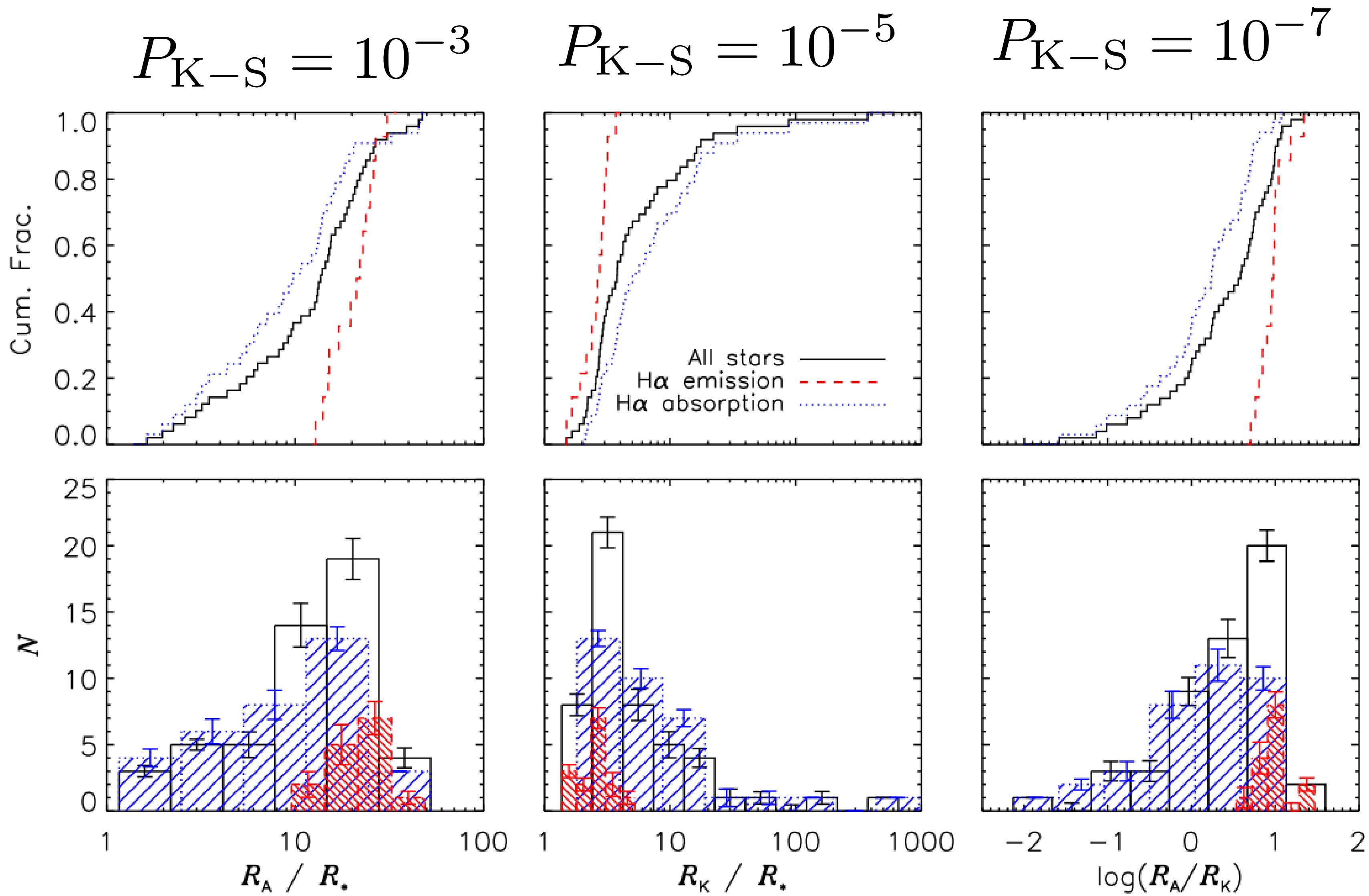


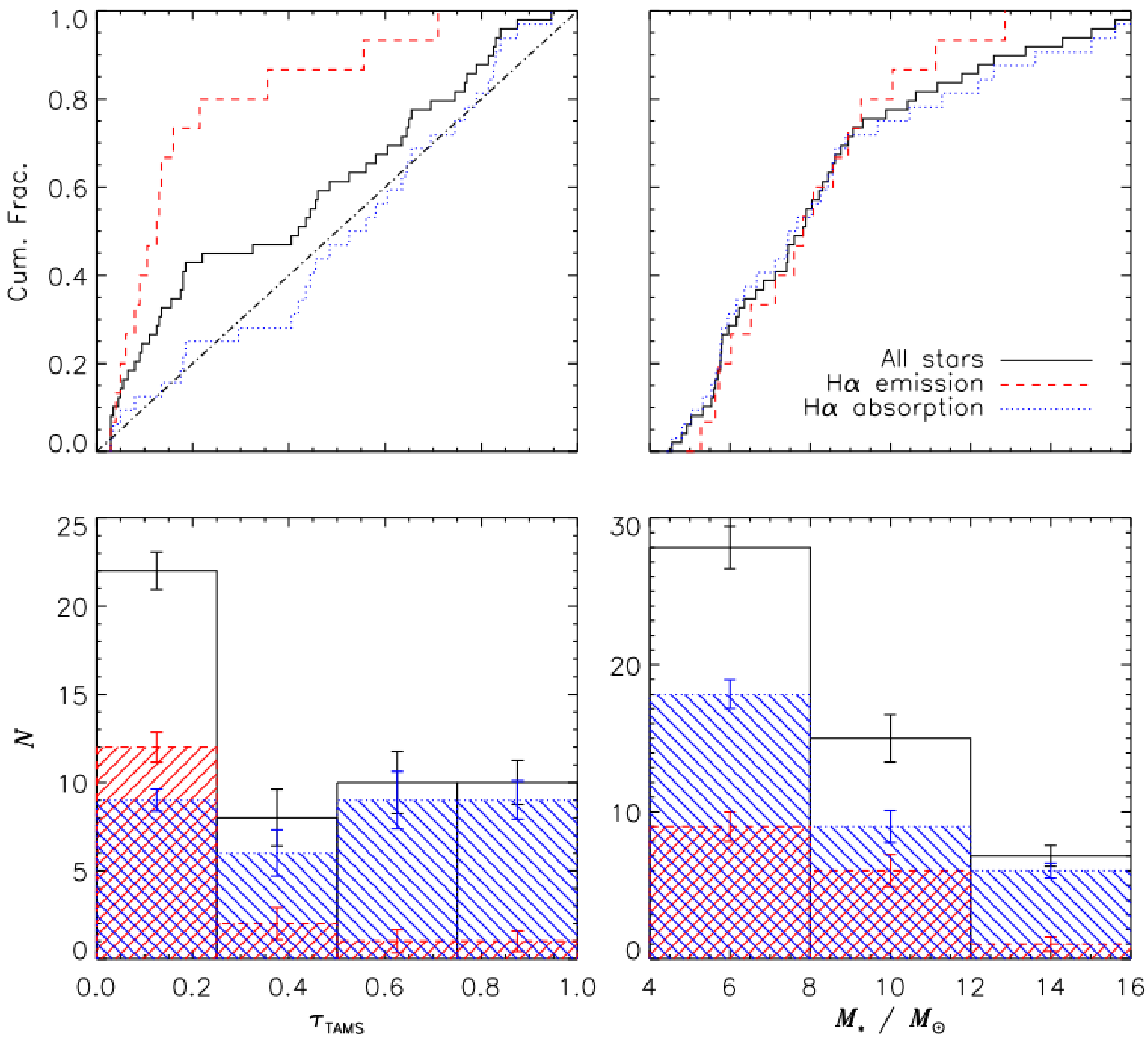




$\xi^1$ CMa: First B-type star with an optically detectable Dynamical magnetosphere (Shultz+2017)

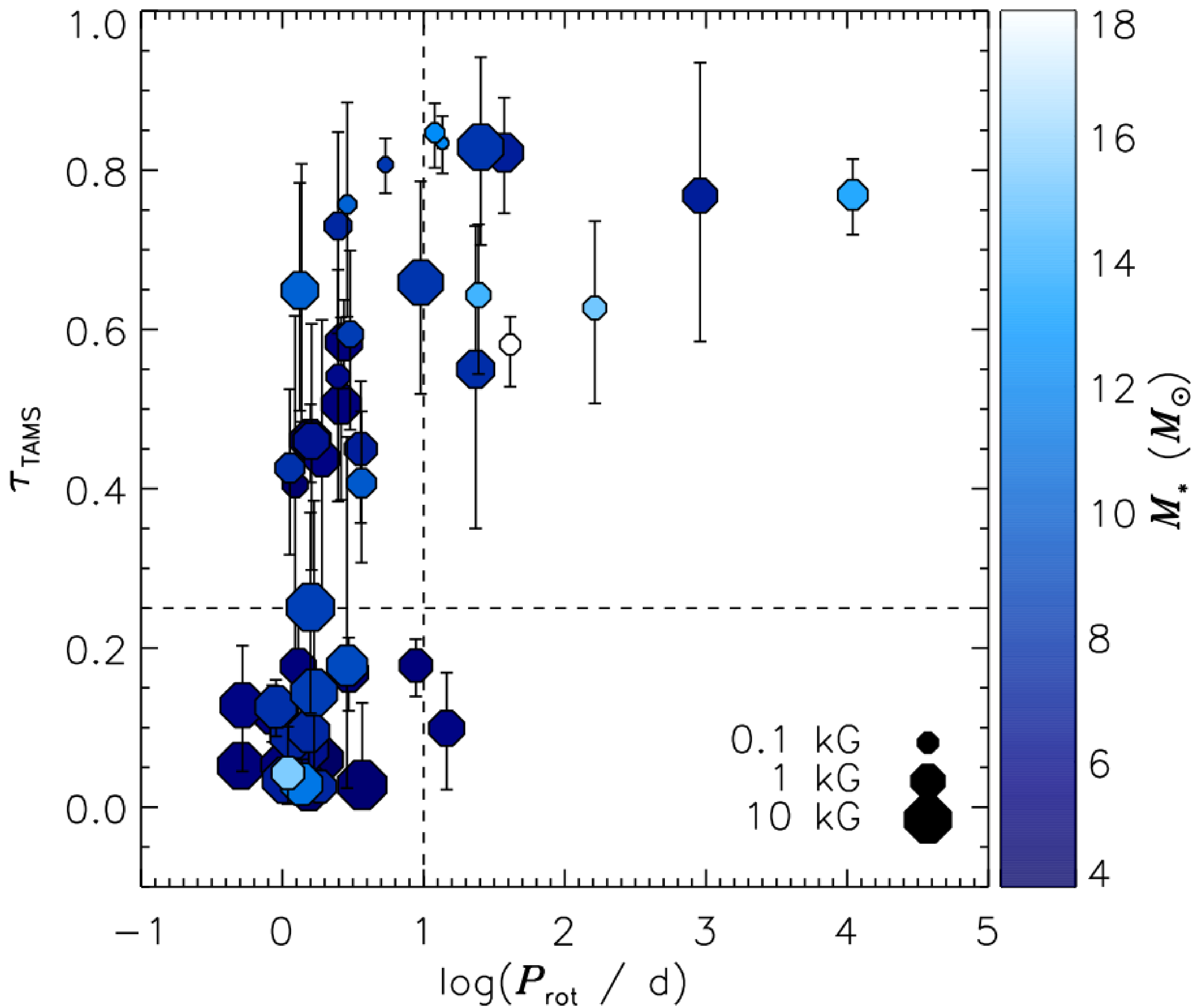
# The presence of Hα emission is highly predictive of rotational and magnetic properties.



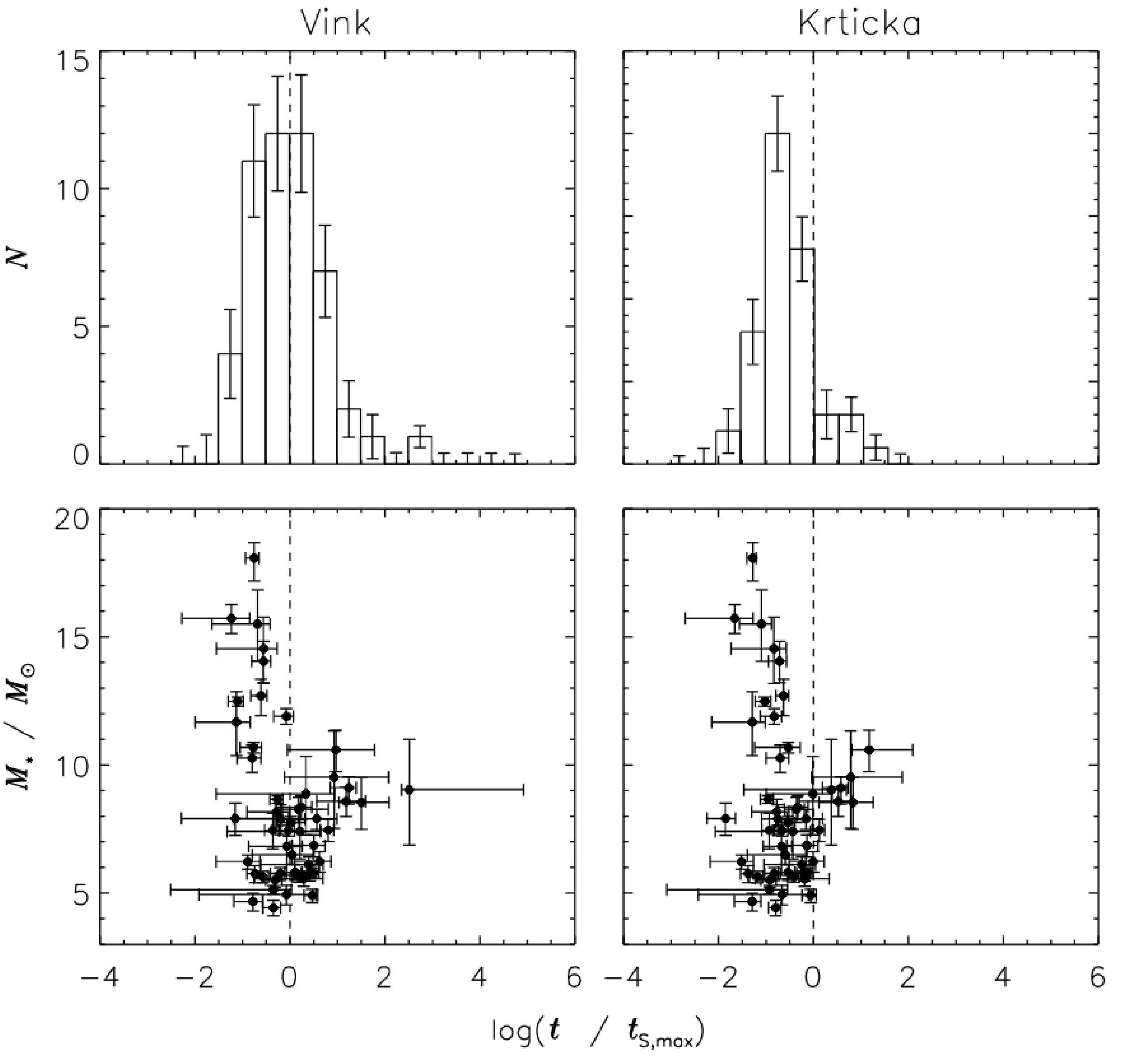
# Emission-line stars are also younger than absorption-line stars.



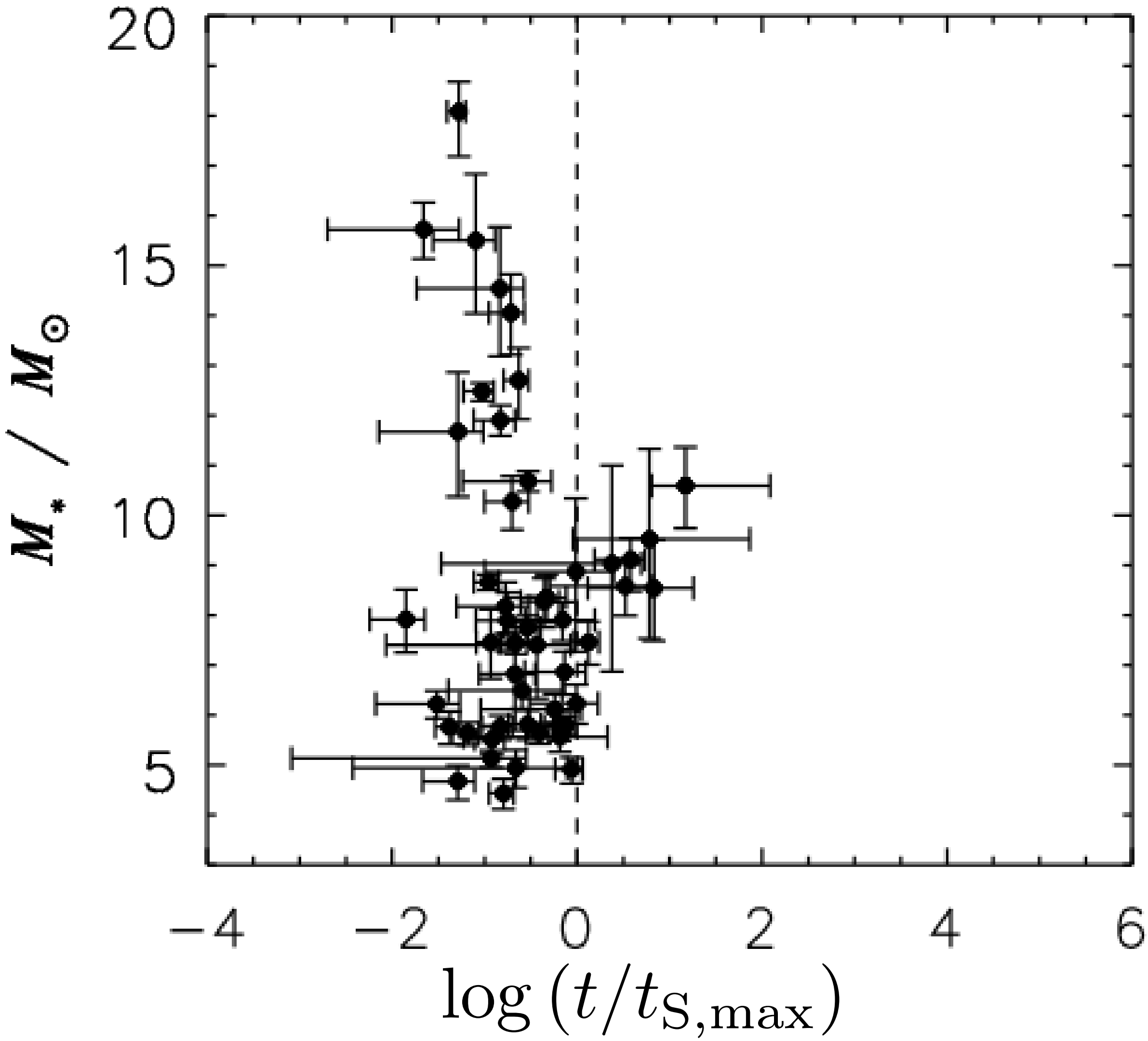
# $P_{rot}$ increases with age.



# Vink mass-loss yields a large spread in $t/t_{S,max}$, but Krticka mass-loss gives $t_{S,max} < t$.



# Why is $t_{S,max} << t$ for so many stars (especially for the most massive stars)?

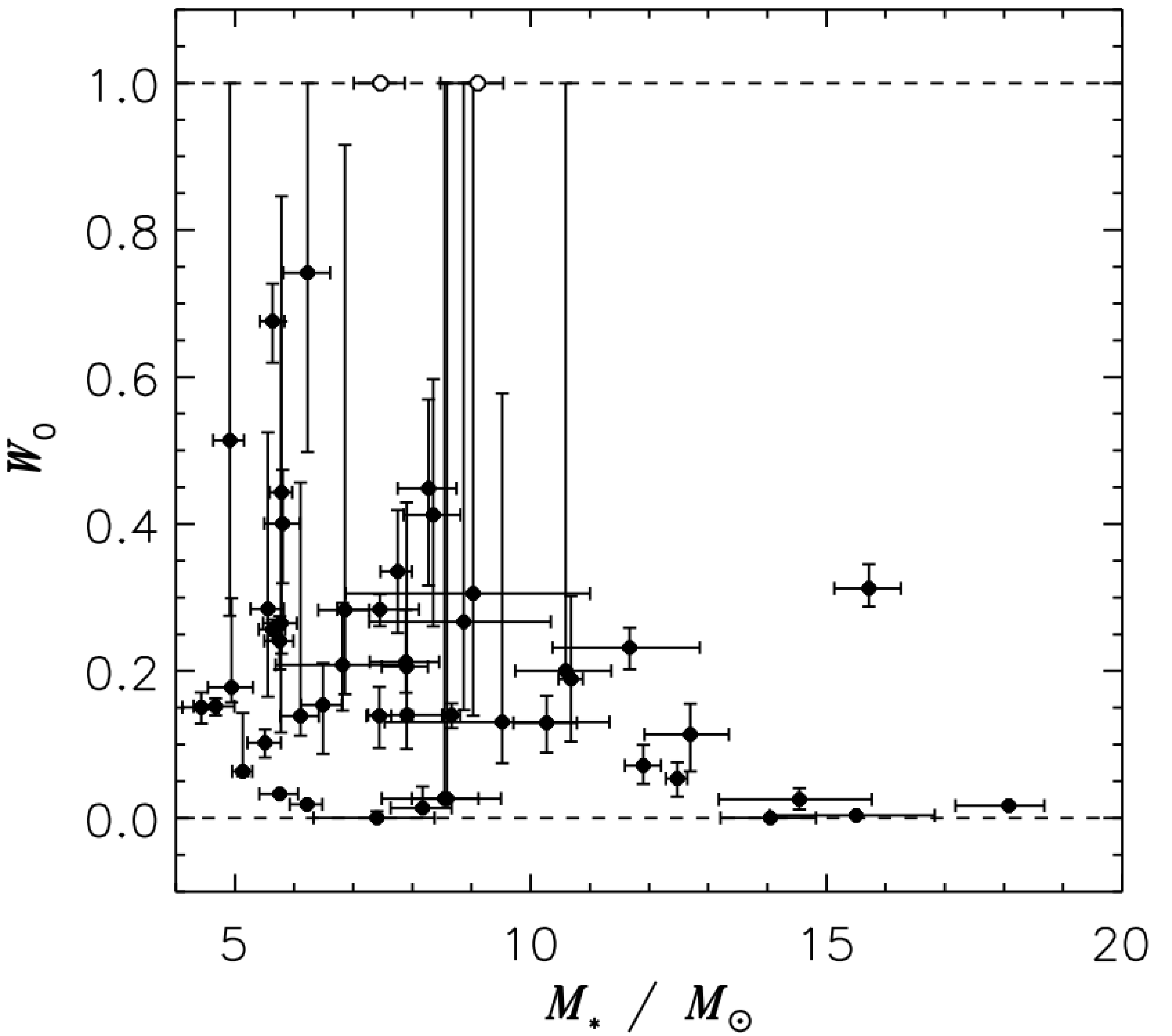



$$\tau_J = \frac{3}{2} r_{gyr}^2 \frac{M_*}{\dot{M}} \left(\frac{1}{R_A}\right)^2$$

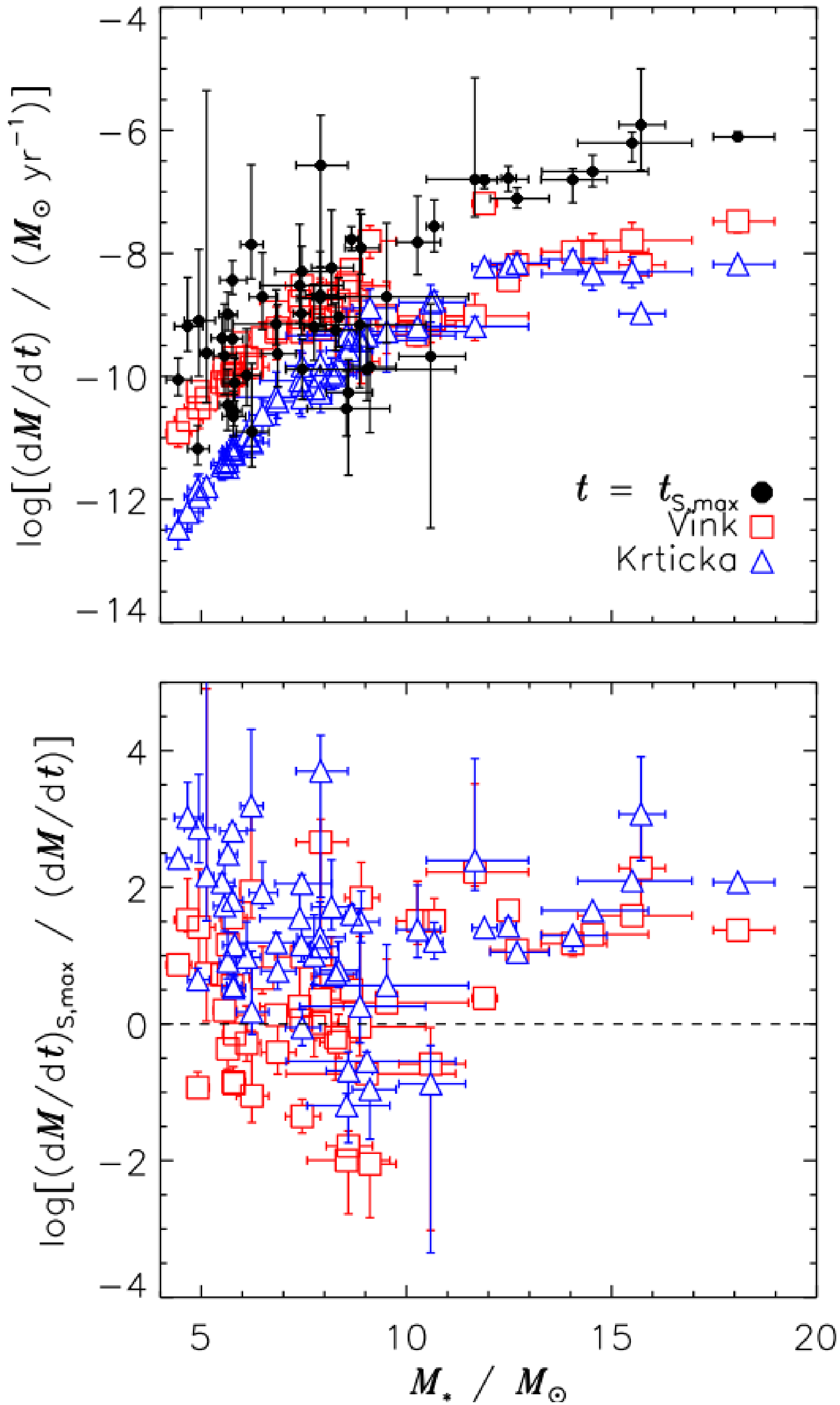
$$t_{S,max} = \tau_J \ln\left(\frac{W_0}{W}\right)$$

ud-Doula+2008

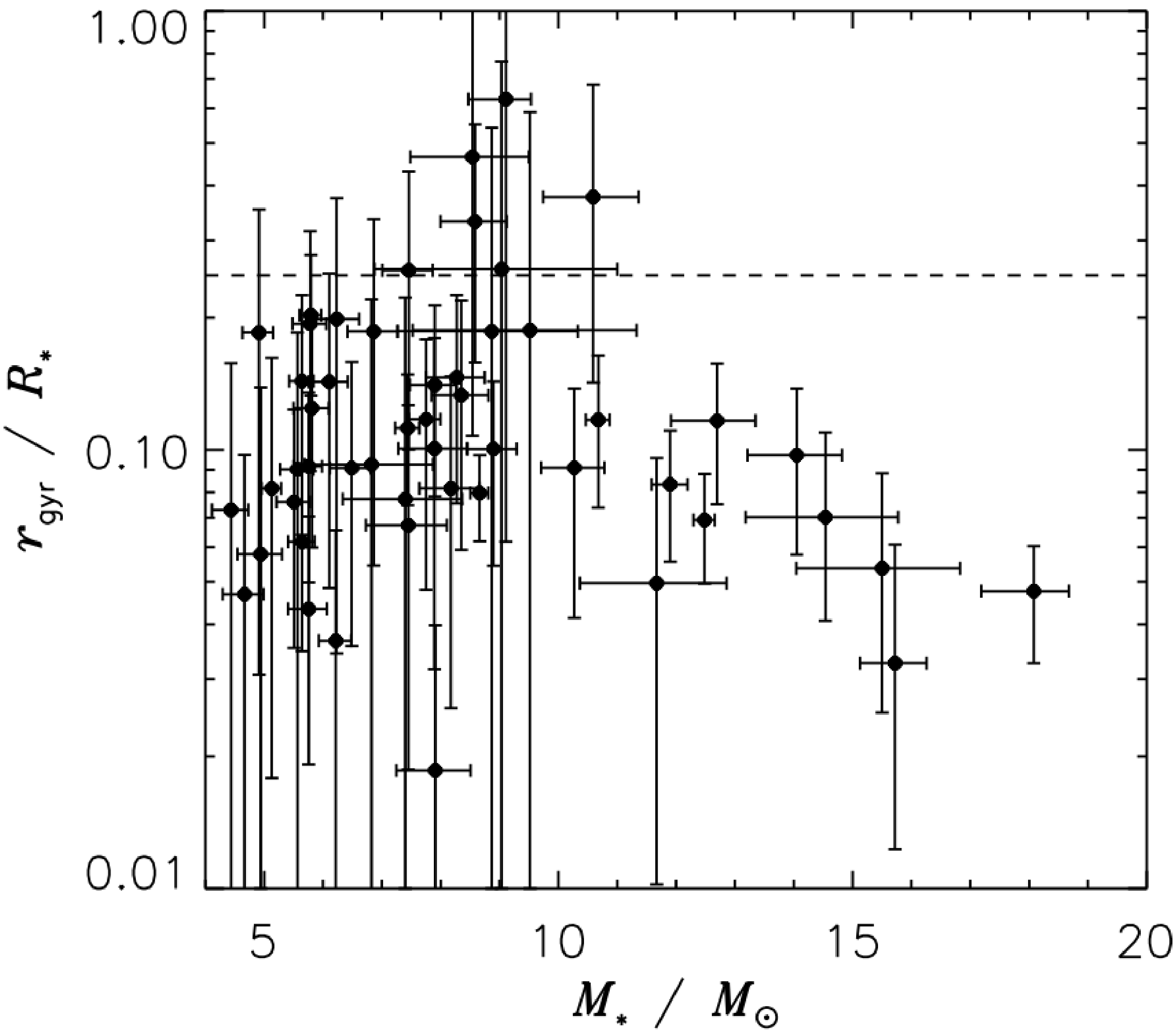
The initial rotation parameter would need to be a strong function of mass.



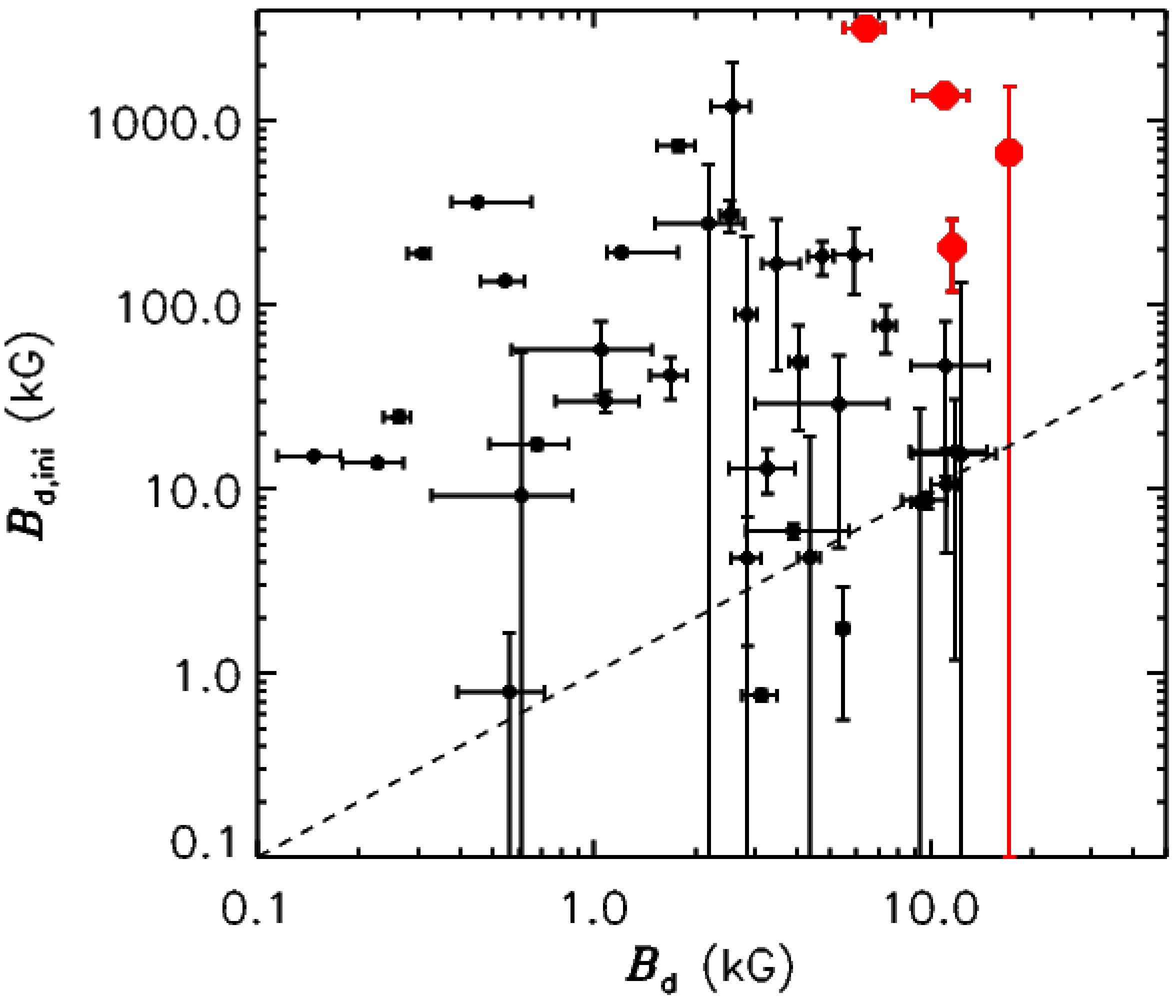
Mass-loss rates would need to be about 2 dex higher (which is pretty unlikely).



# Gyration radii would need to be much smaller.



# Flux decay would require unphysically strong initial magnetic fields.

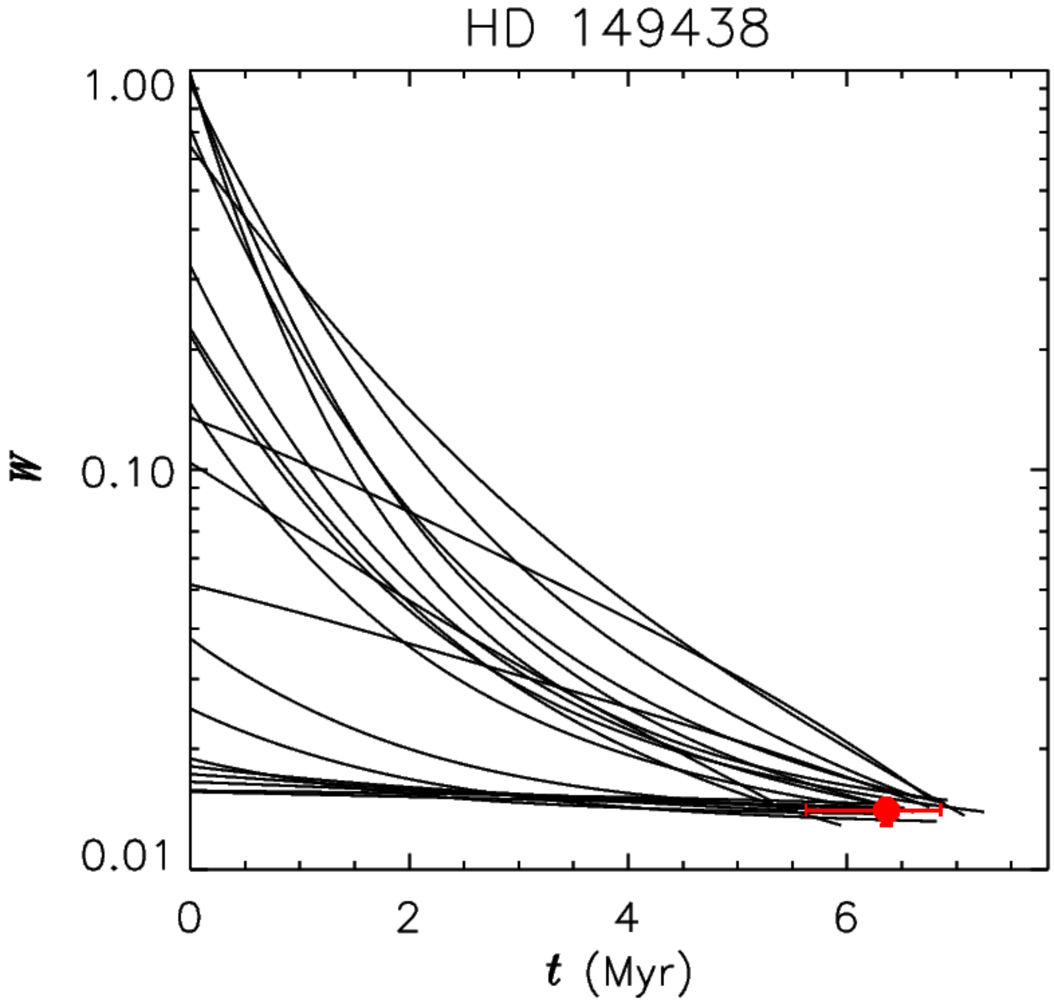



Exponential flux decay:

$$\Phi = \Phi_0 e^{-\xi t}$$

$\tau_{TAMS} < 0.05$

# What if we let the gyration radius, the initial rotation fraction, and the decay exponent vary simultaneously?

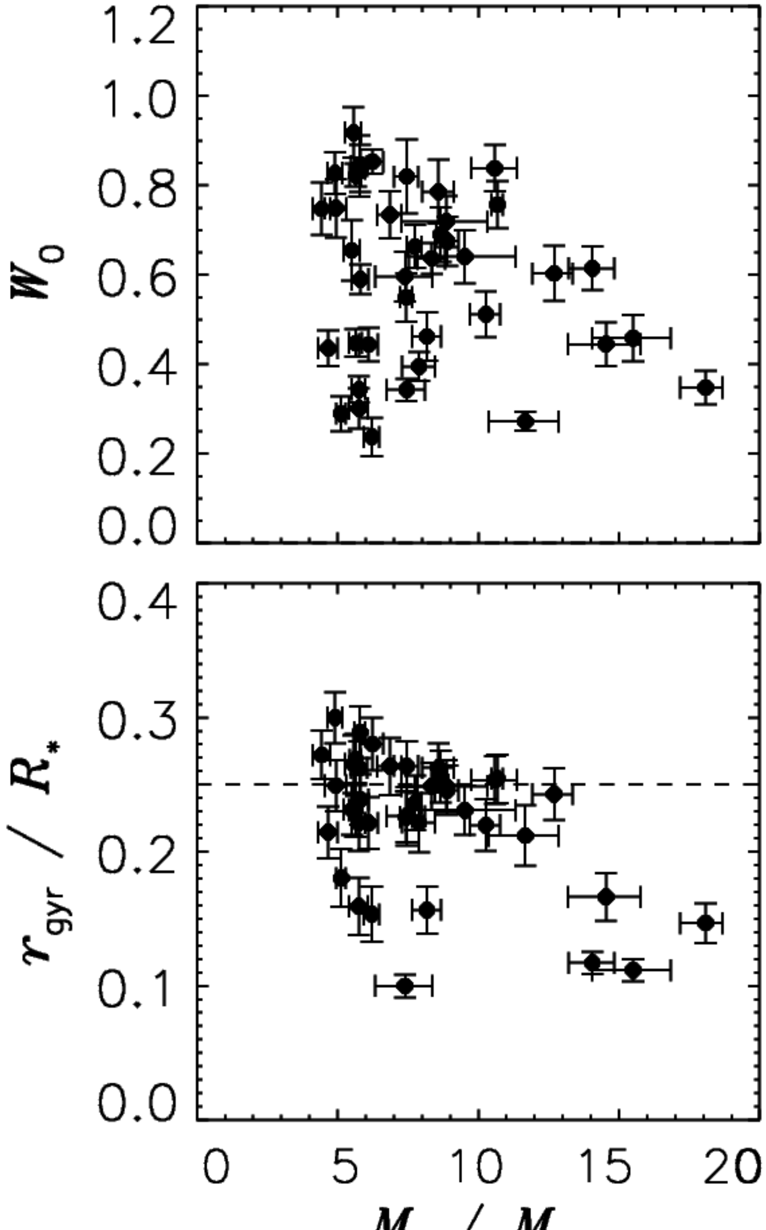


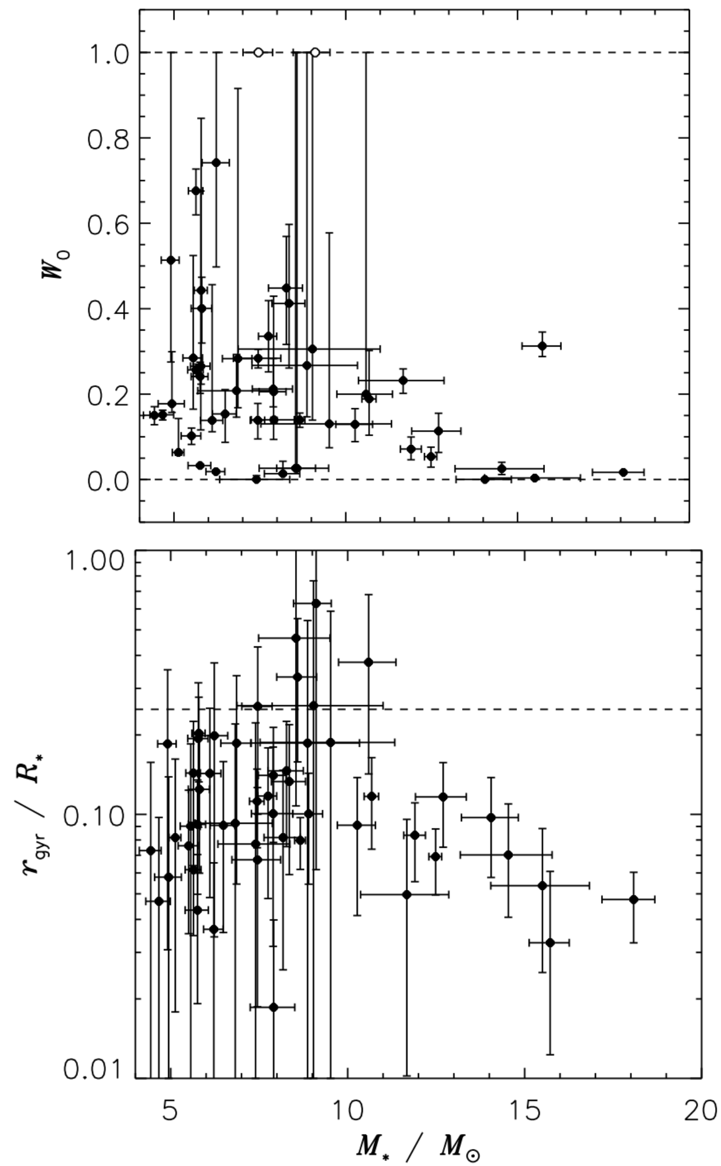

Monte Carlo search in $W_0$, $r_{gyr}$, & ξ parameter space

$W < W_0 < 1$
$0.01 < r_{gyr} < 0.5$
$-0.5 < \xi < 0.5$

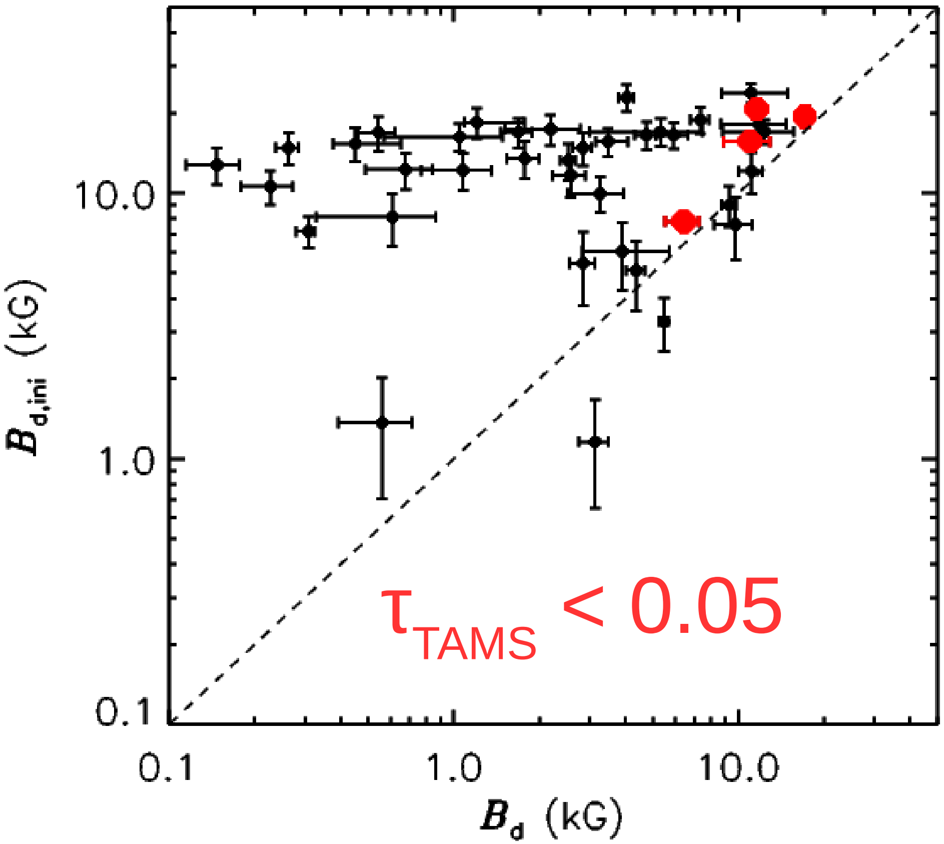
Penalty function prefers:
$W_0 = 1$, $r_{gyr} = 0.25$, $\xi = 0$.

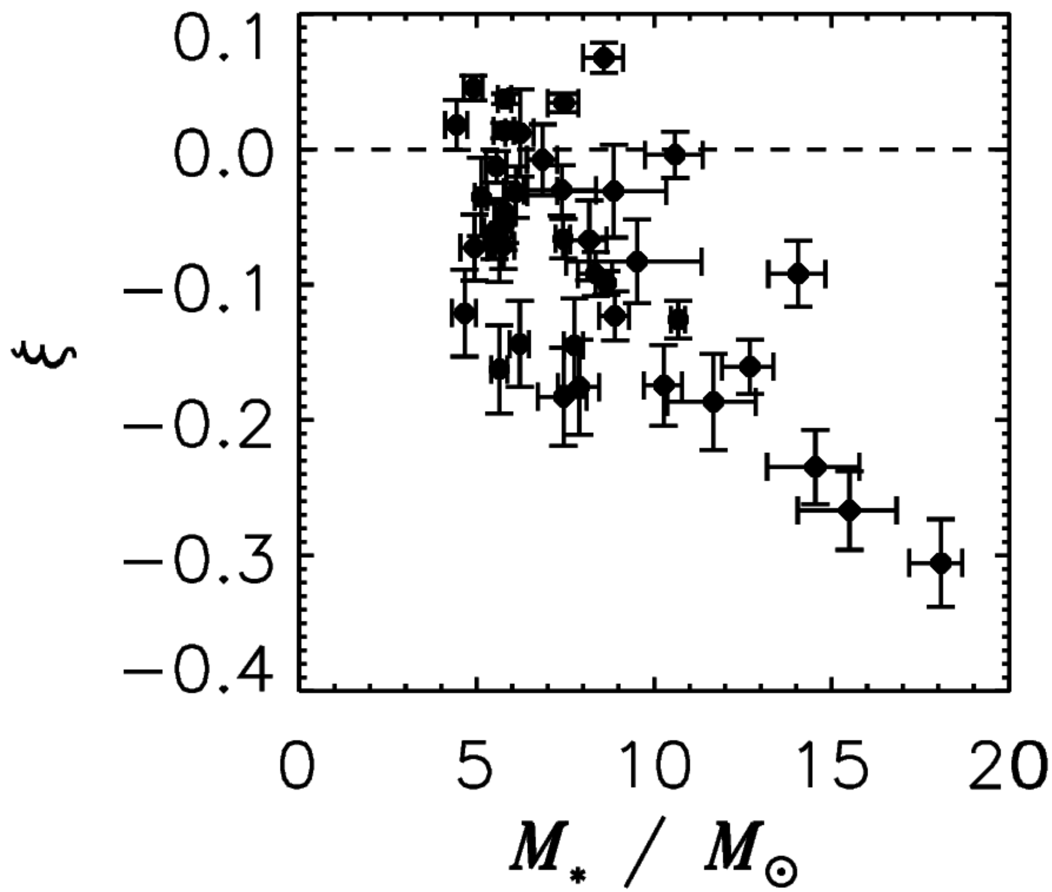
# Allowing for magnetic flux decay leads to higher values of $W_0$ and $r_{gyr}$.



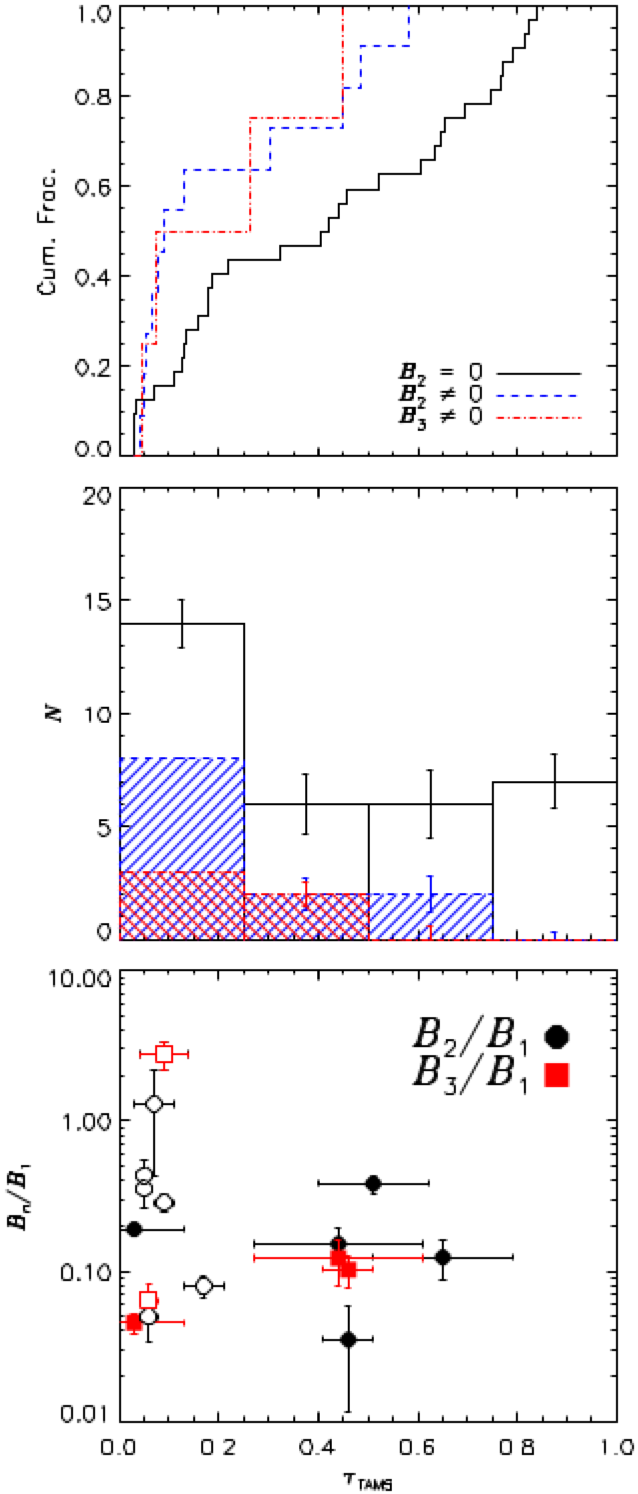
# $B_{d,ini}$ ~ 10 kG for most stars, & the decay exponent increases with mass.



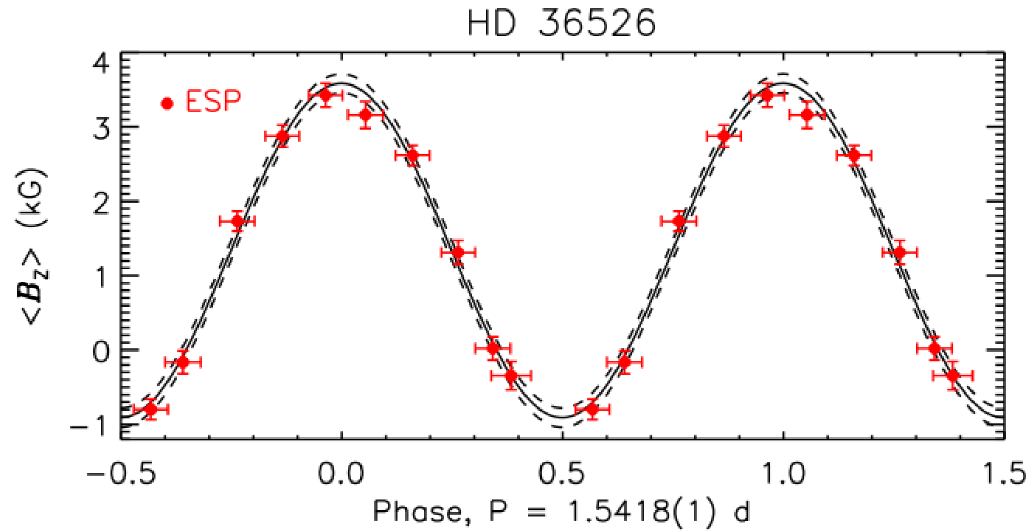
# Conclusions

- Early B-type stars with emission lines are strongly magnetized, rapidly rotating, and young.
  - We should look for more Hα-bright CM stars in young clusters.
  - Can emission strength be used to infer magnetic field strength?
- Surface magnetic fields become weaker over time.
- Flux decay can reconcile spindown ages and evolutionary ages.
- Flux decay seems to accelerate with increasing stellar mass.




Complex surface fields seem to be a feature primarily of younger stars, & higher-order harmonic amplitudes weaken over time.

# Harmonic fits to <$B_z$> were used to determine Bd (and to identify stars with complex magnetic fields).




$$\langle B_z \rangle(\phi) = \sum_{n=0}^{3} B_n \sin\left(n\phi + \Phi_n\right)$$