The Rotation-Activity Relation of 50 Spectroscopically Identified M-Dwarfs from MEarth

Thomas M. Boudreaux & Elisabeth R. Newton

Outline

- Background & Analysis
- Observations and Data
- Results

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Motivation

M-dwarfs are everywhere

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Majority of stars (~80% in our Galaxy)

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Ideal for planet search campaigns

M-dwarfs have excess Magnetic Activity

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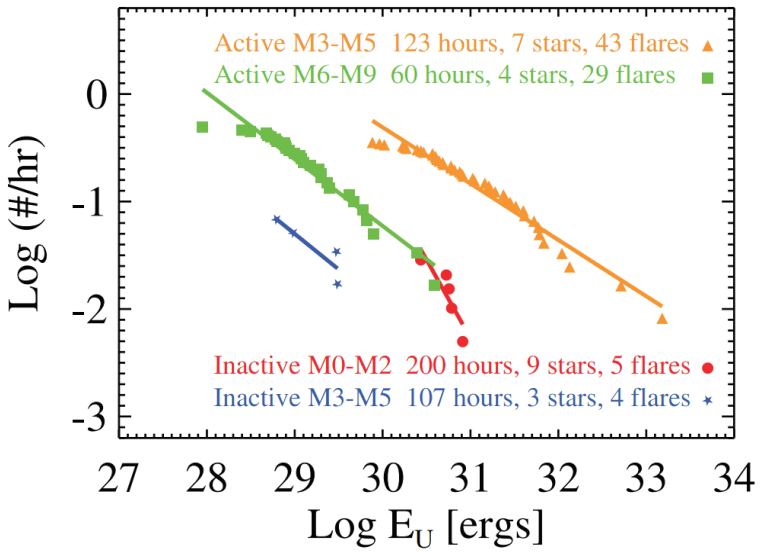
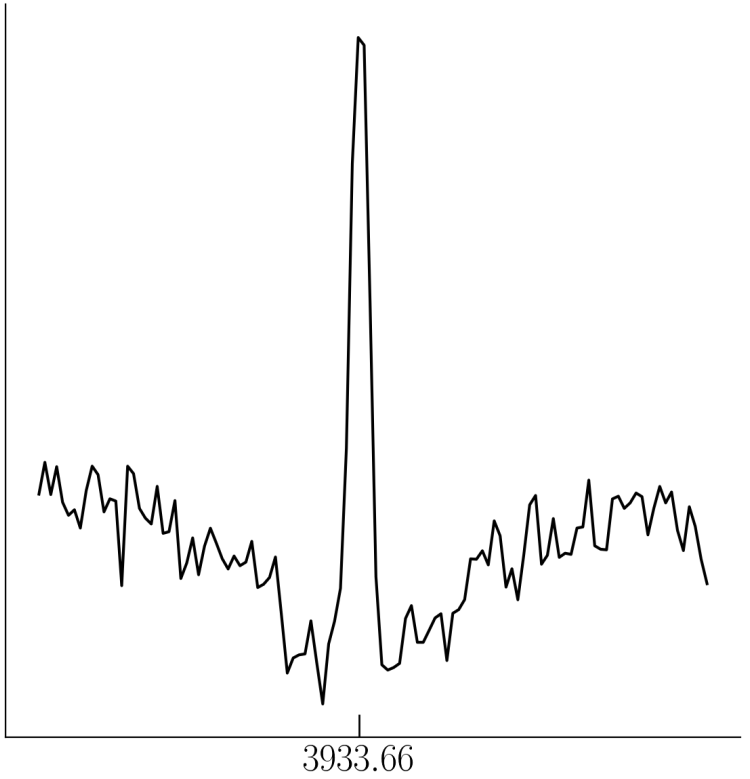
- Excess Flairing (X-Ray Flux)



M-dwarfs have excess Magnetic Activity

- Excess Flairing (X-Ray Flux)
- Non-thermal emission (Ca II H&K)



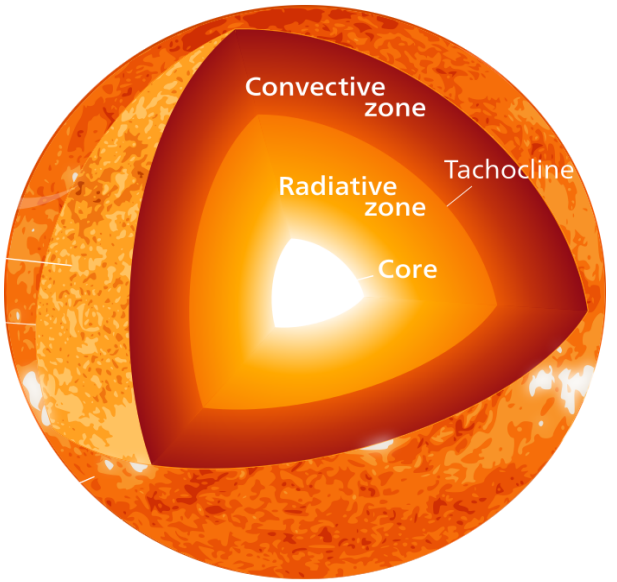
M-dwarfs have excess Magnetic Activity

- Excess Flairing (X-Ray Flux)
- Non-thermal emission (Ca II H&K)
- Direct Measurments (Zeeman Broadening)

Figure 1, Hilton et al. (2010)

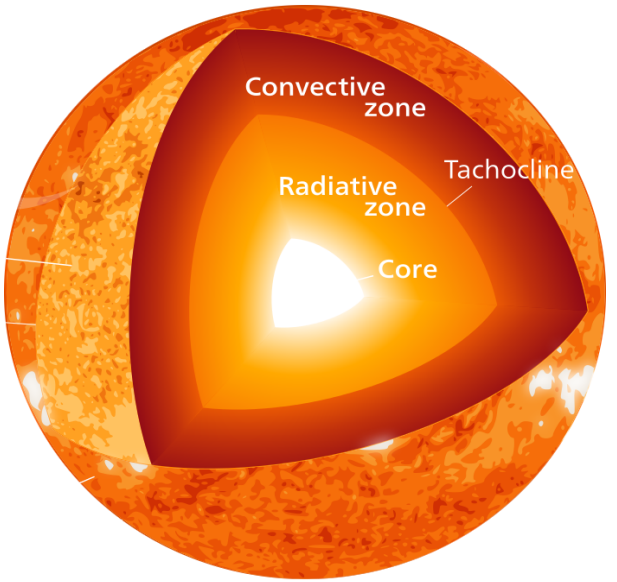
Magnetic Activity In Solar Like (not fully convective) Stars

- Stars are composed of moving, charged, particles



Magnetic Activity In Solar Like (not fully convective) Stars

- Stars are composed of moving, charged, particles
- Therefore, magnetic fields exist all throughout a star



Randomly Oriented Magnetic Fields Exist Throughout a Star

A mechanism must exist to orient these fields into a similar direction

Properties of this mechanism

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- Stable over long time scales

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- Compel magnetic fields into a shared orientation

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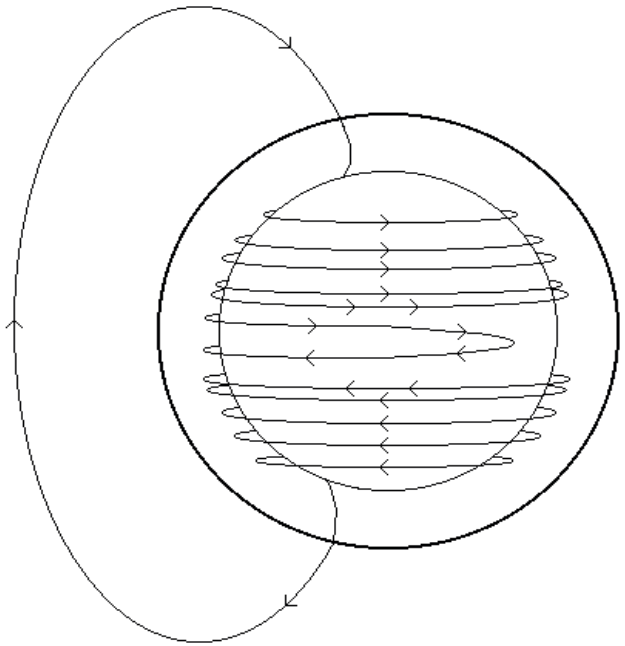
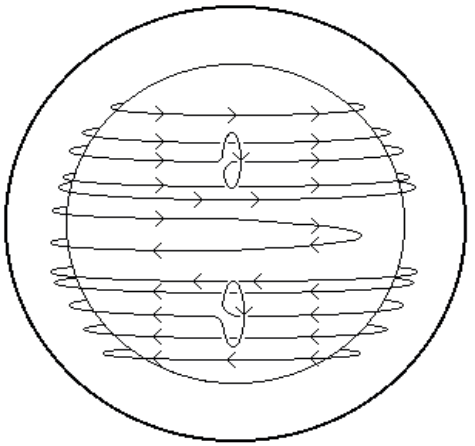
The Tachocline

The Tachocline aranges these (small, randomly oriented) fields to larger scales

The $\alpha\Omega$ Dynamo



The ω-effect



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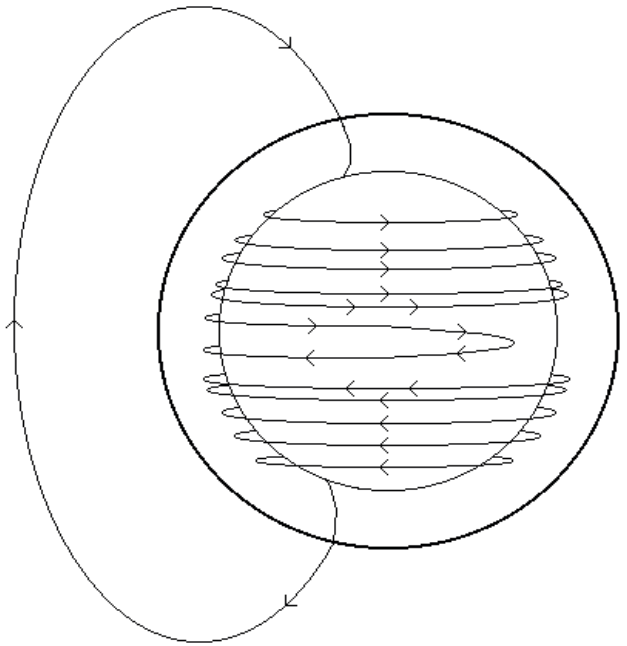

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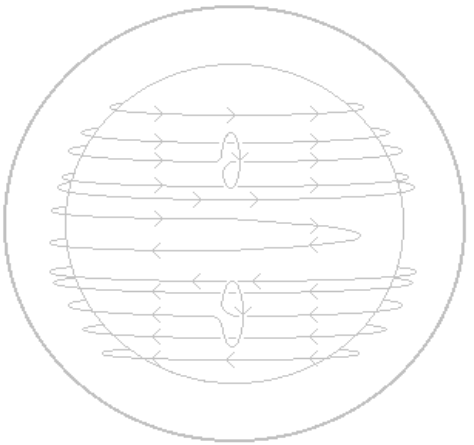

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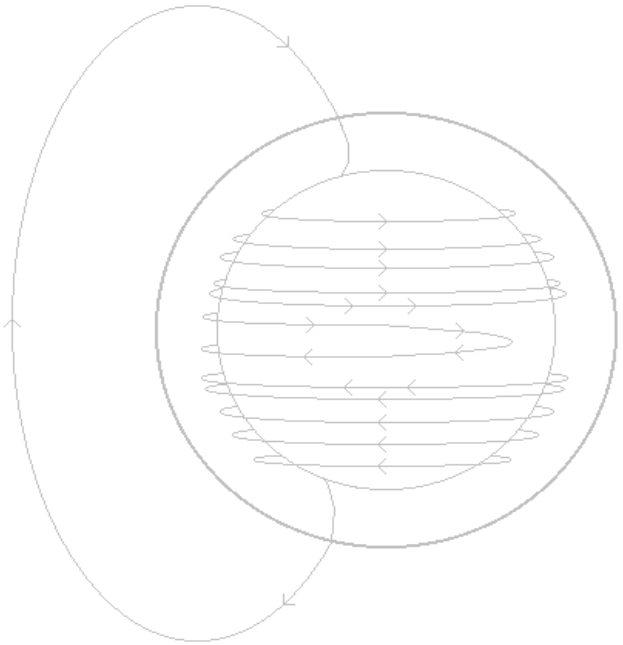

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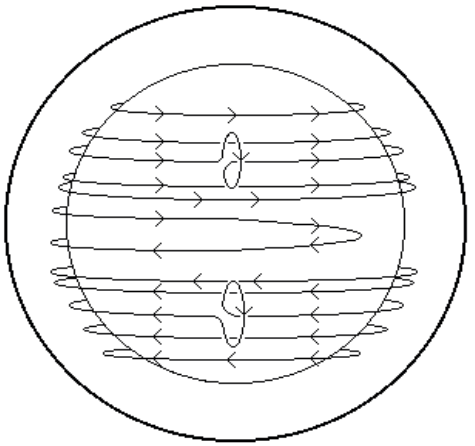

The α-effect

Magnetic Field in Fully Convective Stars

M-dwarfs, latter than M4, are fully convective.

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Therefore, they do not have a tachocline

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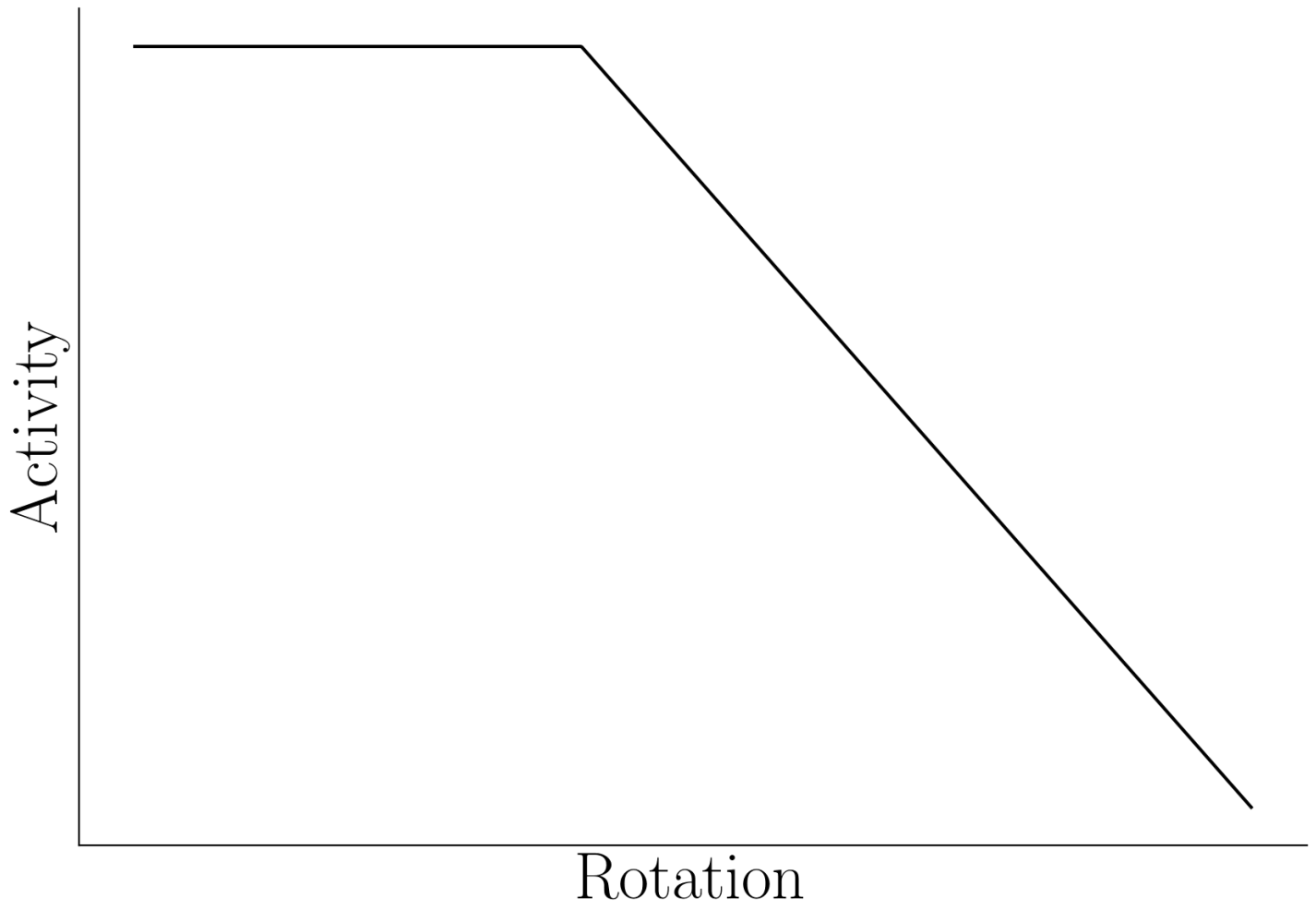
Therefore, they do not have a tachocline

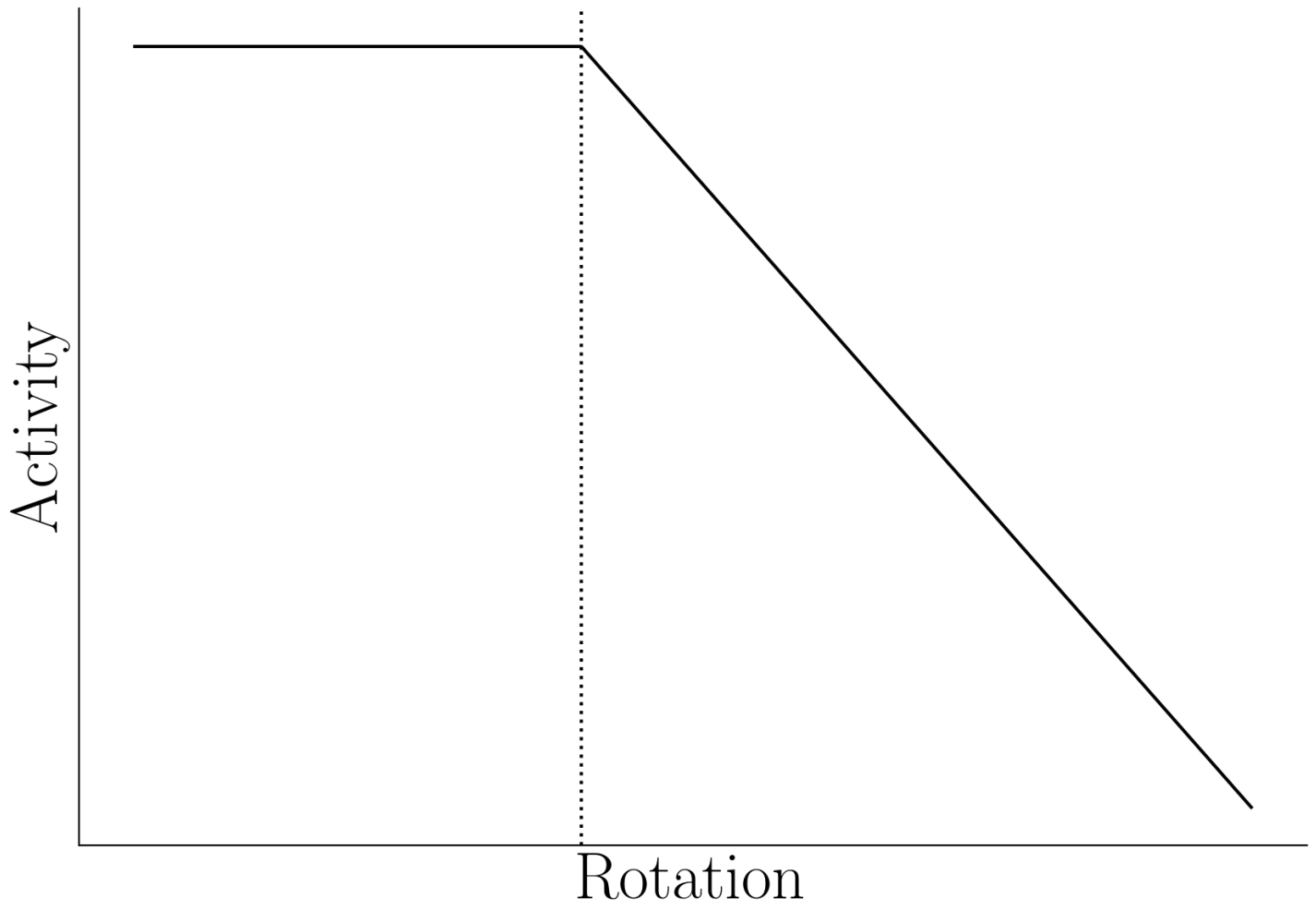
Recall, that they empirically show enhanced magnetic activity.

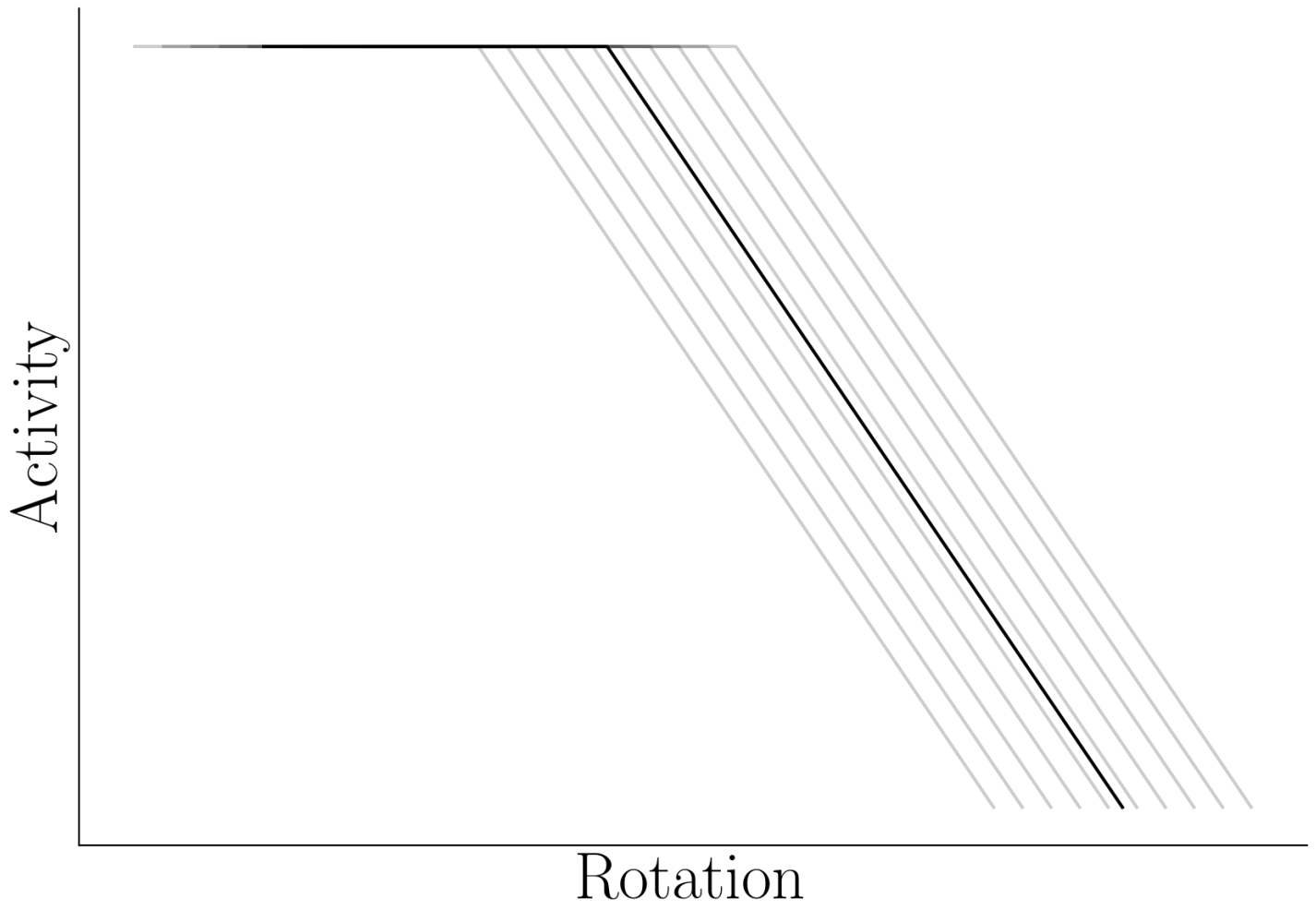
Numerical Models indicate that convective currents and simple rotation are enough to organize small scale fields.

The Rotation-Activity Relation

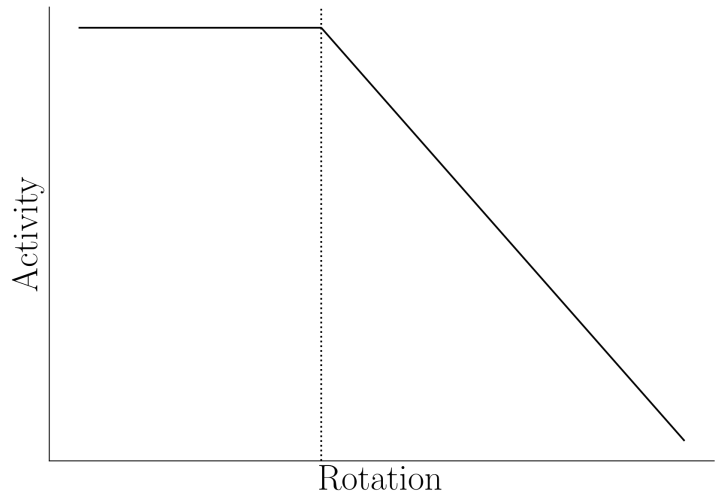
The motion of a chage packets seeds the generation of a magnetic field


Activity
Rotation

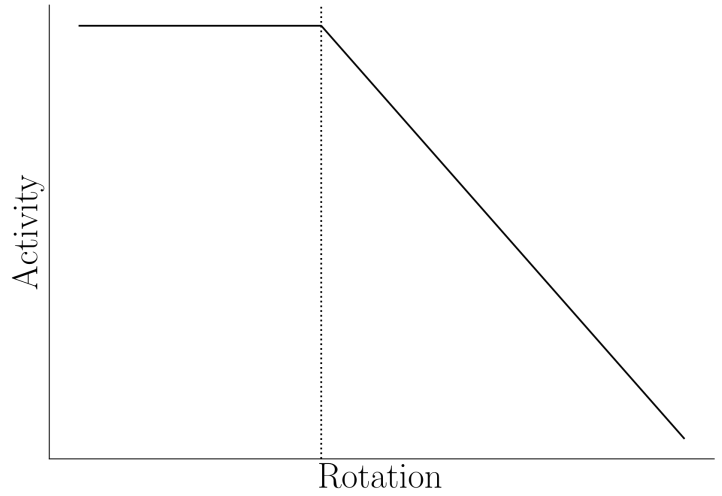

Activity
Rotation


Activity
Rotation

- Rotation is not the only contributing factor to the motion of charge!



- Rotation is not the only contributing factor to the motion of charge!
- Convective Currents also move charge packets



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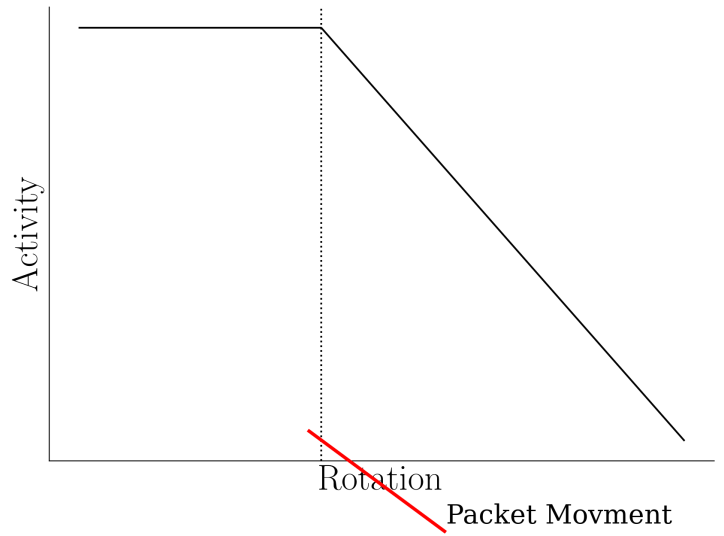
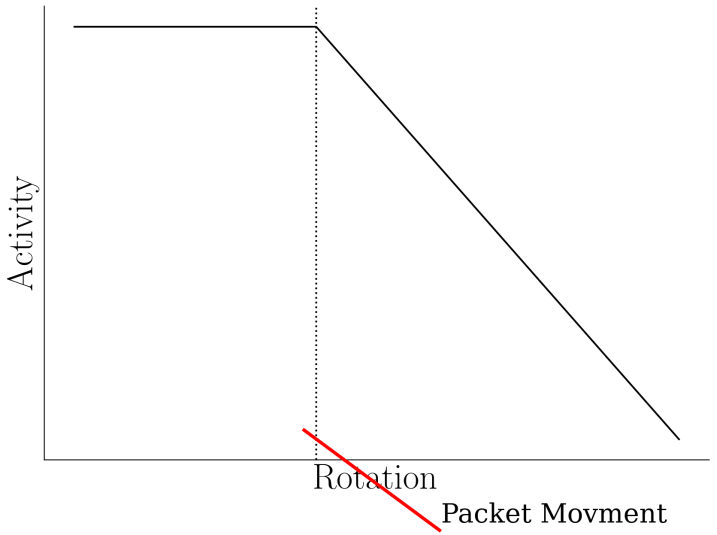
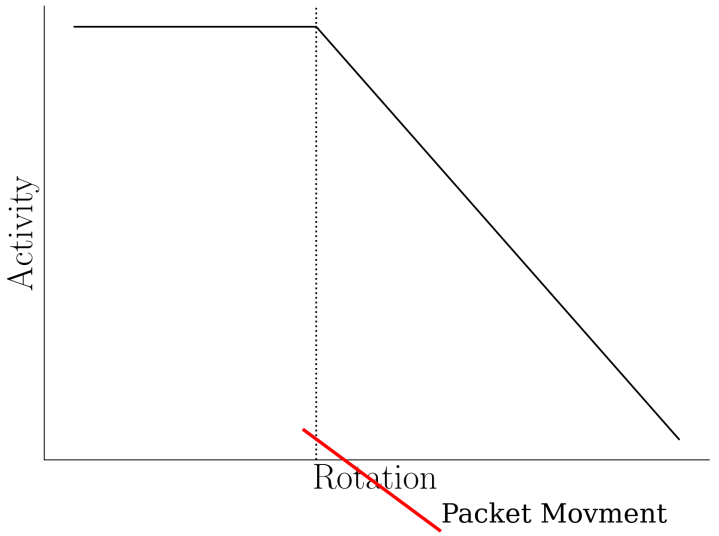


- Rossby Number is formally the ratio of coriolis to interial forces

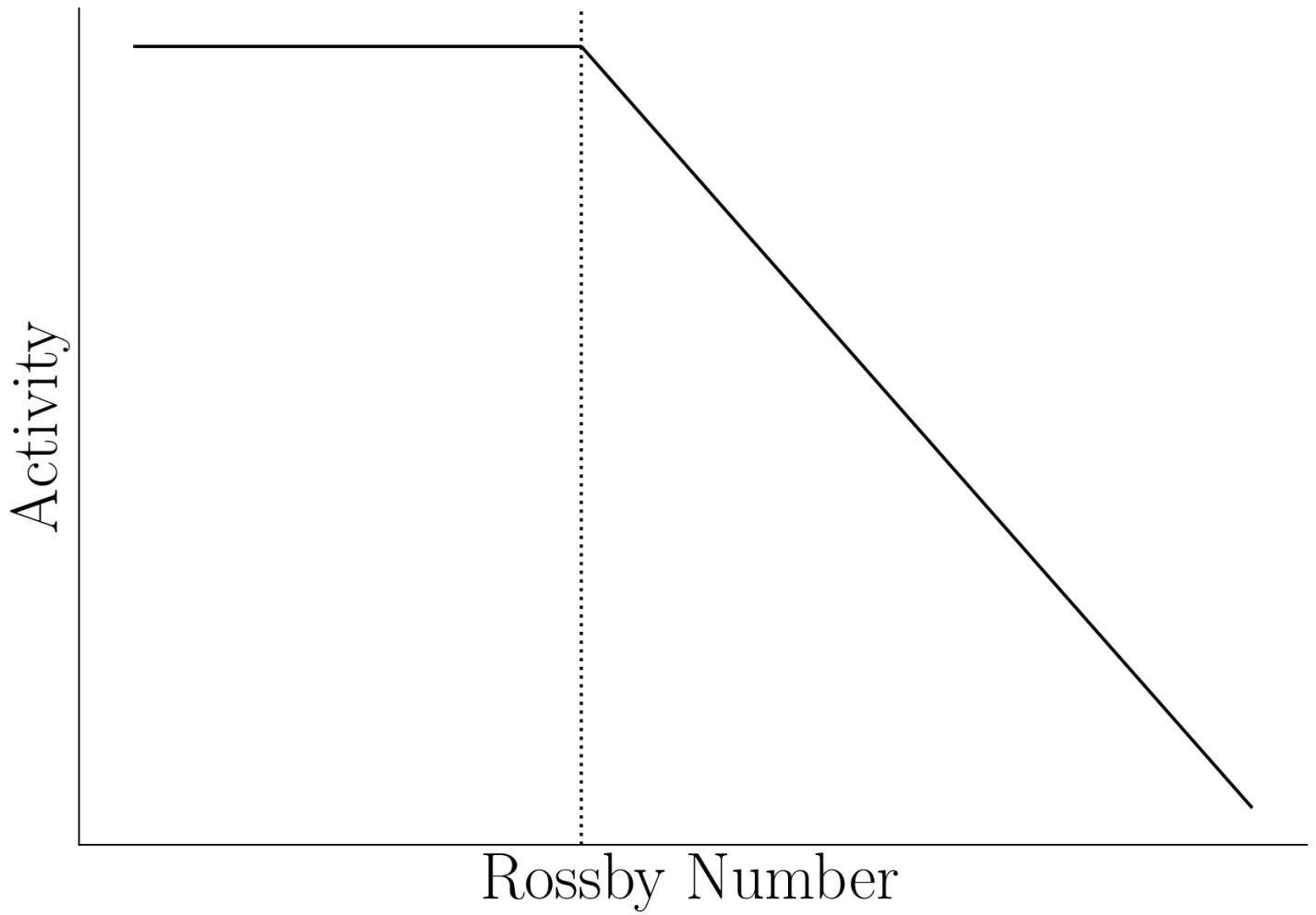


- Rossby Number is formally the ratio of coriolis to interial forces
- An observationally useful proxy for this is:

The ratio of the rotational period (coriolis) to the convective overturn timescale (inertial)

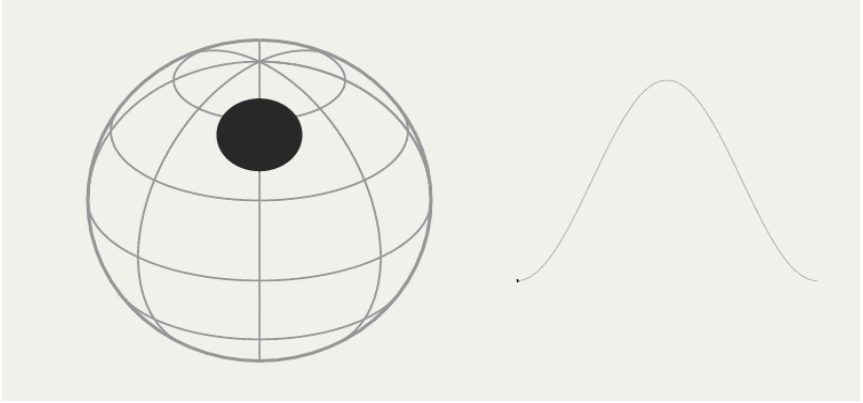


$$Ro = \frac{P_{rot}}{\tau_c}$$


Activity
Rossby Number

Measuring Rotational Period

Measuring Rotational Period



- Photometric Rotational Periods

Measuring Rossby Number

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- Rossby Number includes
  rotational period *and*
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Measuring Rossby Number

- Rossby Number includes rotational period *and* convective over turn time
- Convective Overturn callibrated to remove x offset between stars of different mass / color

$$\log(\tau_c) = 0.64 + 0.25(V - K)$$

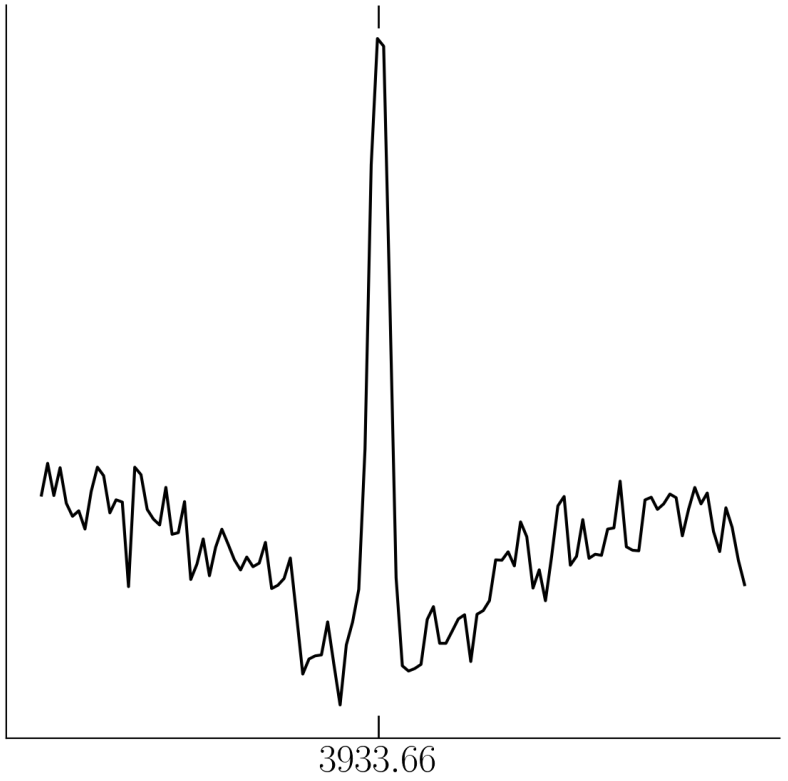
Davenport, Wright et al. (2018)

Quantifying the Activity

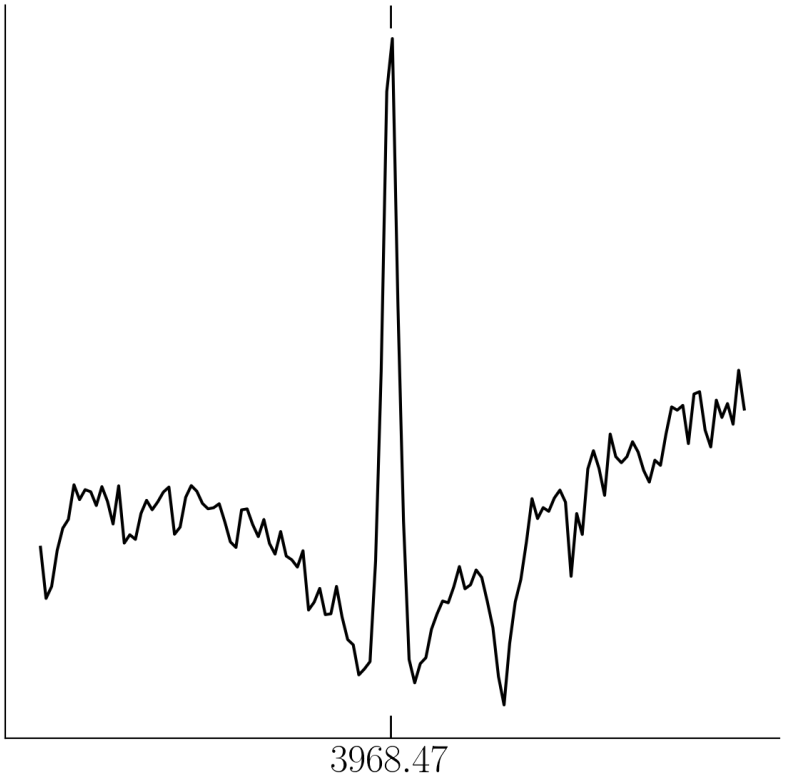
Magnetic activity leads to non-themal heating of the upper chronosphere

Ca II H&K Emission

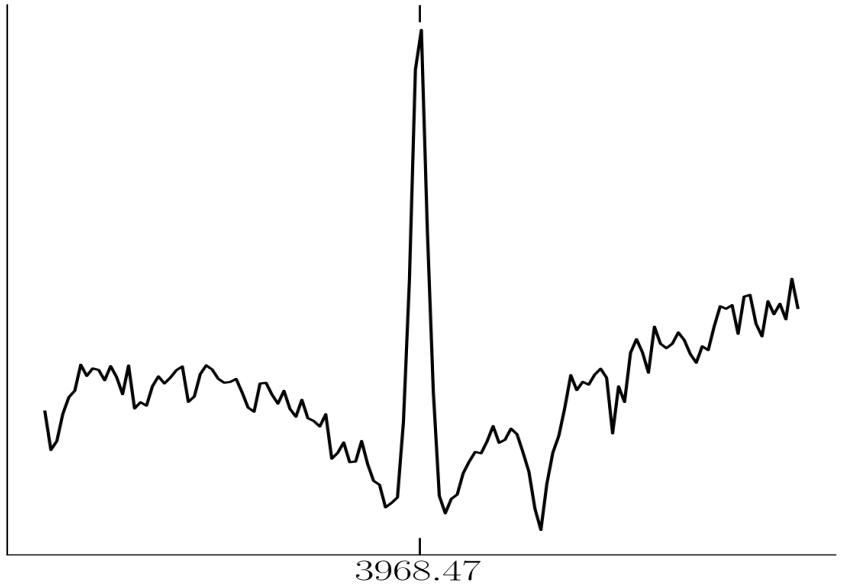
Ca II K Emission Line



Ca II H Emission Line



Ca II H&K Emission



Narrow emission (chromosphere) superimposed on broad absorbtion (photosphere)

S-Index!

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Ratio of Ca II H&K Emission to contiumn emission

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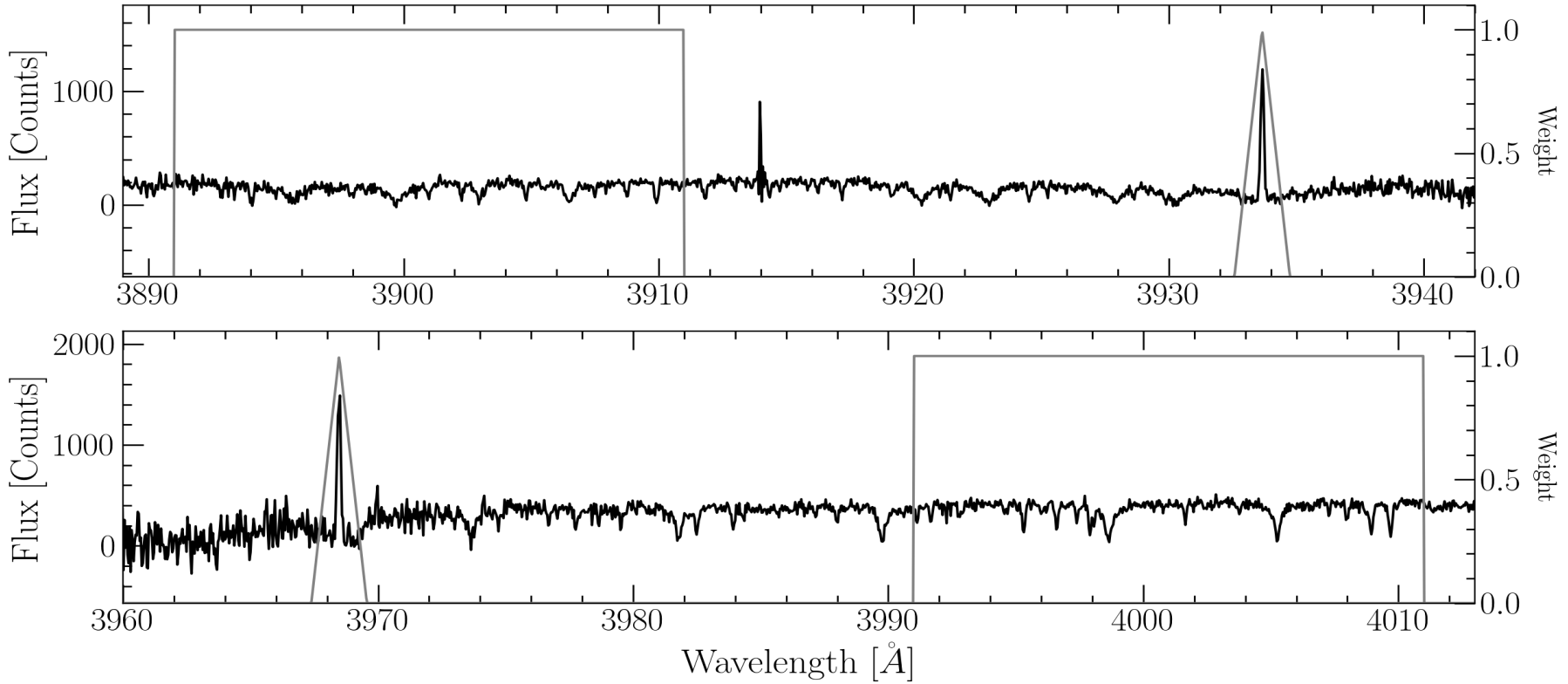
- Ratio of Ca II H&K Emission to contiumn emission
- Developed At Mount Wilson in the 1960s for classifiction of the suns magnetic activity


Flux [Counts]
1000
0
3890
3900
3910
3920
3930
3940
1.0
0.5
0.0
Weight
Flux [Counts]
2000
1000
0
3960
3970
3980
3990
4000
4010
1.0
0.5
0.0
Weight
Wavelength [Å]

S-Index

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$$S \propto \frac{f_H + f_K}{f_V + f_R}$$

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$$S \propto \frac{f_H + f_K}{f_V + f_R}$$

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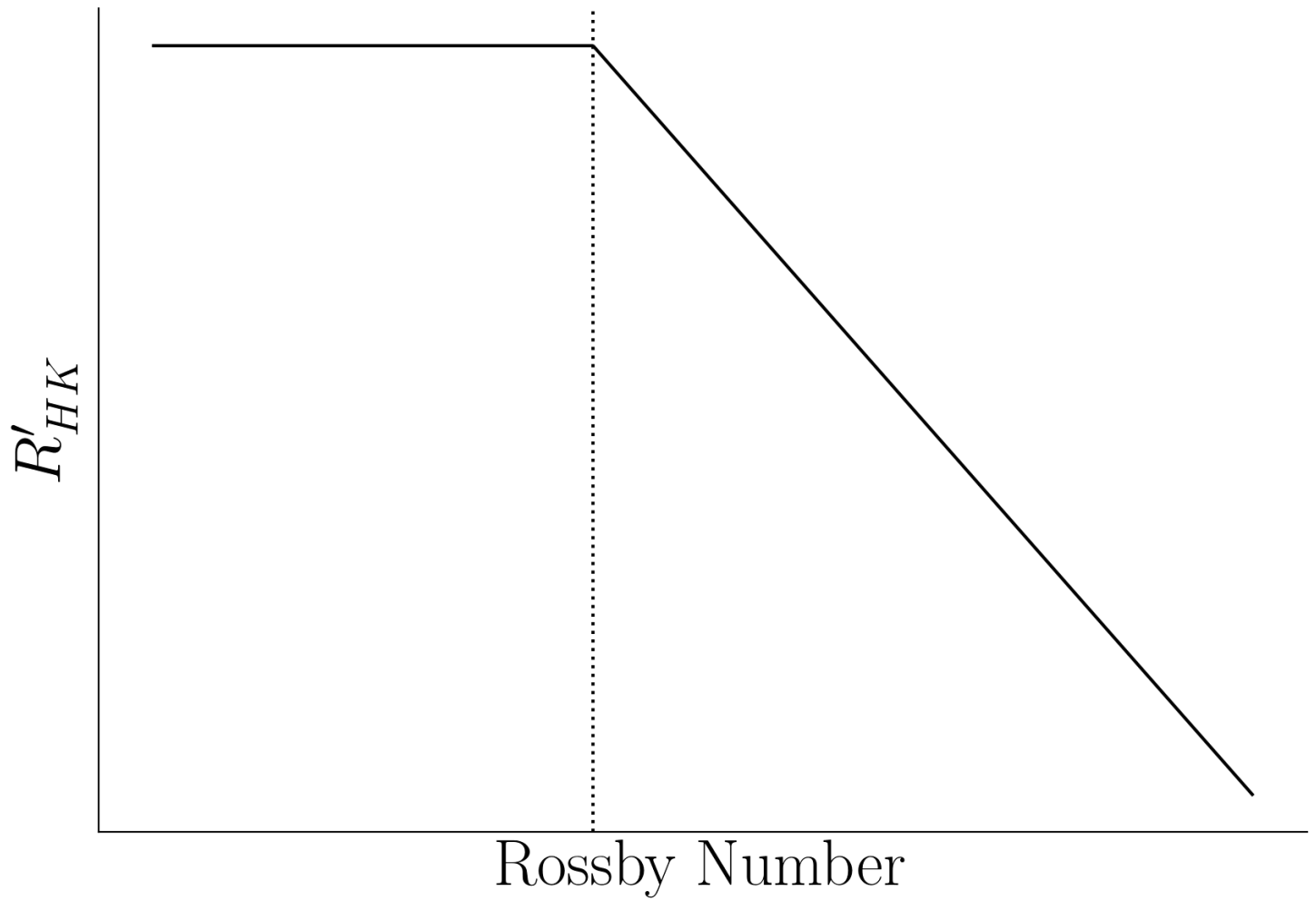
$$S_{HK} = \alpha_H \frac{\tilde{f}_H + \tilde{f}_K}{\tilde{f}_V + \tilde{f}_R}$$

$$R'_{HK}$$

$$R'_{HK}$$

$$R'_{HK} = \lambda C_{cf} S - R_{phot}$$
$$\lambda \equiv 1.887 \times 10^{-4}$$

- Bolometric Flux Normalized Transformation of S-Index


R'_{HK}
Rossby Number

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Target Selection

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- Selected for:

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  - High Proper Motion

Target Selection

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  - Measured Photometric Rotational Periods

MIKE Observations

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- High Resolution Echell Spectrograph
- Blue (335-500 nm) and red arms (490-950 nm)
- Resolution ~ 32700

MIKE Observations

- High Resolution Echell Spectrograph
- Blue (335-500 nm) and red arms (490-950 nm)
- Resolution ~ 32700
- Data Reduced With `CarPy`
- Background Subtracted, Blaze Corrected, and Wavelength Calibrated
- All Spectra Shifted to the Rest Frame

Bernstien et al. (2003), Kelson (2003), Kelson (2006)

Outline

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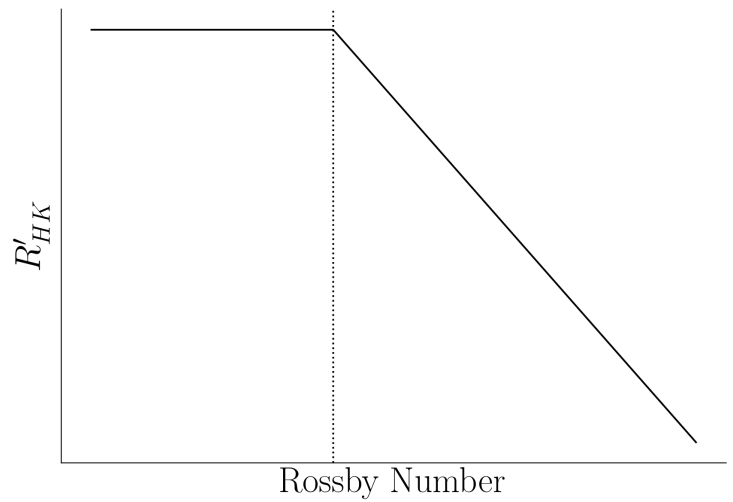
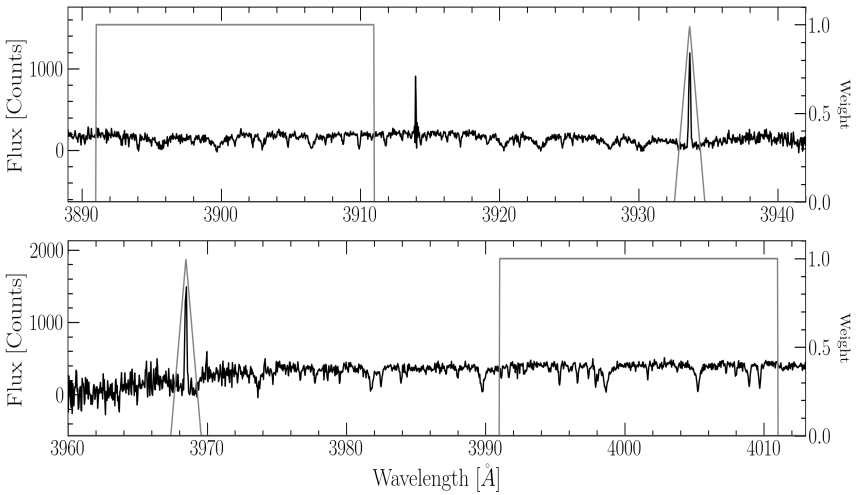
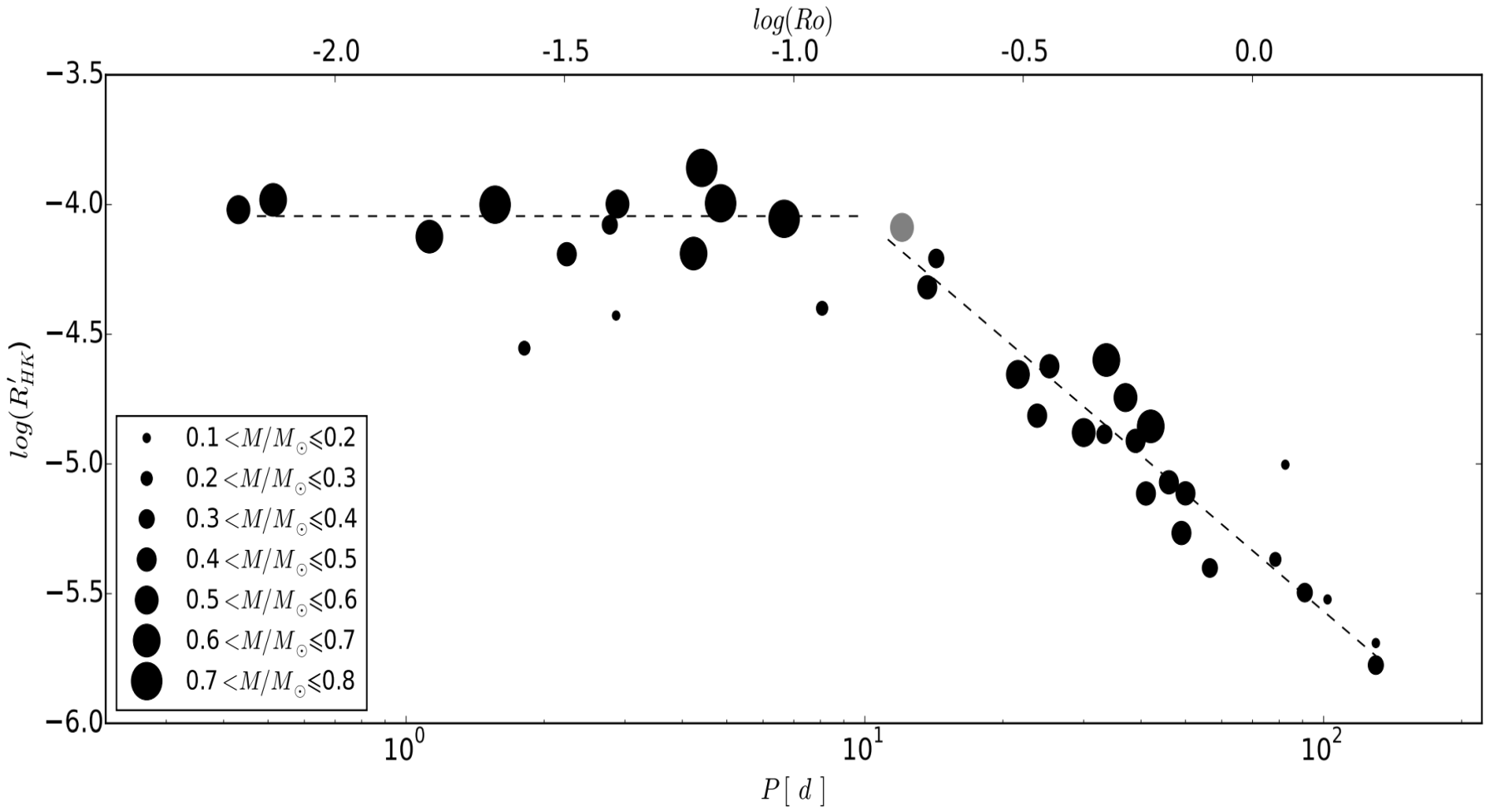
The Rotation-Activity Relation

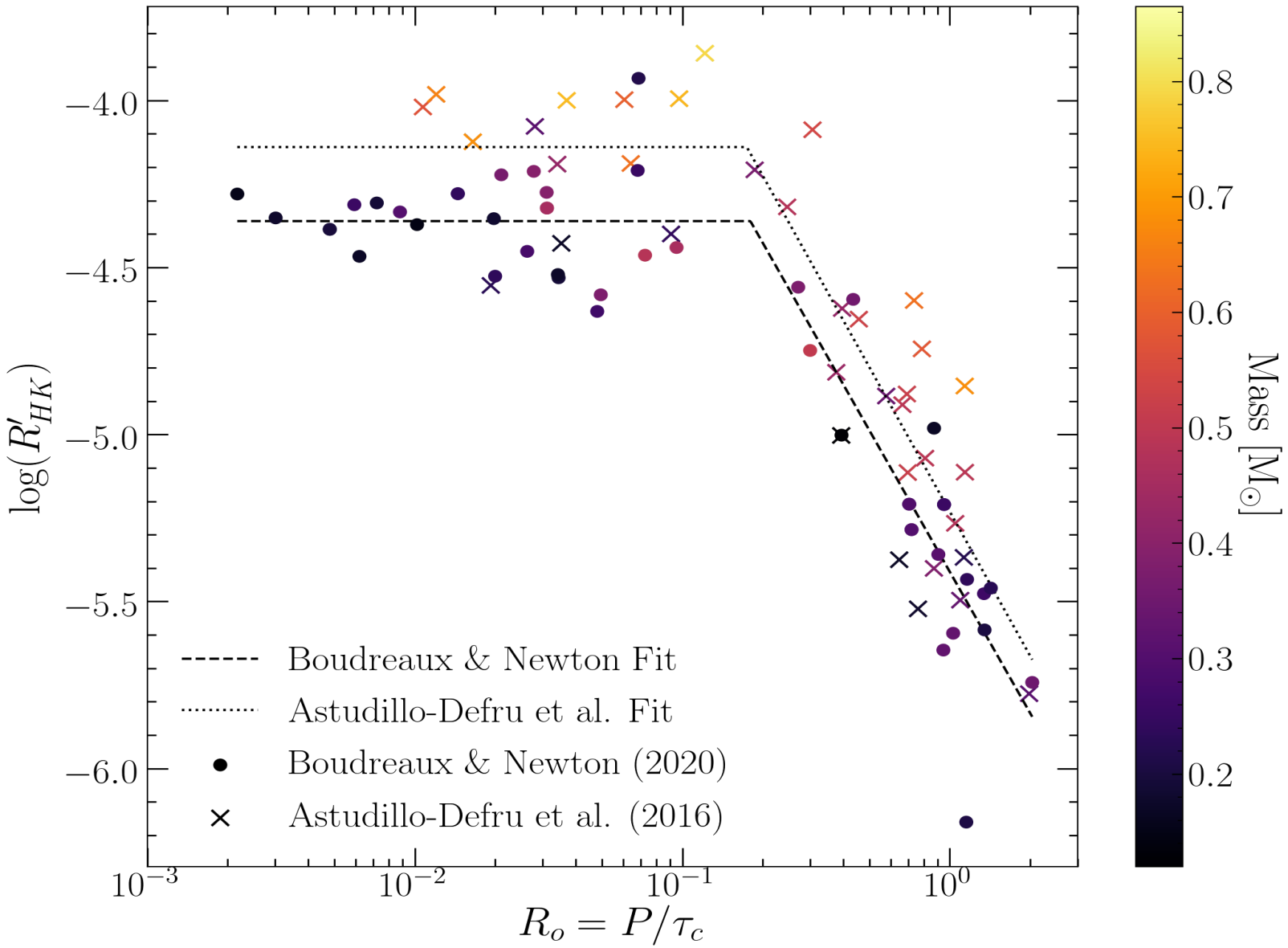
Recall


R'_{HK}
Rossby Number

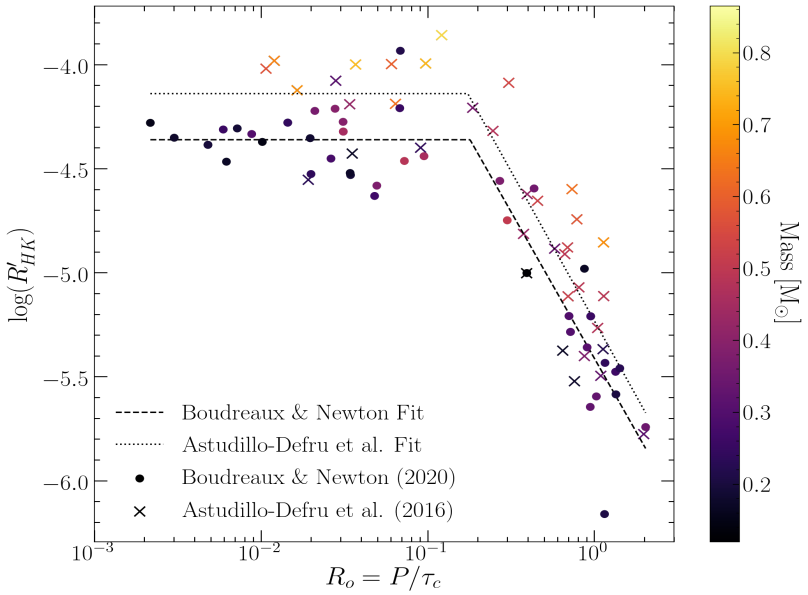

Flux [Counts]
1000
0
3890
3900
3910
3920
3930
3940
1.0
0.5
0.0
Weight
2000
1000
0
3960
3970
3980
3990
4000
4010
Wavelength [Å]

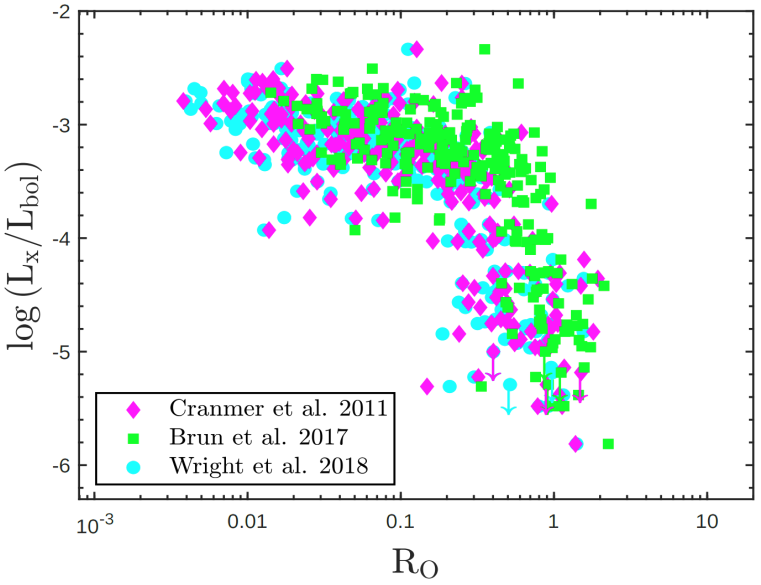
Astudillo-Defru et al. (2017) Rotation-Activity Relation




−4.0
−4.5
−5.0
−5.5
−6.0
$\log(R'_{HK})$
10^{-3}
10^{-2}
10^{-1}
10^{0}
$R_o = P/\tau_c$
Boudreaux & Newton Fit
Astudillo-Defru et al. Fit
Boudreaux & Newton (2020)
Astudillo-Defru et al. (2016)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Mass [$M_\odot$]

Traced through L_X / L_{bol}





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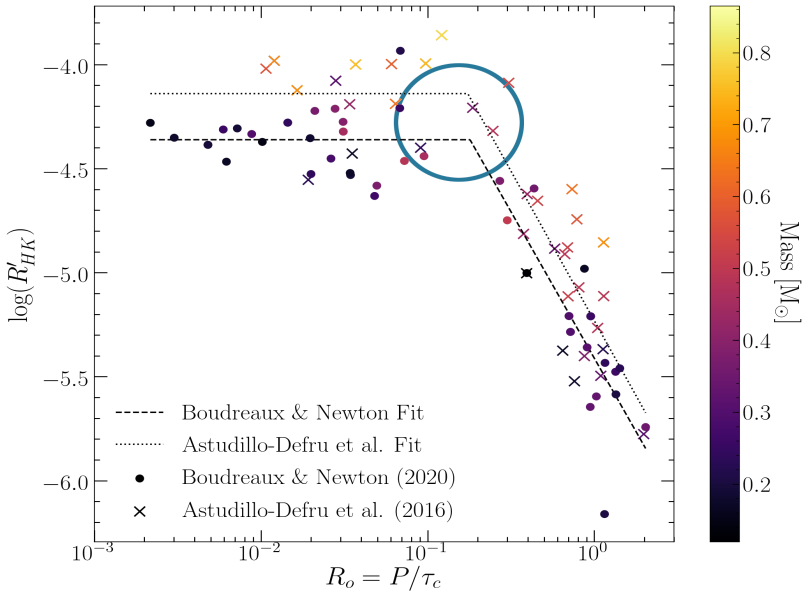

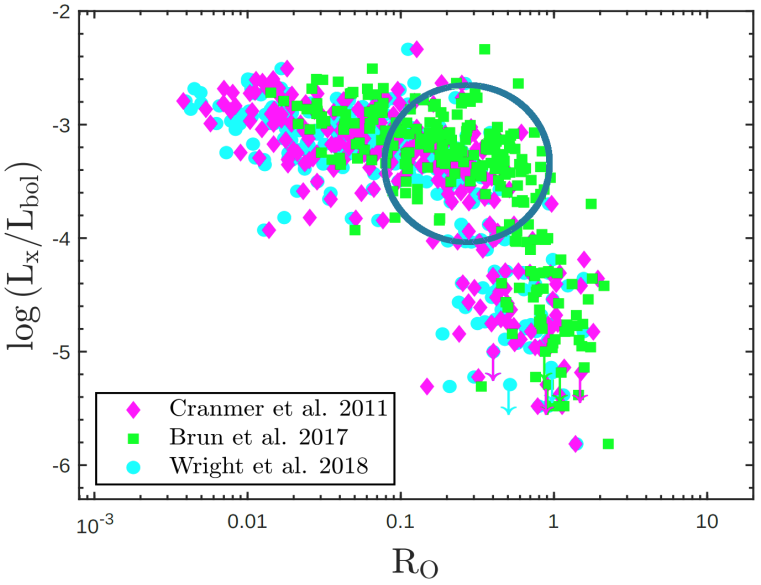

Figure 8, Magaudda et al. (2020)

Conclusion

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- Doubled the Number of M-dwarfs with measured R'_{HK} and P_{rot} values.

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- Doubled the Number of M-dwarfs with measured R'_{HK} and P_{rot} values.
- Strengthening constraints when infering P_{rot}

With Thanks To.

Dr. Elisabeth Newton

Dr. Brian Charboyer

Dr. John Thorstenton

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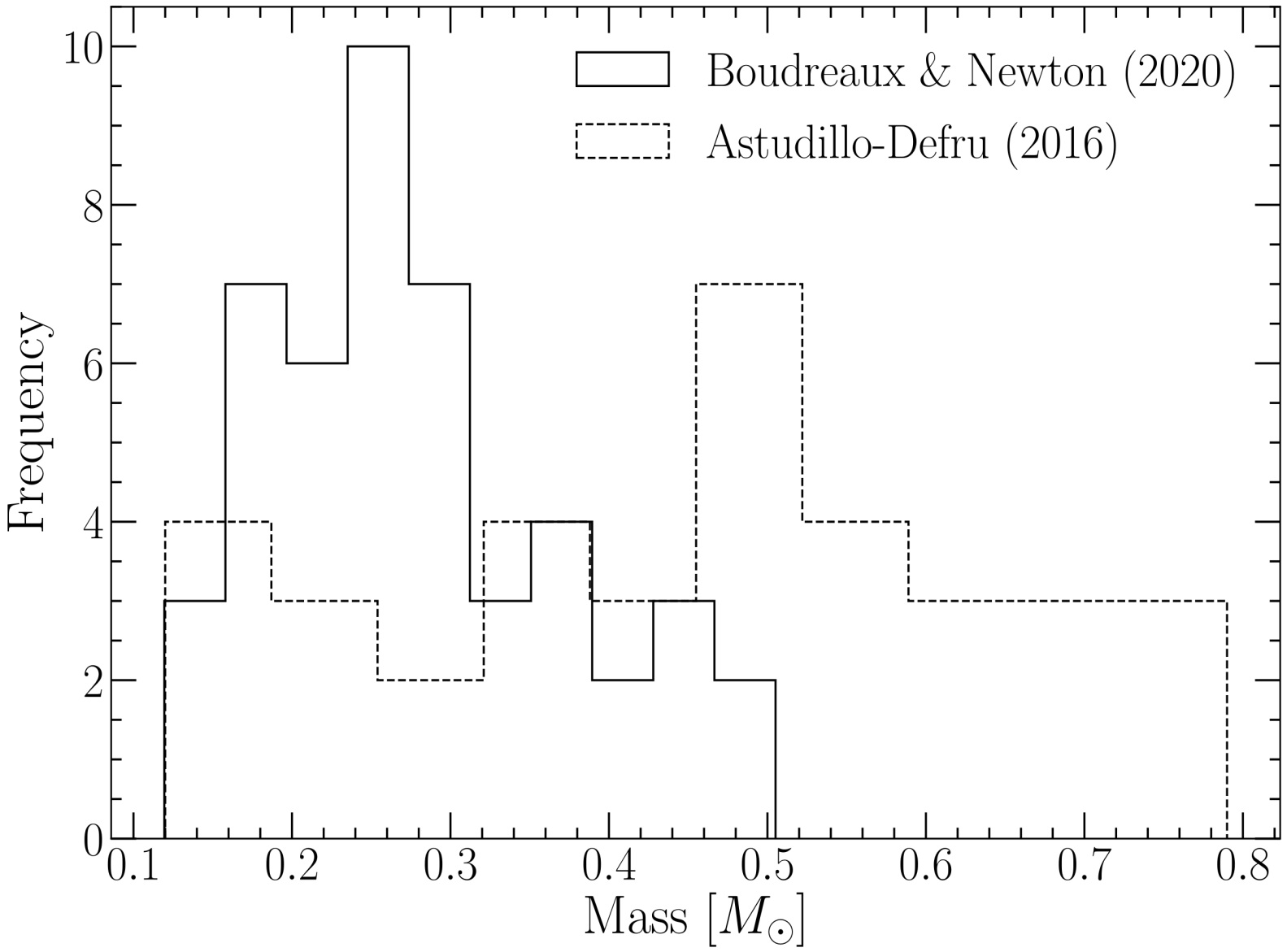
Boudreaux & Newton (2020)
Astudillo-Defru (2016)
Frequency
Mass [$M_\odot$]
0
2
4
6
8
10
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8