Toward an Astrophysically–Motivated Predictor of Stellar Radial Velocity Jitter

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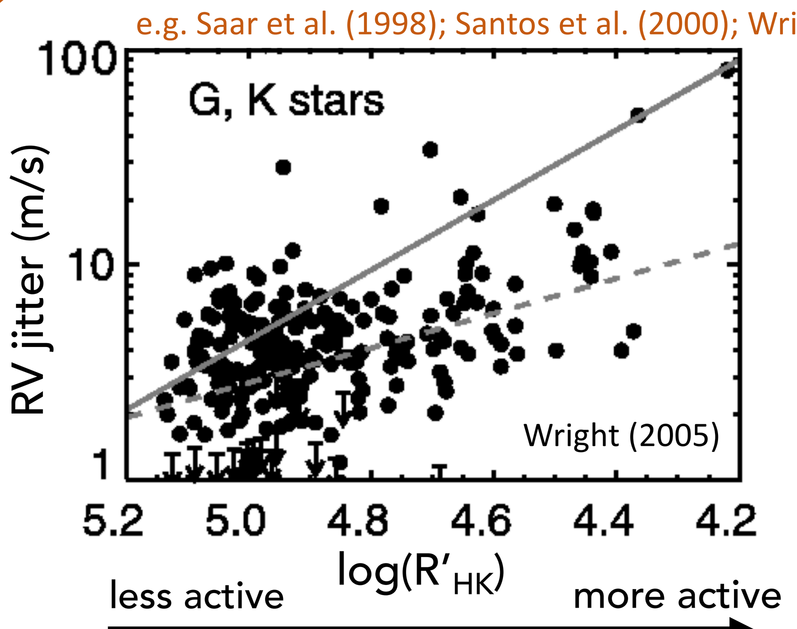
RV Jitter Increases with Activity

e.g. Saar et al. (1998); Santos et al. (2000); Wright (2005); Isaacson & Fischer (2010)

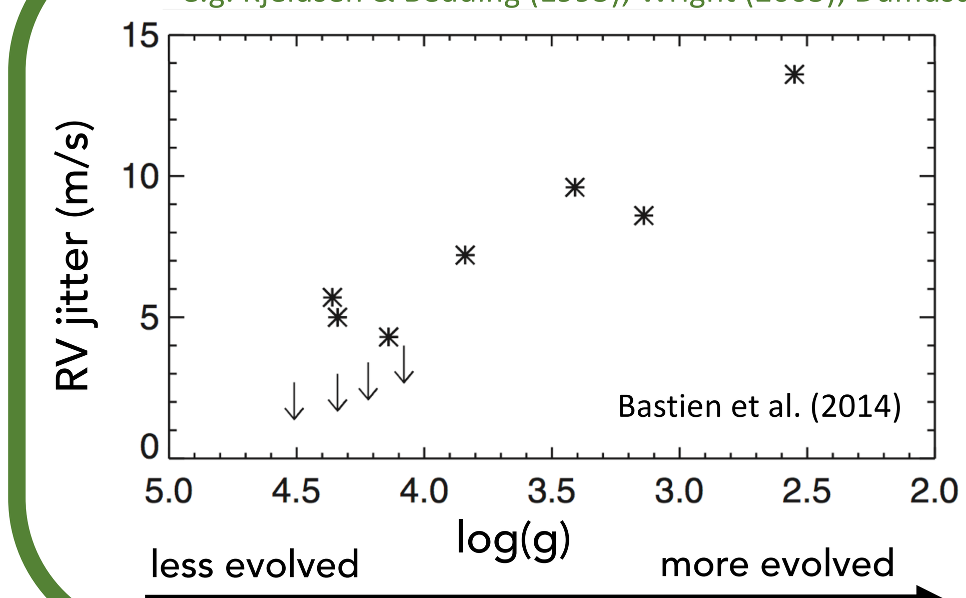


Radial velocity (RV) *jitter* – RMS scatter in precise (~m/s) radial velocity measurements – correlates with tracers of magnetic activity (Calcium H & K chromospheric emission)

Interpretation: increased activity leads to an increase in magnetic features (spots, faculae, flares) that affect the ability to accurately measure a radial velocity

RV Jitter Increases with Evolution

e.g. Kjeldsen & Bedding (1995); Wright (2005); Dumusque et al. (2011); Bastien et al. (2014)



Radial velocity jitter correlates with tracers of evolution (surface gravity) among inactive stars

Interpretation: decreased surface gravity leads to increased convective power (granulation, oscillations) that affects the ability to accurately measure a radial velocity

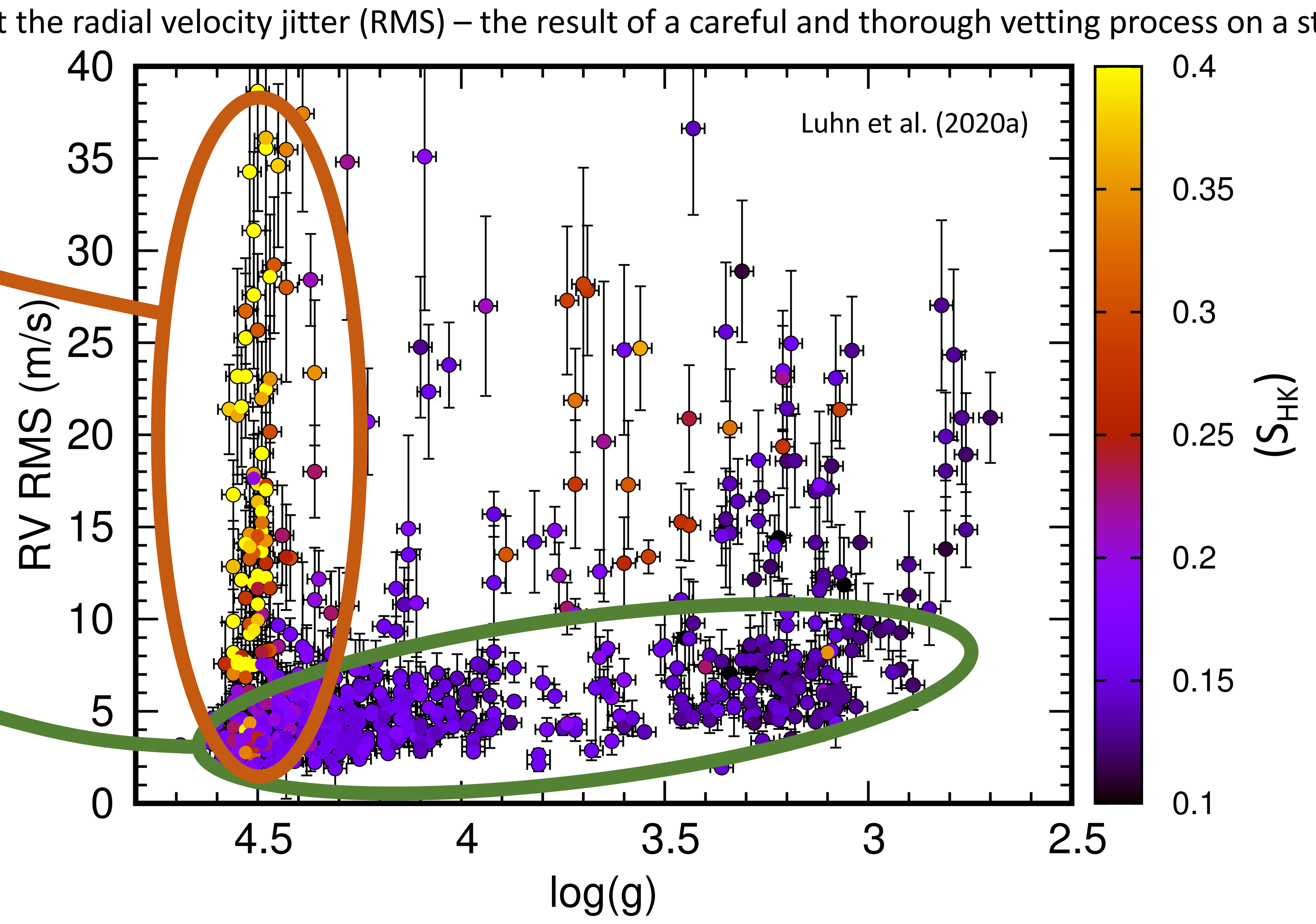
Two Regimes of RV Jitter: Activity-dominated and Convection-dominated

Luhn et al. (2020a)

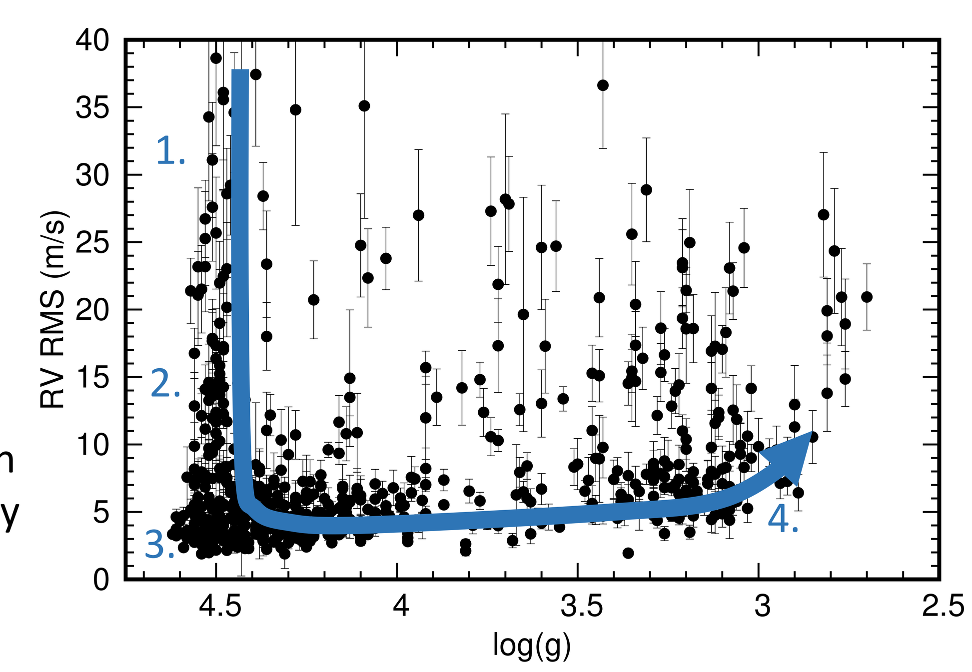
In the plots below we present the radial velocity jitter (RMS) – the result of a careful and thorough vetting process on a star by star basis – of more than 600 stars in the California Planet Search.

Activity-dominated stars are those with high surface gravities (main sequence stars) and show an increase in jitter with activity as expected (see box above left)

Convection dominated stars are seen across a range of surface gravities (including main sequence) and show increase in jitter with evolution as expected (see box above right)



Interpretation: *RV jitter tracks stellar evolution!* A given star goes through the following stages of "jitter evolution"

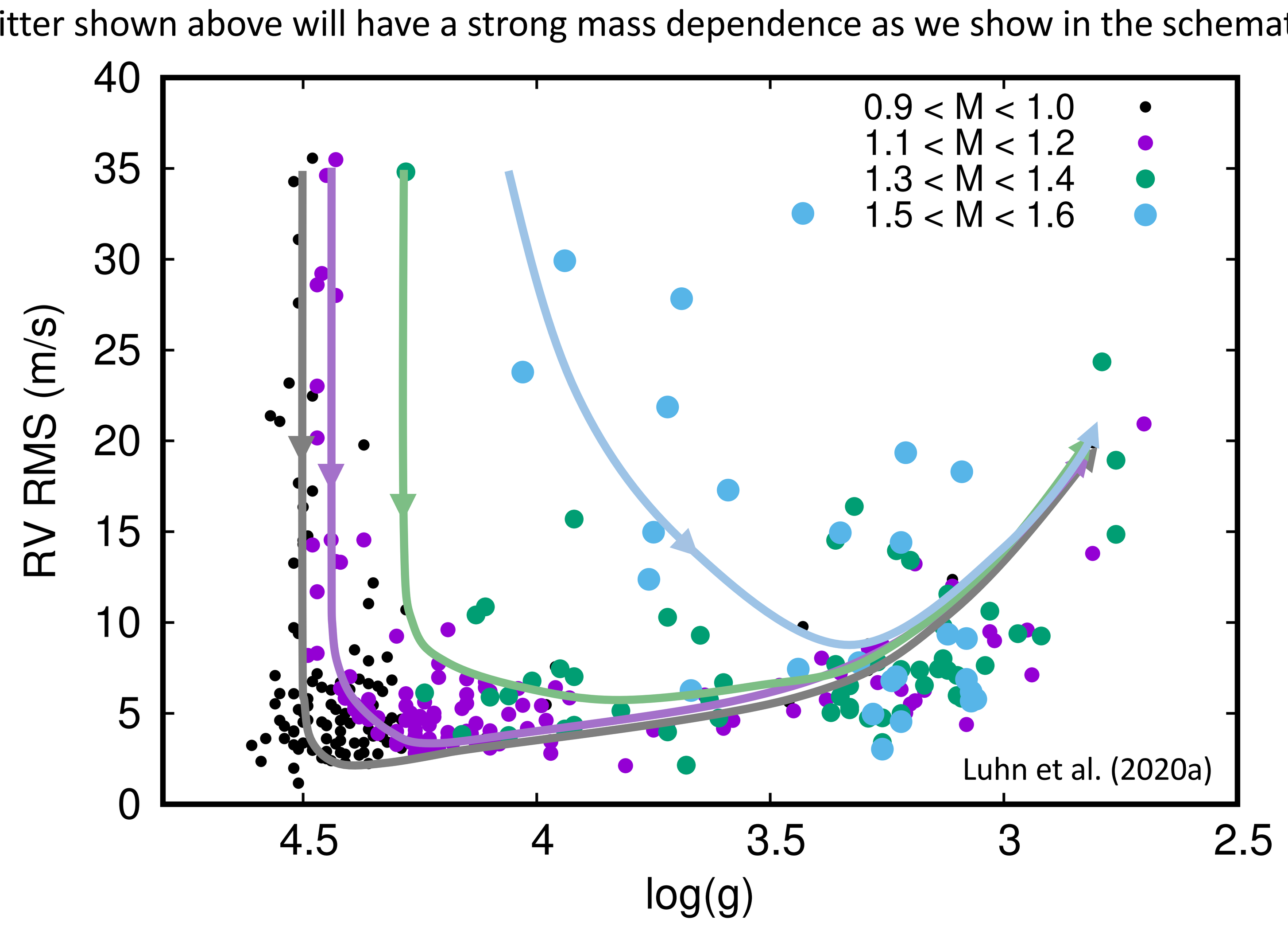


1. Star is born, rapidly rotating, very active, and with high jitter dominated by activity
2. Star gives off magnetic winds, loses angular momentum, spins down and decreases in activity and jitter
3. Falls to a "jitter minimum" as it transitions from activity-dominated to convection-dominated
4. Gradual increase in jitter from convection as it evolves into subgiant/giant phases

The Mass Dependence of RV Jitter

Luhn et al. (2020a)

Stellar evolutionary timescales are driven by mass. Thus, the picture of the evolution of stellar RV jitter shown above will have a strong mass dependence as we show in the schematic below



Low mass stars: decrease vertically in jitter with a sharp transition from activity-dominated to convection-dominated

Intermediate mass stars: trace a smoother transition from activity-dominated to convection-dominated

High mass stars: move diagonally downward to the right before reaching their jitter minimum at later evolutionary stages

Interpretation: *Higher mass stars evolve more quickly and therefore reach their jitter minimum at later stages of stellar evolution*. Additionally, the highest mass stars in this sample undergo delayed spin down since they lack convective envelopes during the main sequence.

Predicting Stellar RV Jitter

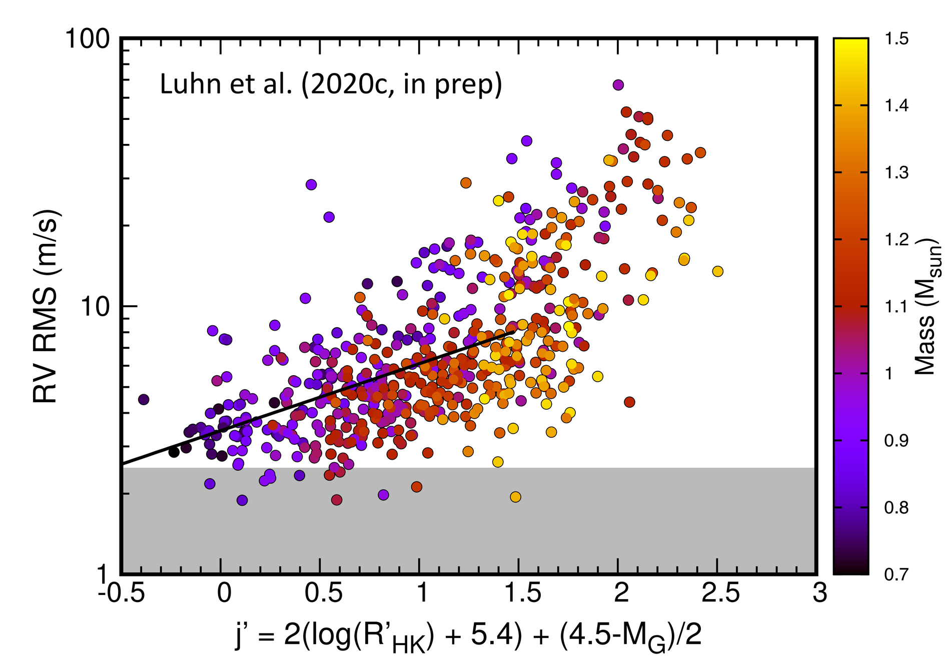
Luhn et al. (2020c, in prep.)

Using this sample, we show preliminary results of two efforts to predict stellar RV jitter:

1) A simple predictor:

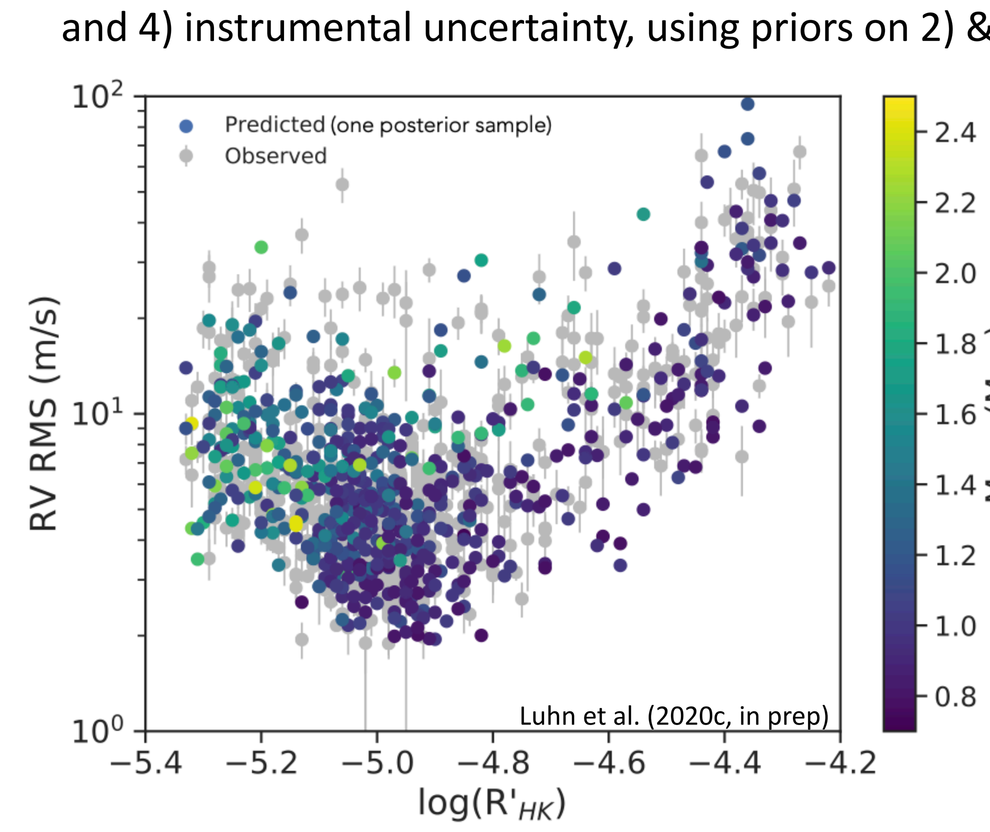
The jitter metric *j'* (used initially for *F stars* in Luhn et al. 2020b) can predict jitter for low jitter stars (*j'* < 1.5) with a median percent error of ~27%

Caveat: the Keck HIRES instrumental uncertainty (~2.5 m/s) makes predictions below this level (or translating to other instruments) difficult for this simple case

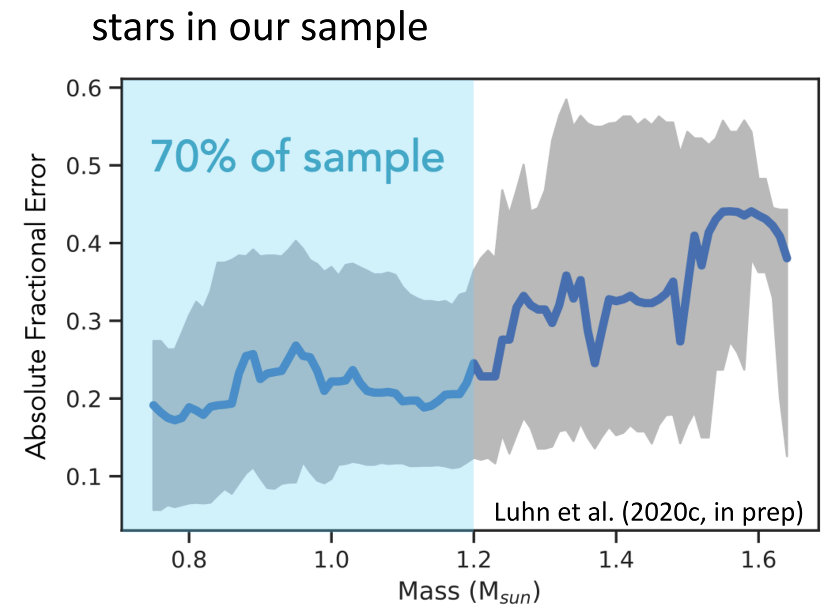


2) Hierarchical Bayesian model (HBM):

We can model RV jitter as a 4 component HBM that fits: 1) activity, 2) granulation, 3) oscillation, and 4) instrumental uncertainty, using priors on 2) & 3) based in theory (Kjeldsen & Bedding 2011)



This model predicts jitter with a median percent error of 20-25% for most of the stars in our sample



Predicting each component (including instrumental) allows for future RV observations to be tailored to each star (and instrument) based on the expected contribution of each component!

Conclusions and Implications

RV jitter tracks stellar evolution as a star transitions from activity-dominated to convection dominated due to stellar spin-down and subsequent evolution.

Higher mass stars reach their jitter minimum at later stages of stellar evolution due to longer spin-down timescales *relative to their evolution timescales*.

We can use this sample to predict both the expected *magnitude* and *dominant jitter component* of RV jitter for stars for future RV follow-up.

Further Reading

Bastien et al.,2014, AJ
Dumusque et al.,2011, A&A
Isaacson & Fischer, 2010, ApJ
Kjeldsen & Bedding, 1995, A&A
Saar et al.,1998, ApJL
Santos et al., 2000, A&A
Wright, 2005, PASP
Yu et al.,2018, MNRASL