🐦 @jacobkluhn

jluhn@psu.edu

JACOB LUHN

NSF Graduate Research Fellow
Penn State University

An Astrophysically-Motivated Predictor of Stellar RV Jitter

Jason Wright, Angie Wolfgang, Howard Isaacson, Andrew Howard

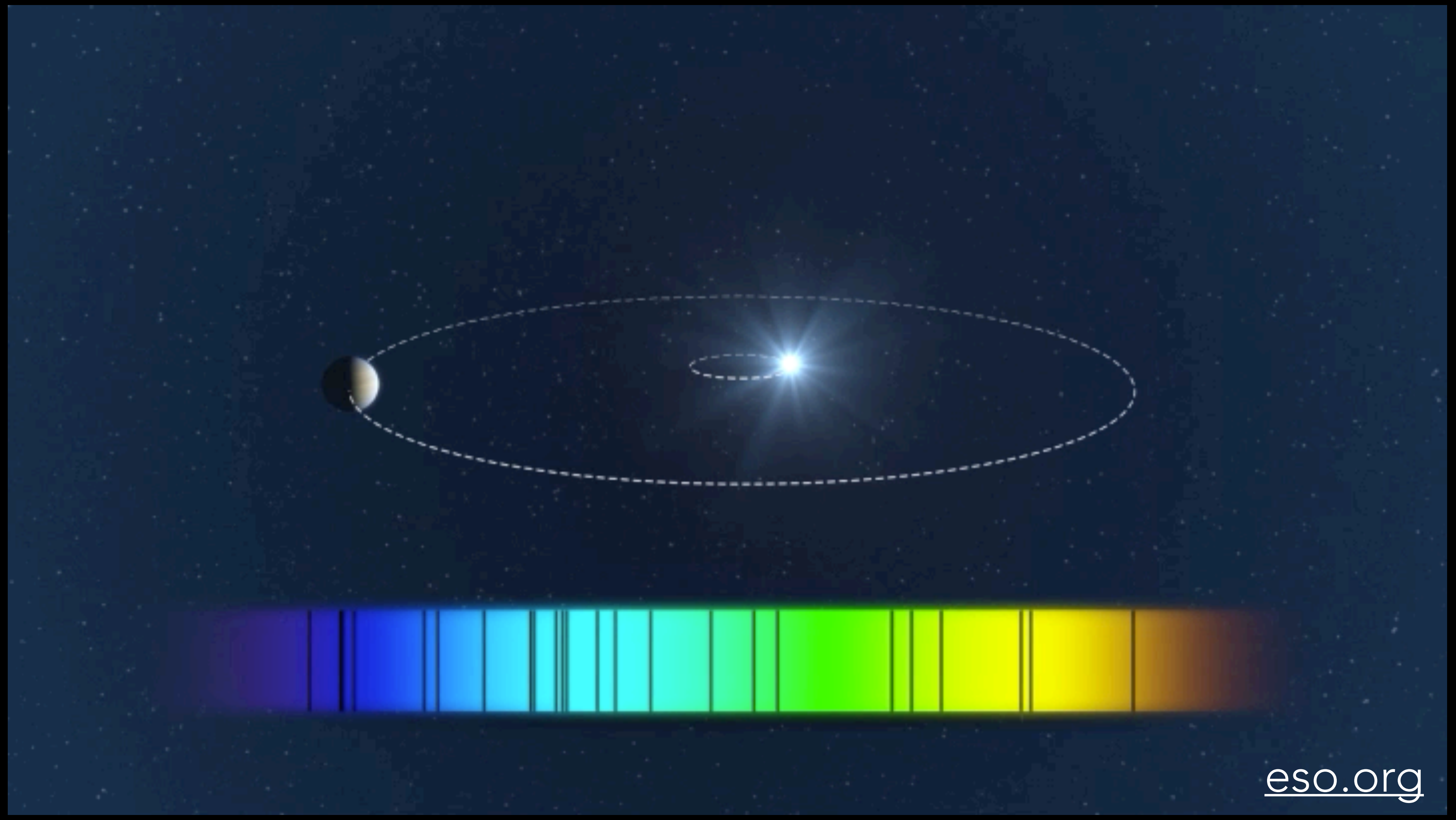
Special thanks to Fabienne Bastien

PennState

RVs IN THE TRANSIT ERA

Radial velocities are crucial for transit follow-up:

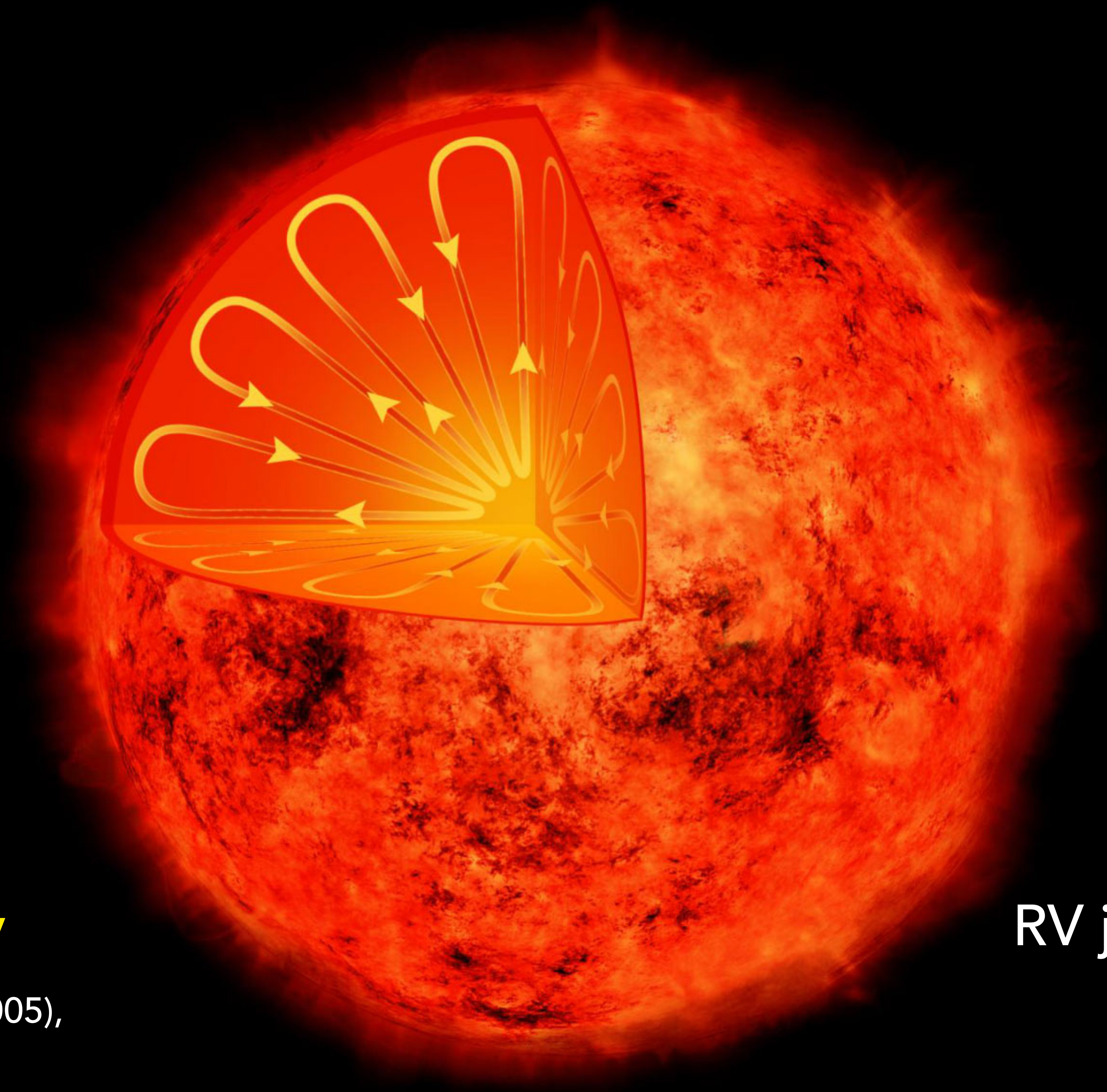
- planet confirmation/rejection
- mass (RV) + radius (transit) = planet densities


eso.org

Between survey programs and follow-up,
RV facilities can't keep up!

STELLAR RADIAL VELOCITY JITTER

In short, RV variations induced by stellar variability



Magnetically driven

star spots/faculae

flares

…

RV jitter increases with activity

Saar et al. (1998), Santos et al. (2000), Wright (2005), Isaacson & Fischer (2010)…among others

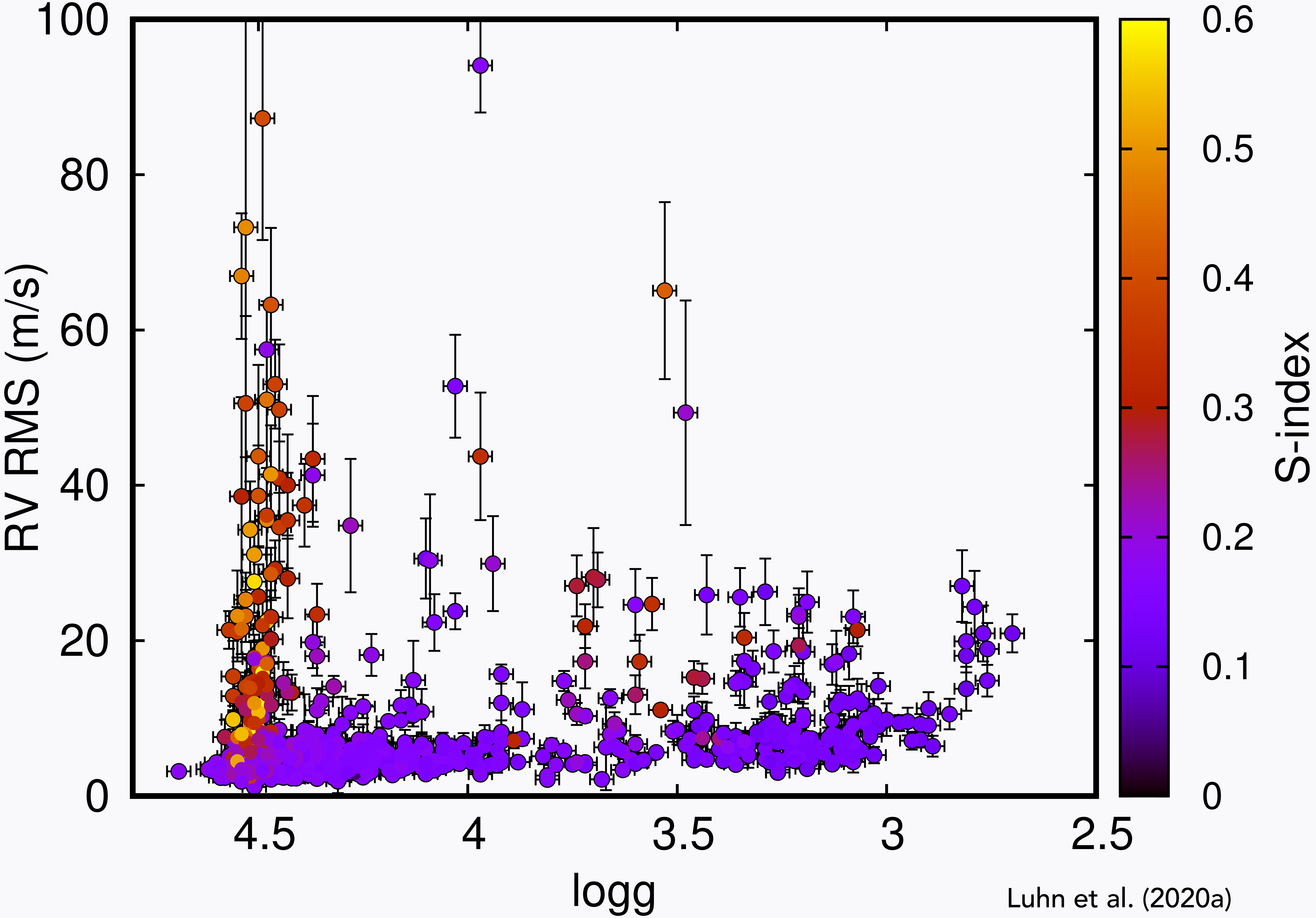
Convection driven

granulation

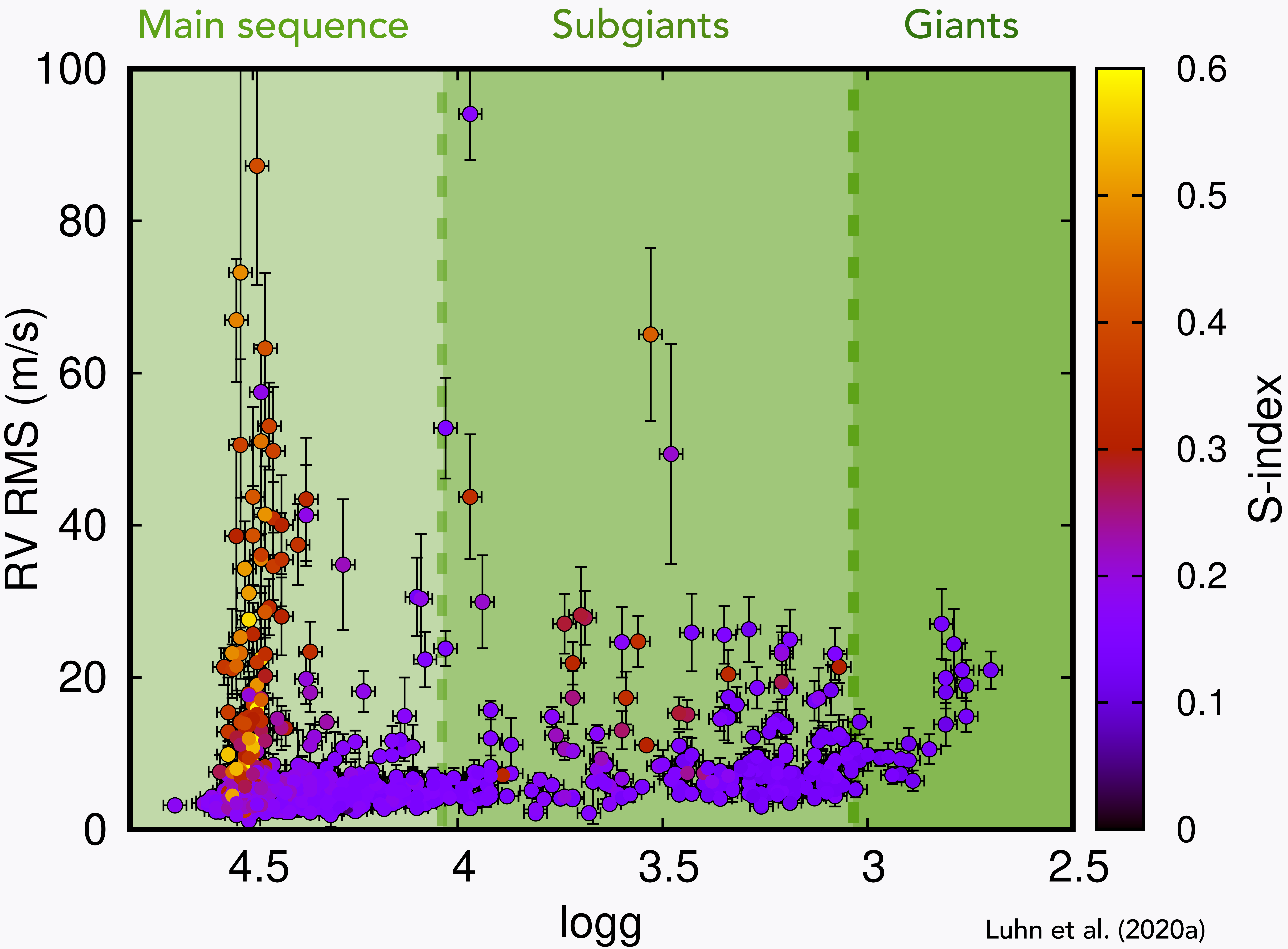
oscillations

RV jitter increases with convection

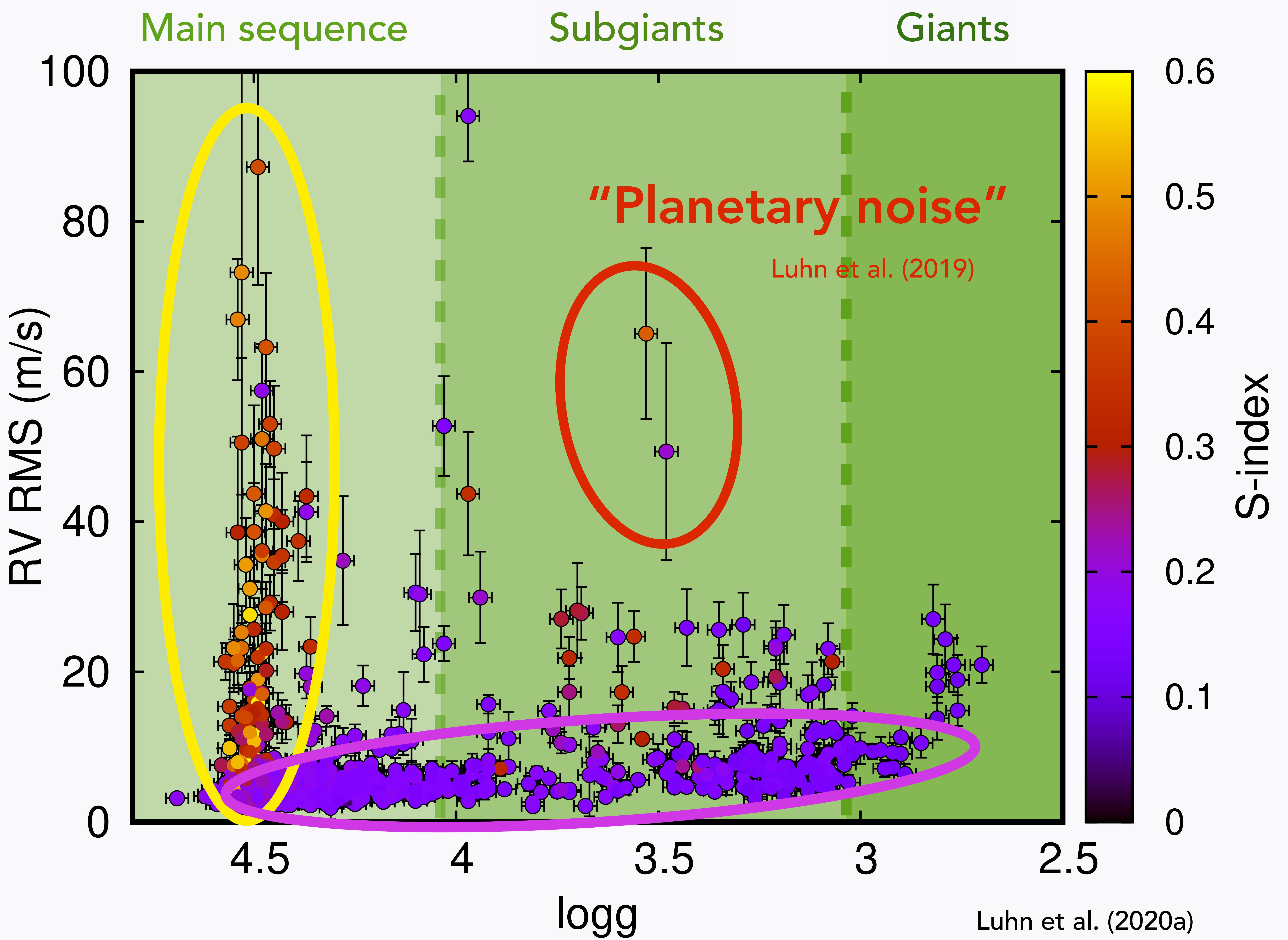
Wright et al. (2005), Dumusque et al. (2011), Bastien et al. (2014)



Luhn et al. (2020a)



Luhn et al. (2020a)



Luhn et al. (2020a)

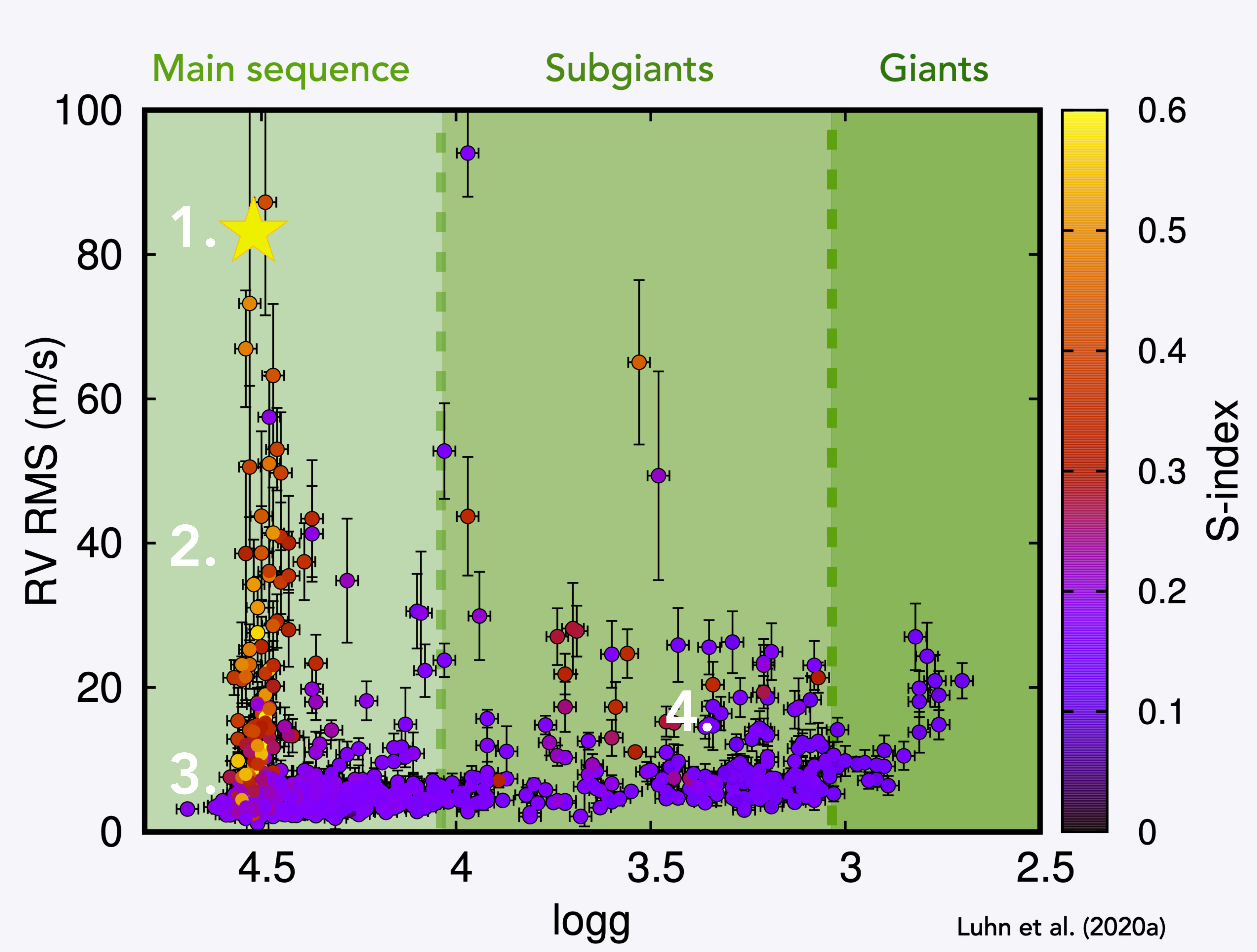
Activity-dominated

Active stars pile up
toward high logg
(~ZAMS)

Convection-dominated

Inactive stars increase
with evolution

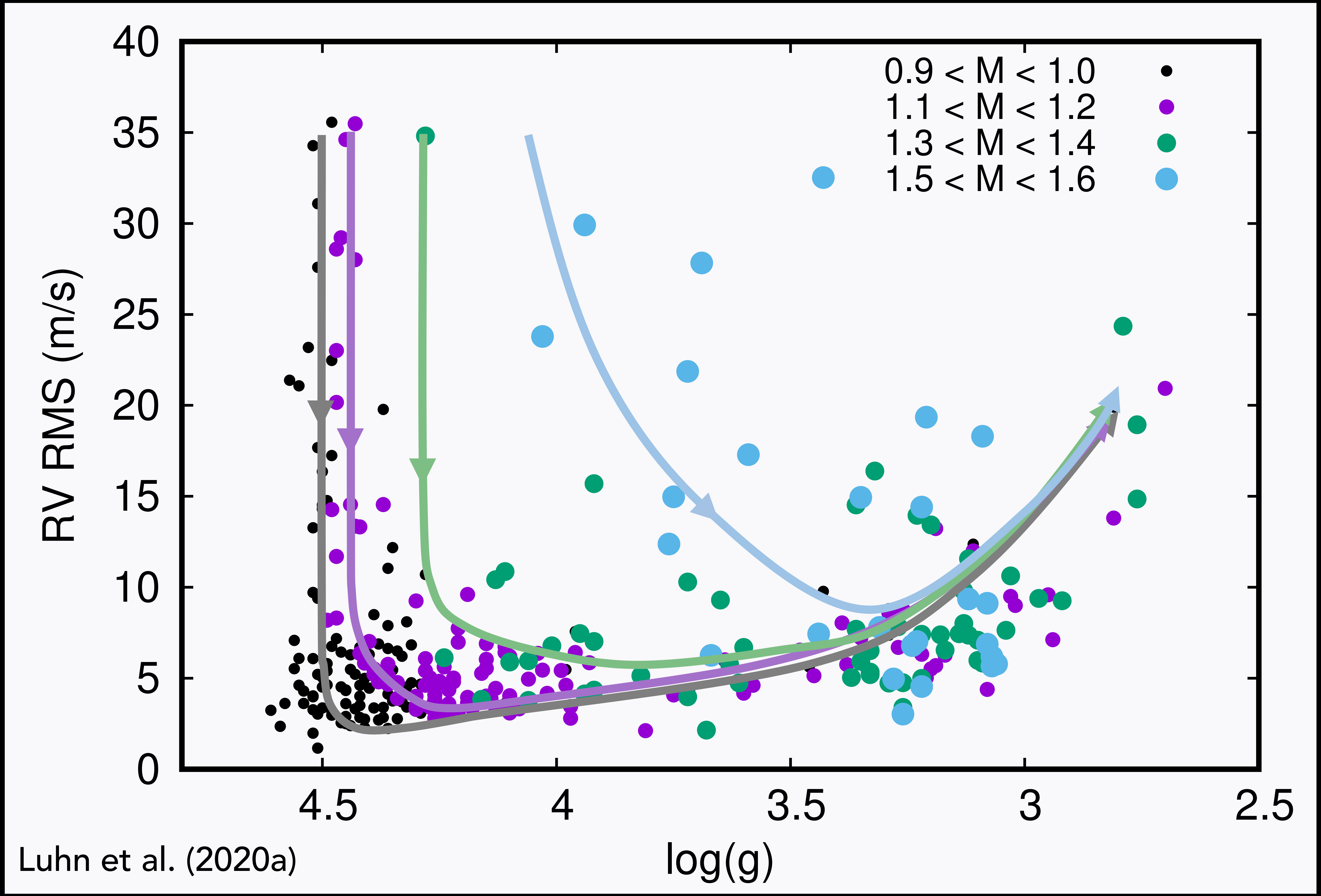
RV JITTER TRACKS STELLAR EVOLUTION



Luhn et al. (2020a)

1. Star is born, active and jittery
2. Spins down, decrease in activity/jitter
3. Falls to "jitter minimum"
4. Gradual increase from convection

JITTER MINIMUM DEPENDS ON MASS



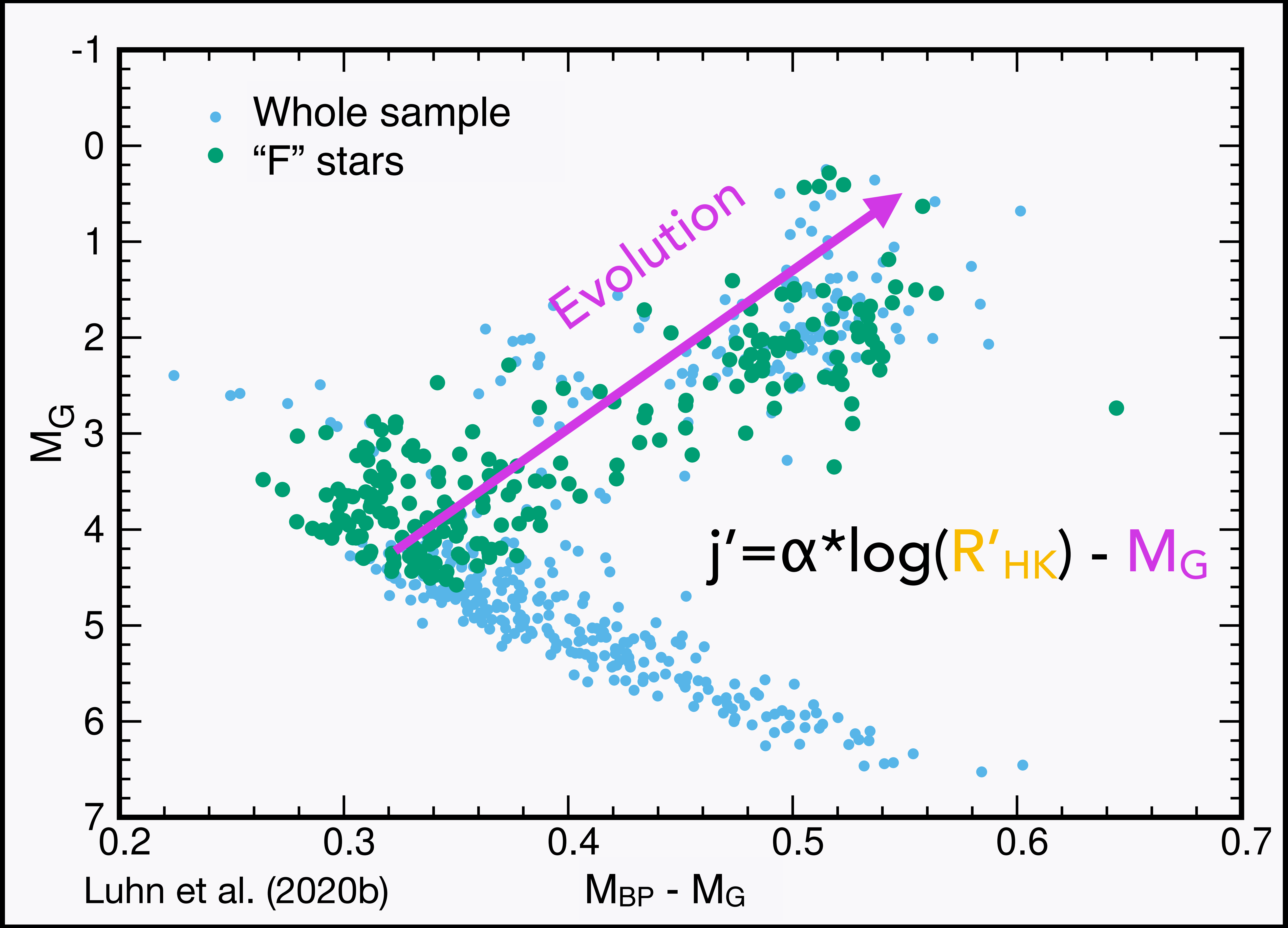
Luhn et al. (2020a)

More massive stars hit jitter minimum at later evolutionary stages

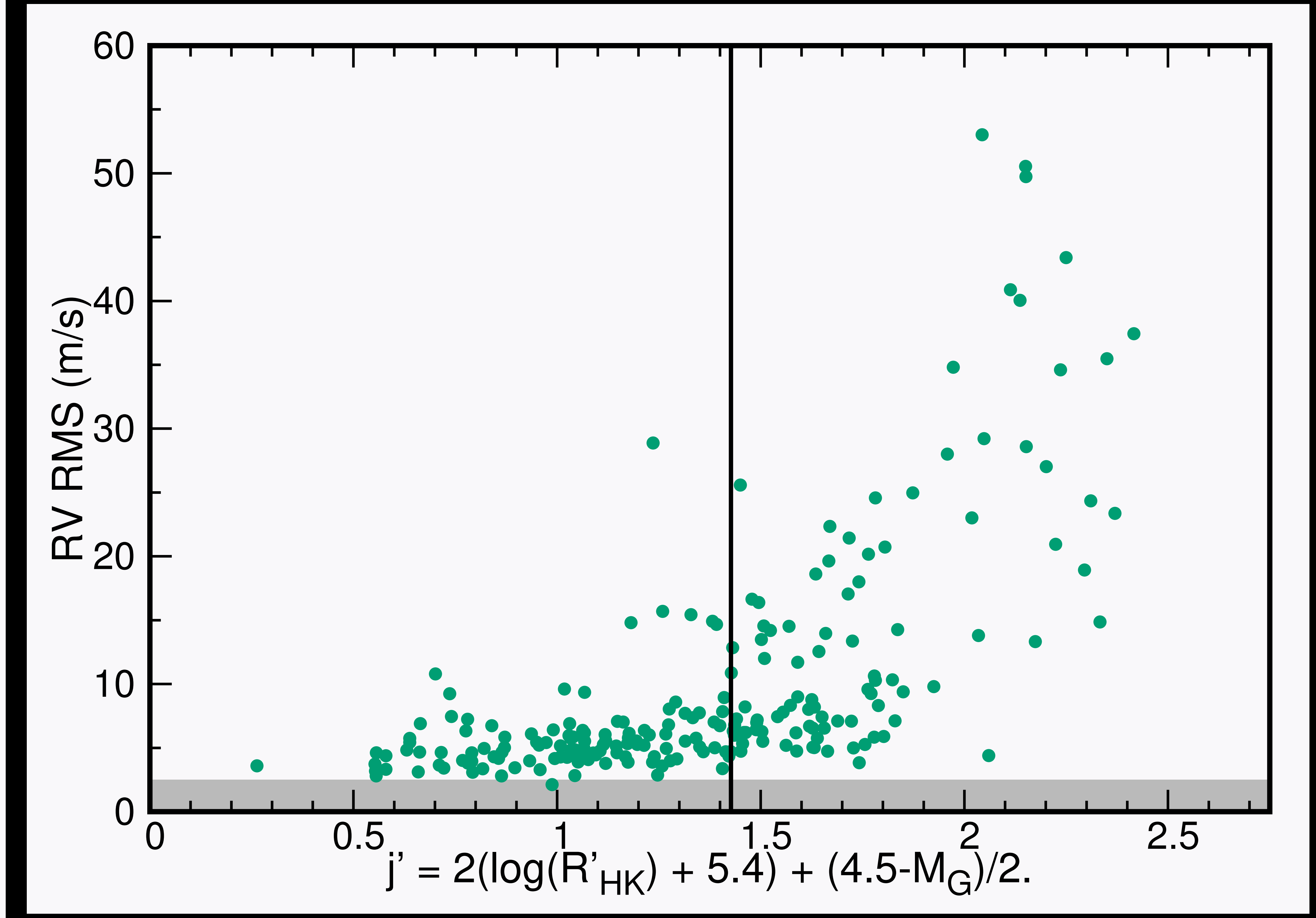
- Massive stars evolve more quickly
- Stars above the Kraft break only spin down after they gain a convective envelope in the SG phase

DISTINGUISHING LOW JITTER F STARS

Insight: high jitter stars will be either active or evolved

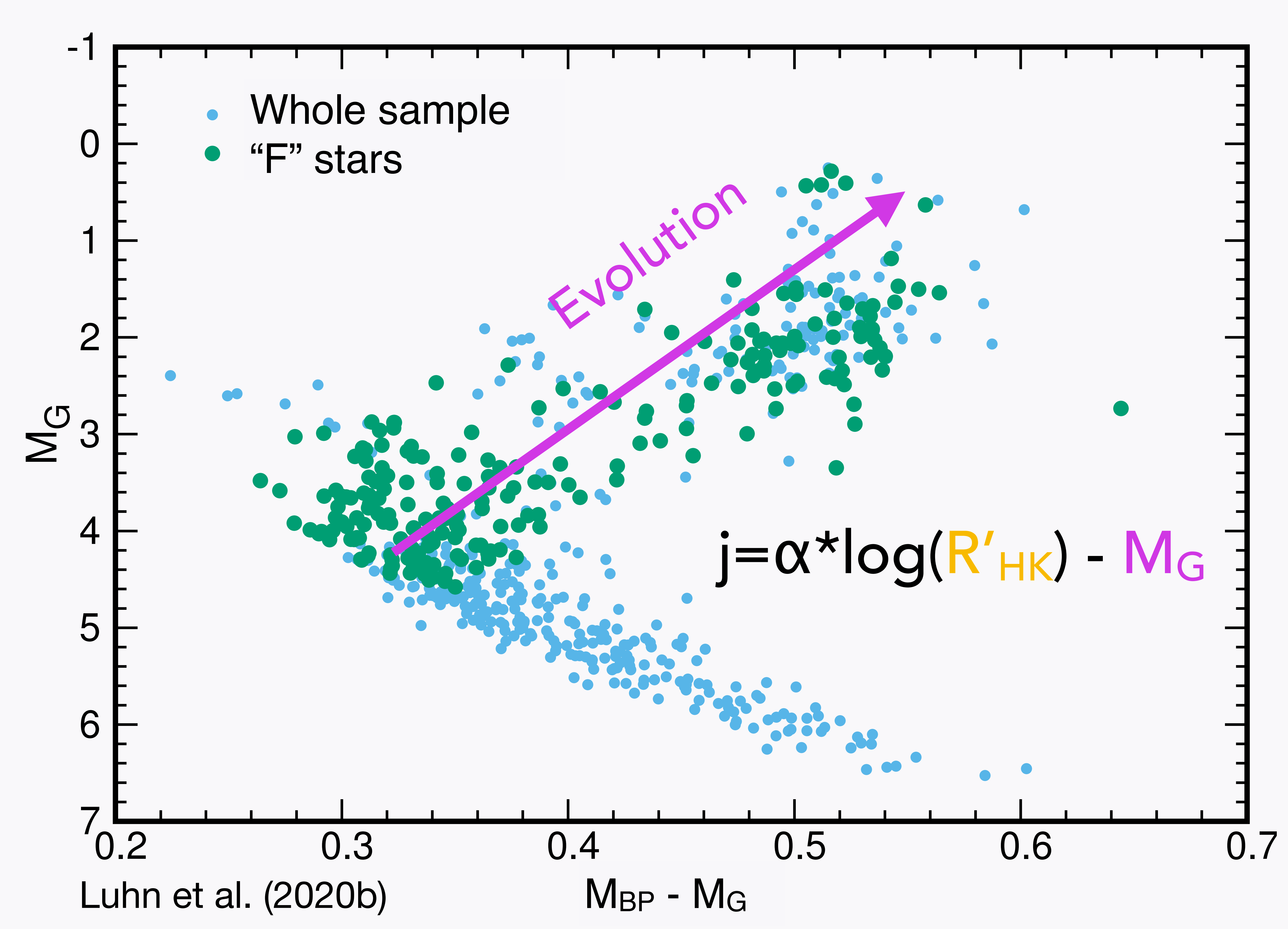


Luhn et al. (2020b)



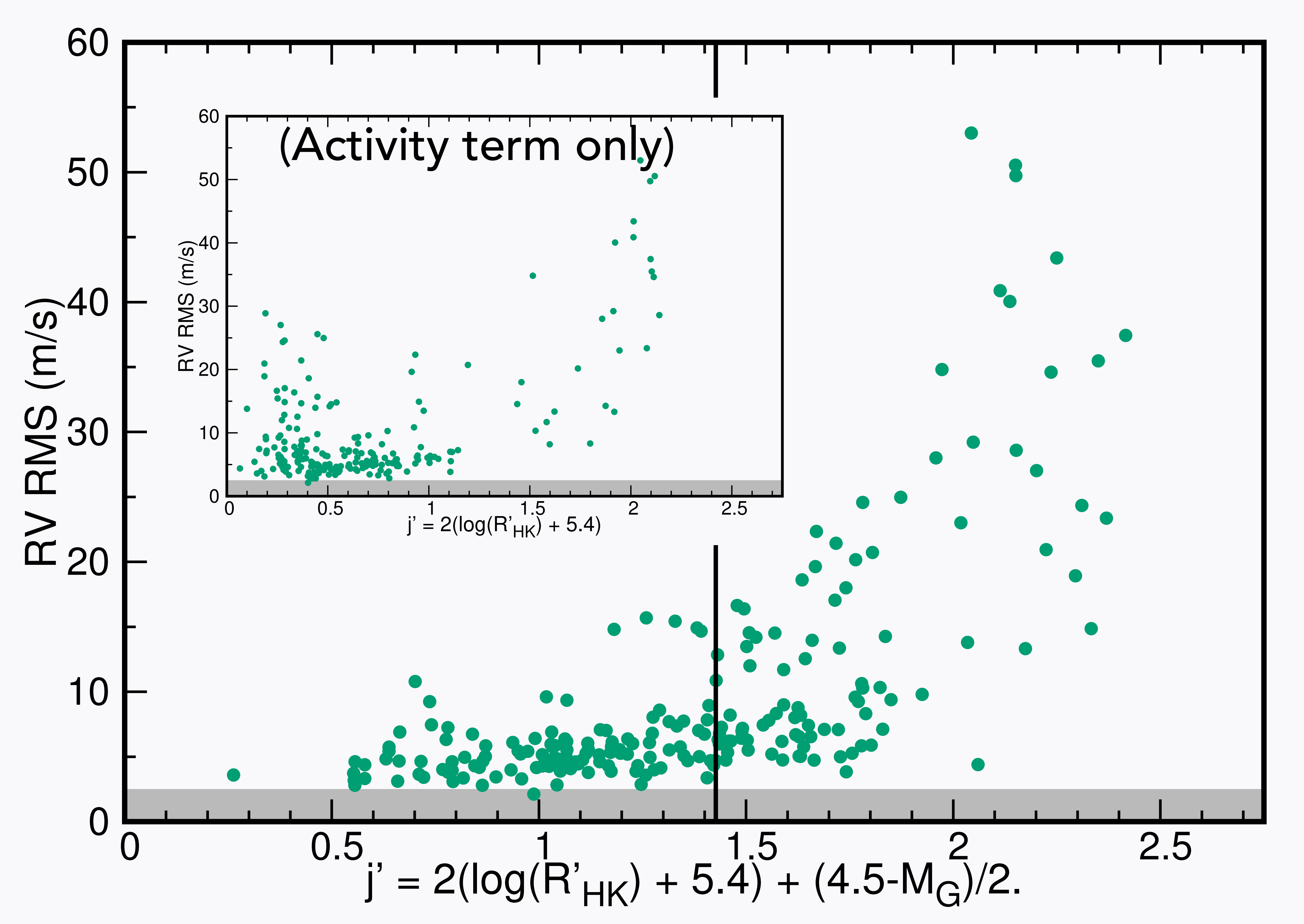
DISTINGUISHING LOW JITTER F STARS

Insight: high jitter stars will be either active or evolved



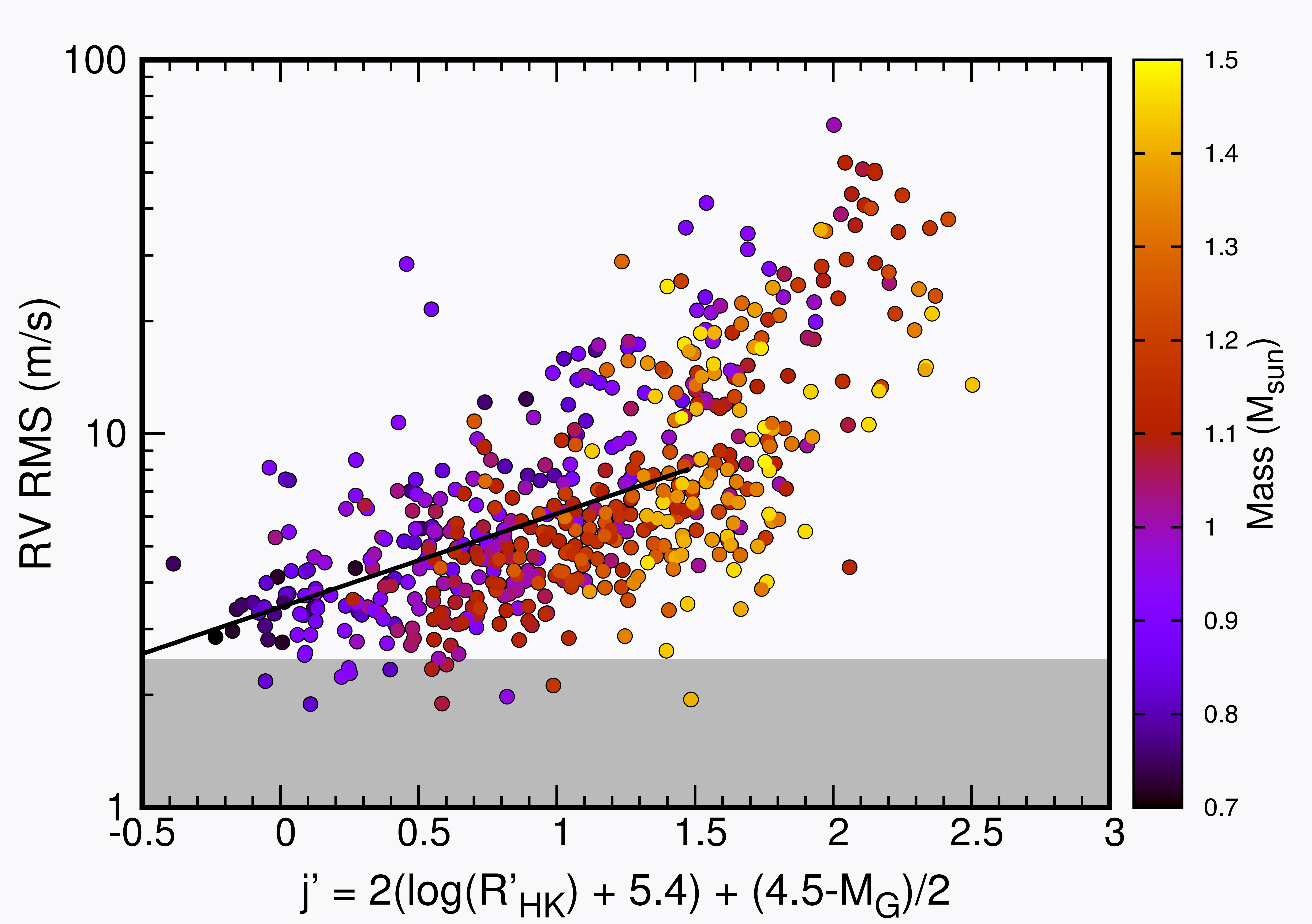
$j=\alpha*\log(R'_{HK}) - M_G$

Luhn et al. (2020b)



Made to *separate* high and low jitter F stars

A SIMPLE JITTER PREDICTOR



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

Stars with j' < 1.5

$$log(\sigma_{RV}) = a \times j' + b$$

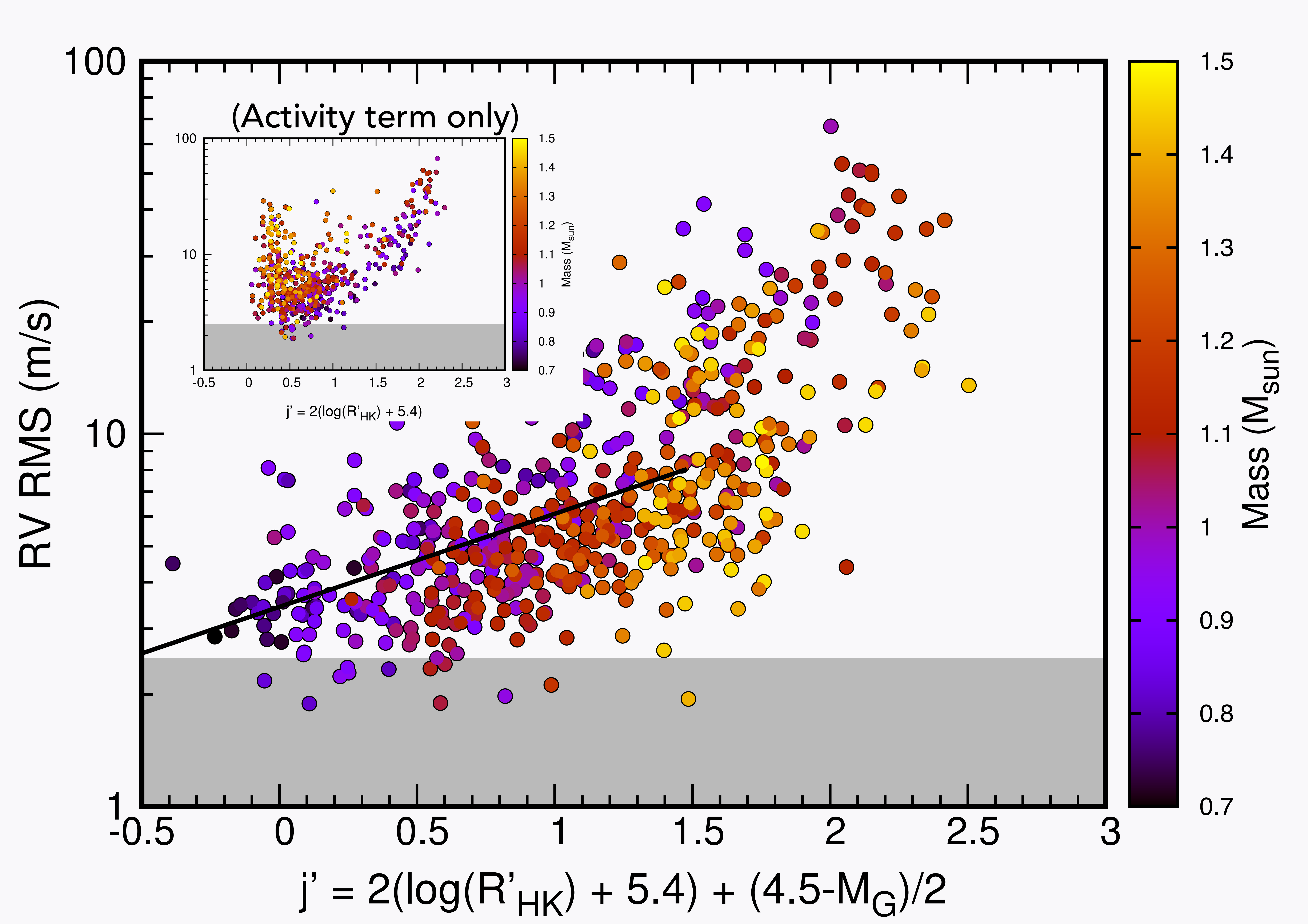
$$a = 0.24978$$

$$b = 0.53587$$

Median percent error: 27%

Wright (2005) predictor is good to a factor of ~2

A SIMPLE JITTER PREDICTOR



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

Stars with j' < 1.5

$$log(\sigma_{RV}) = a \times j' + b$$

$$a = 0.24978$$

$$b = 0.53587$$

Median percent error: 27%

Wright (2005) predictor is good to a factor of ~2

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL

$$J_i^2 = \underbrace{F_i^2}_{\text{Activity}} + \underbrace{G_i^2}_{\text{Granulation}} + \underbrace{H_i^2}_{\text{Oscillations}} + \underbrace{I^2}_{\text{Instrumental}}$$

$$\log F_i = \eta_1 \log R'_{HK,i} + \kappa_1 \log M_i + c_1$$

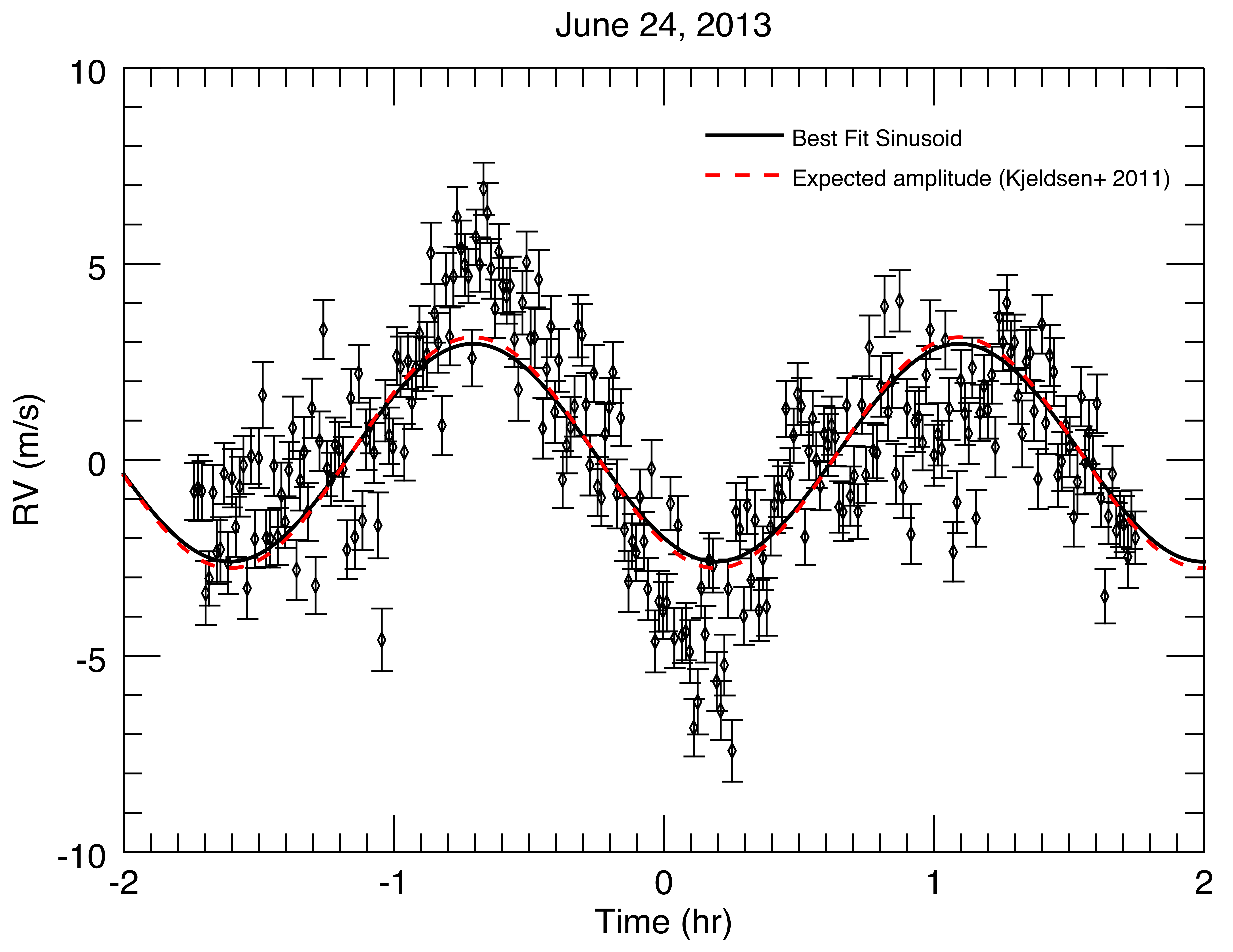
$$\log G_i = \boxed{\gamma_2} \log T_{eff,i} + \boxed{\beta_2} \log g_i + \boxed{\alpha_2} \log R_i + \boxed{c_2}$$

$$\log H_i = \boxed{\gamma_3} \log T_{eff,i} + \boxed{\beta_3} \log g_i + \boxed{\alpha_3} \log R_i + \boxed{c_3}$$

Priors on hyperparameters for G and H come from scaling relations in Luhn et al. (2020a), based on Kjeldsen & Bedding (2011)

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

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL



June 24, 2013

Resolved oscillations match predicted amplitude of Kjeldsen & Bedding (2011)

Priors on hyperparameters for G and H come from scaling relations in Luhn et al. (2020a), based on Kjeldsen & Bedding (2011)

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL

$$J_i^2 = \underset{\text{Activity}}{F_i^2} + \underset{\text{Granulation}}{G_i^2} + \underset{\text{Oscillations}}{H_i^2} + \underset{\text{Instrumental}}{I^2}$$

$$\log F_i = \eta_1 \log R'_{HK,i} + \kappa_1 \log M_i + c_1$$

$$\log G_i = \gamma_2 \log T_{eff,i} + \beta_2 \log g_i + \alpha_2 \log R_i + c_2$$

$$\log H_i = \gamma_3 \log T_{eff,i} + \beta_3 \log g_i + \alpha_3 \log R_i + c_3$$

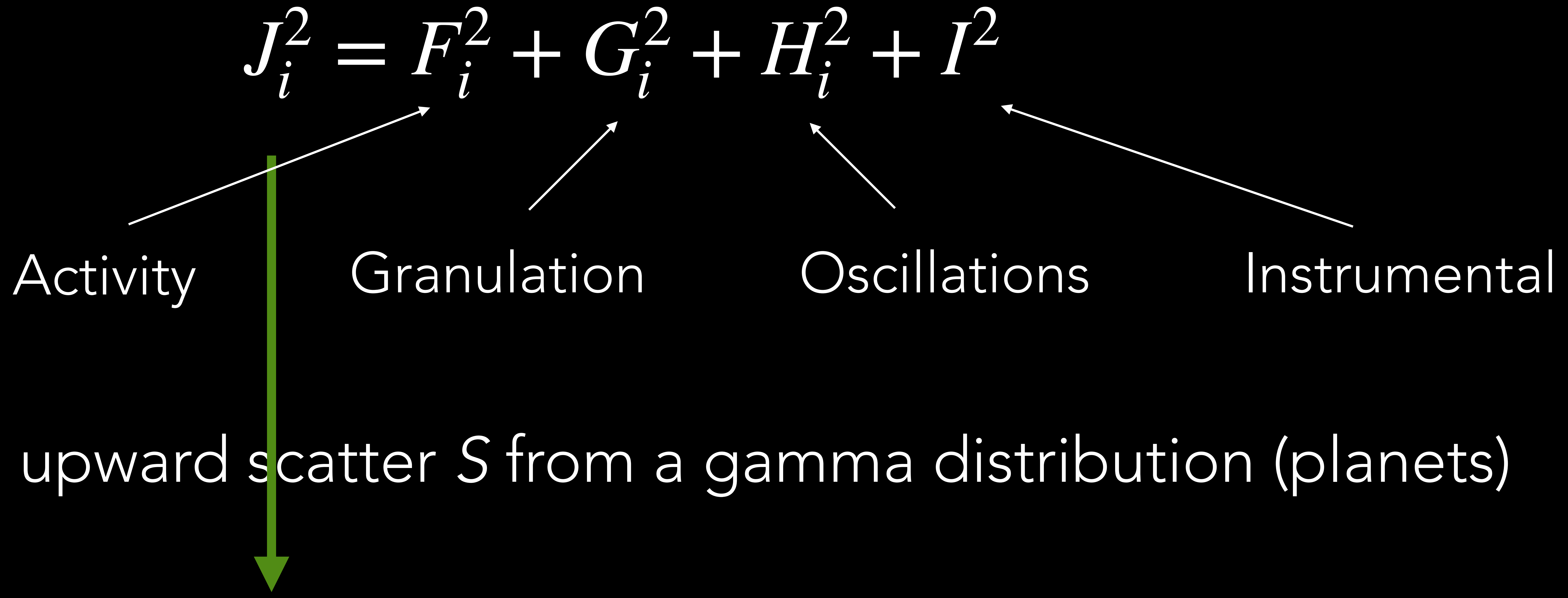
Priors on hyperparameters for G and H come from scaling relations in Luhn et al. (2020a), based on Kjeldsen & Bedding (2011)

With this model we can easily incorporate the stellar uncertainties into the fit

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

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL

Fitting the Jitter *Floor*



$$J_i^2 = F_i^2 + G_i^2 + H_i^2 + I^2$$

Activity

Granulation

Oscillations

Instrumental

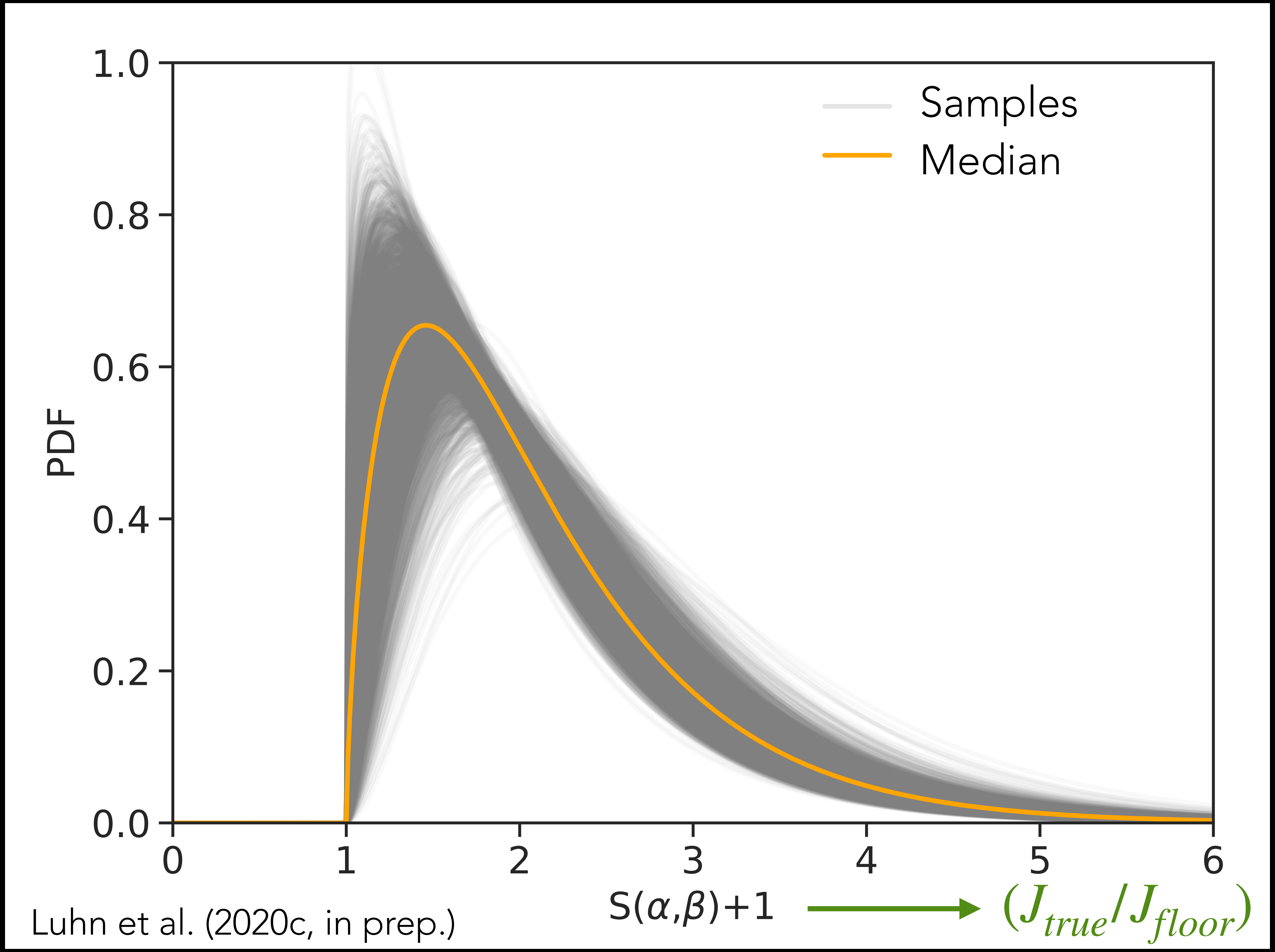
Introduce upward scatter *S* from a gamma distribution (planets)

$$J_{true,i} = J_{floor,i} \times (S_i + 1) \qquad S_i \sim \Gamma(\alpha, \beta)$$

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

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL

Fitting the Jitter *Floor*



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

$$J_{true,i} = J_{floor,i} \times (S_i + 1)$$

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL

Fitting Results

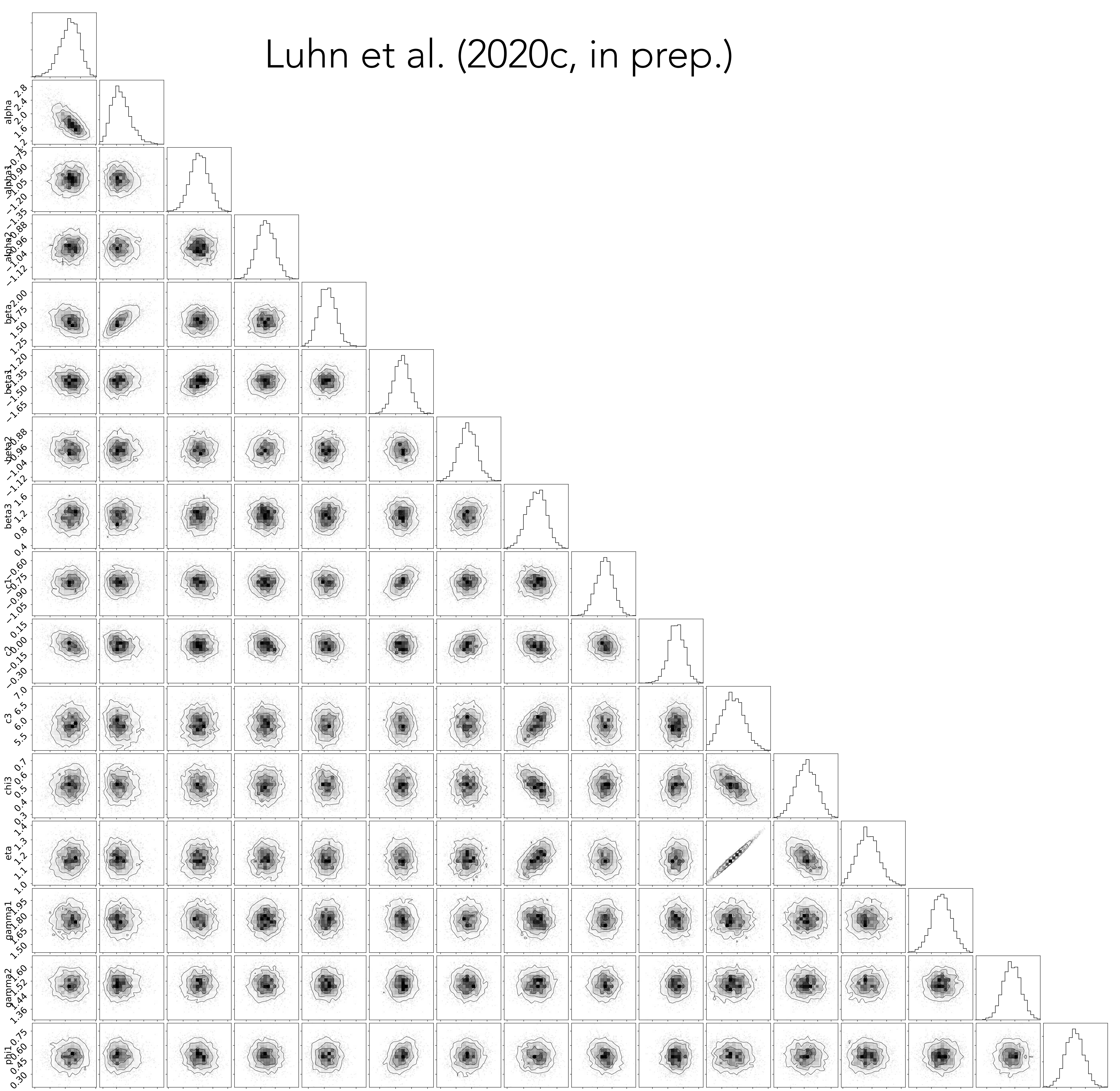
Luhn et al. (2020c, in prep.)

Data

Fit

This is our ability to *fit* with this model… we want to *predict*

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL



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

Sample from the best fit posterior using the input stellar parameters to *predict* RV jitter

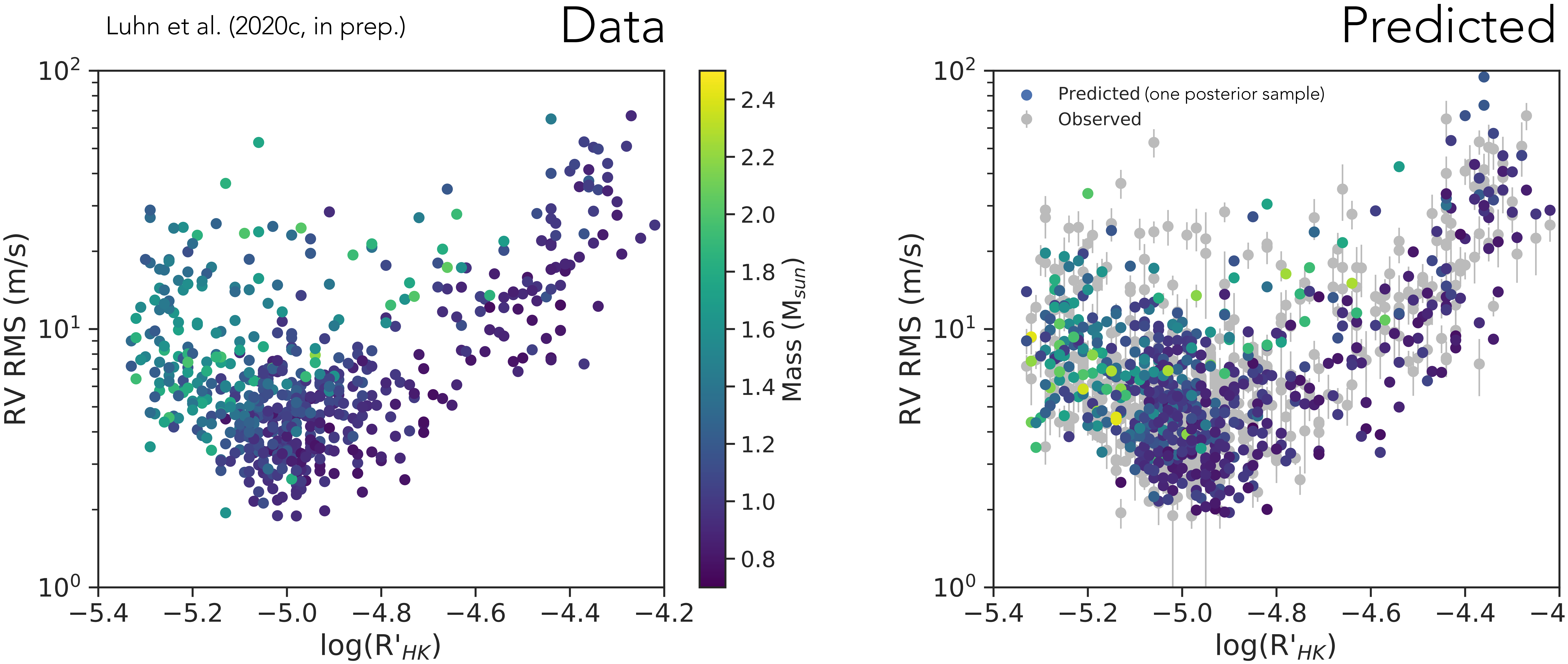
This gives a *probabilistic RV jitter with uncertainty coming from:*

- *hyperparameter uncertainties*
- *stellar uncertainties*
- *scatter above the floor*

JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL

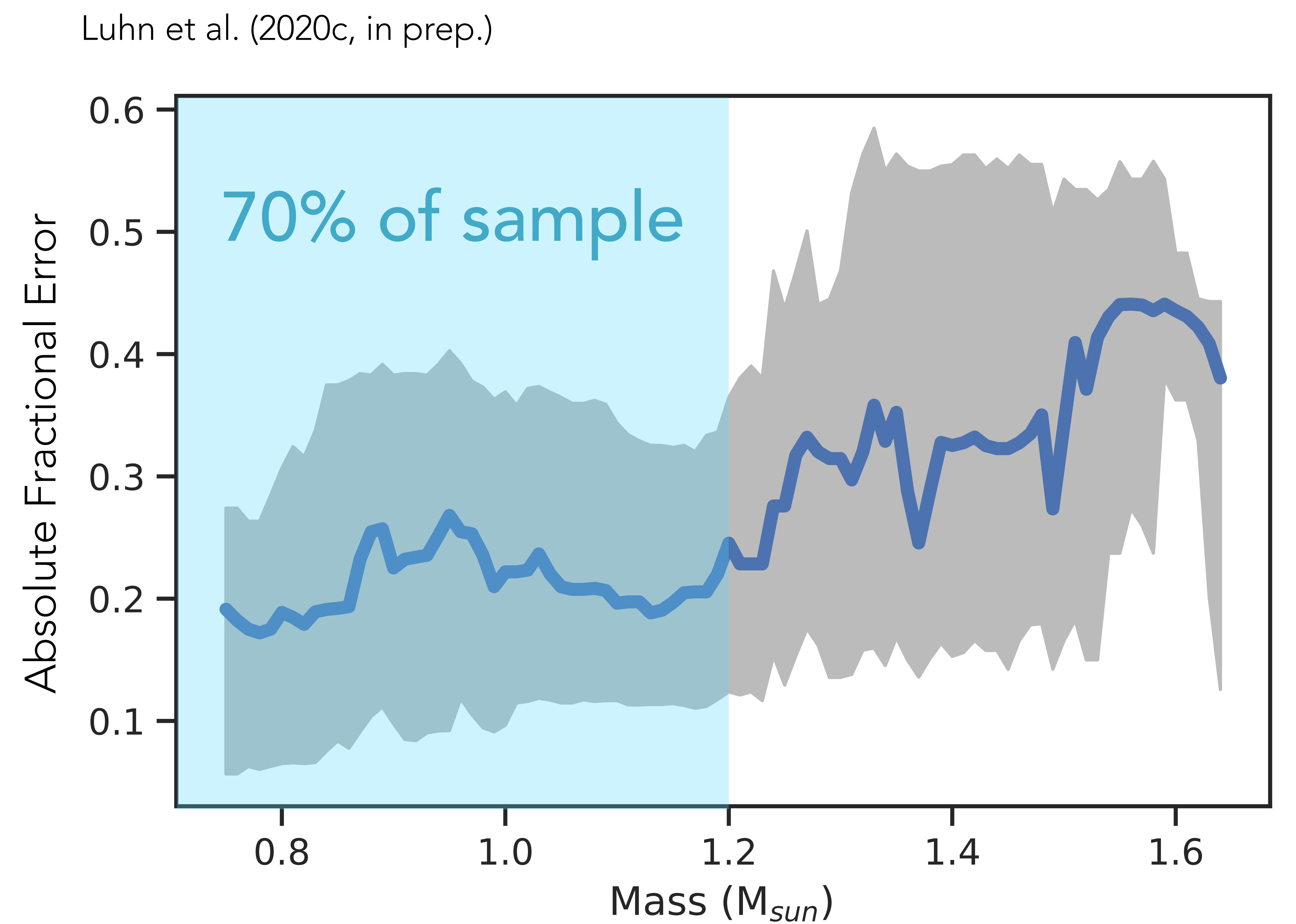
Predicting Results

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



JITTER PREDICTOR: HIERARCHICAL BAYESIAN MODEL

Predicting Results



Can predict jitter to 20-25% error for most stars!

Models all stars in sample!

Models individual components of RV jitter!

JITTTER IS THE TOOL TO ESTIMATE RV

JITTTER IS THE TOOL TO ESTIMATE RV

A public Python package to allow users to predict RV jitter …coming soon

- Returns individual components of RV jitter for the astrophysical floor
- Allows for user-input stellar parameter PDFs
- Modeling instrumental uncertainty allows translating to other instruments

Jacob Luhn jluhn@psu.edu @jacobkluhn

CONCLUSIONS

RV jitter evolves from activity- to convection-dominated

More massive stars reach their "jitter minimum" at later evolutionary stages

Low jitter (< ~5m/s) F stars exist and can be distinguished

The F star "jitter metric" works for other stellar types!

We are building a tool to predict jitter for a wide range of stars!

By modeling individual components of RV jitter we can inform:

- target selection & prioritization
- observation strategies (mitigating individual components)

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