A Data-Driven Model for Measuring Low *v*sin*i*:

Building Towards Obliquities En Masse

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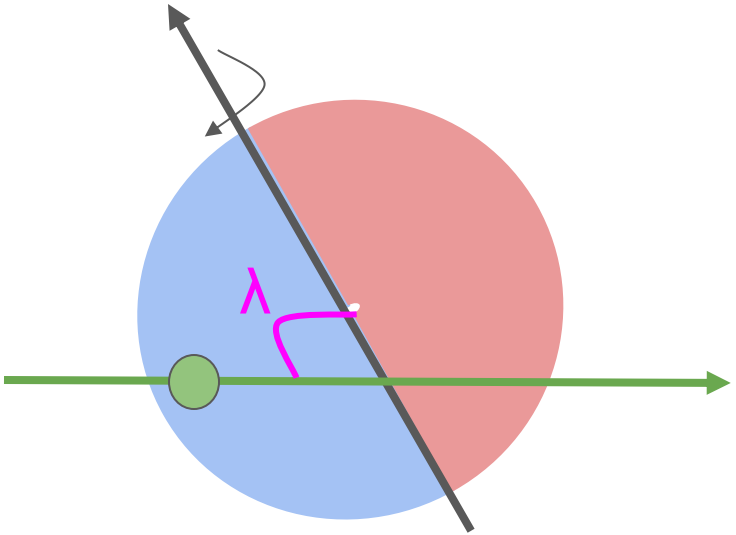
Primary Science Motivation: Obliquities En Masse

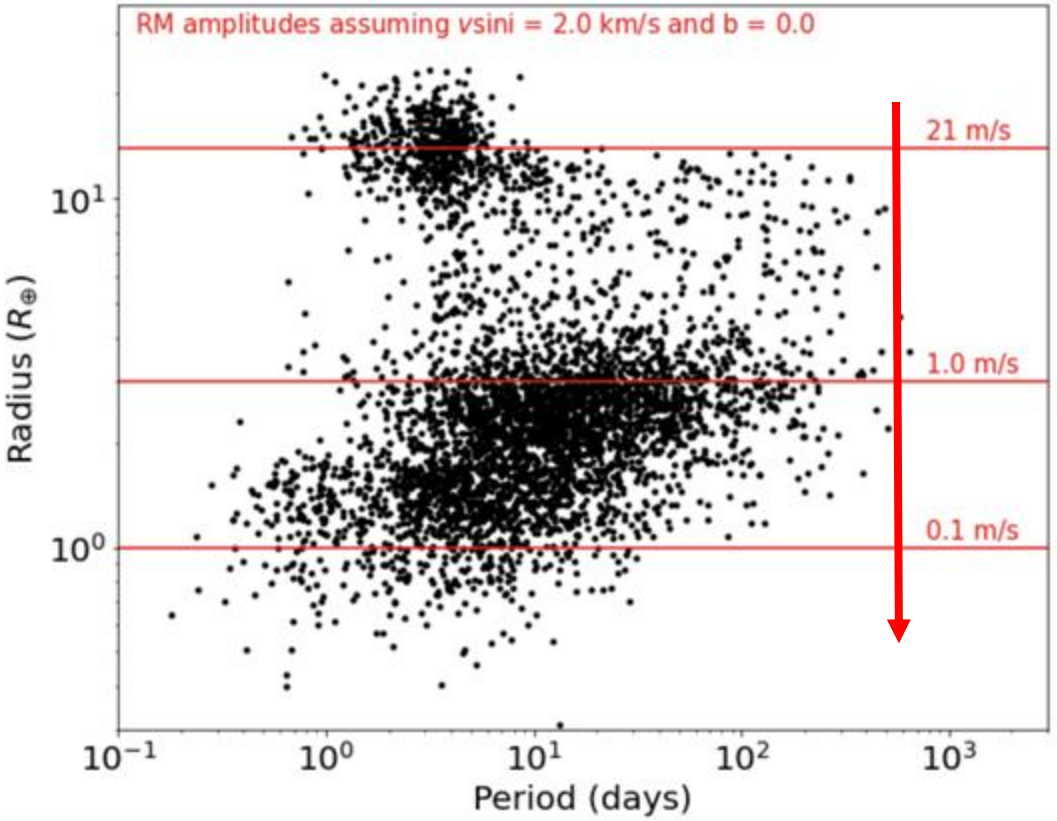
Rossiter-Mclaughlin Effect

Sky-Projected Obliquity

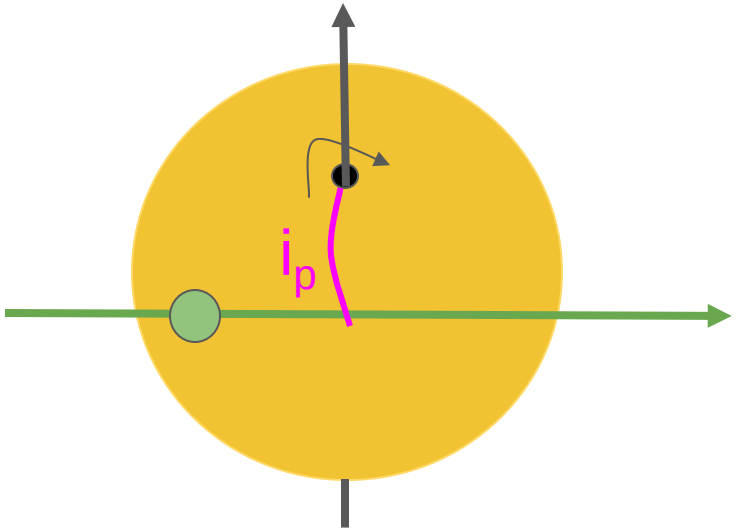


Seek to Probe Small Planet Obliquities

Most small planet sky-projected obliquities via the RM effect are still out of reach



Alternative Method

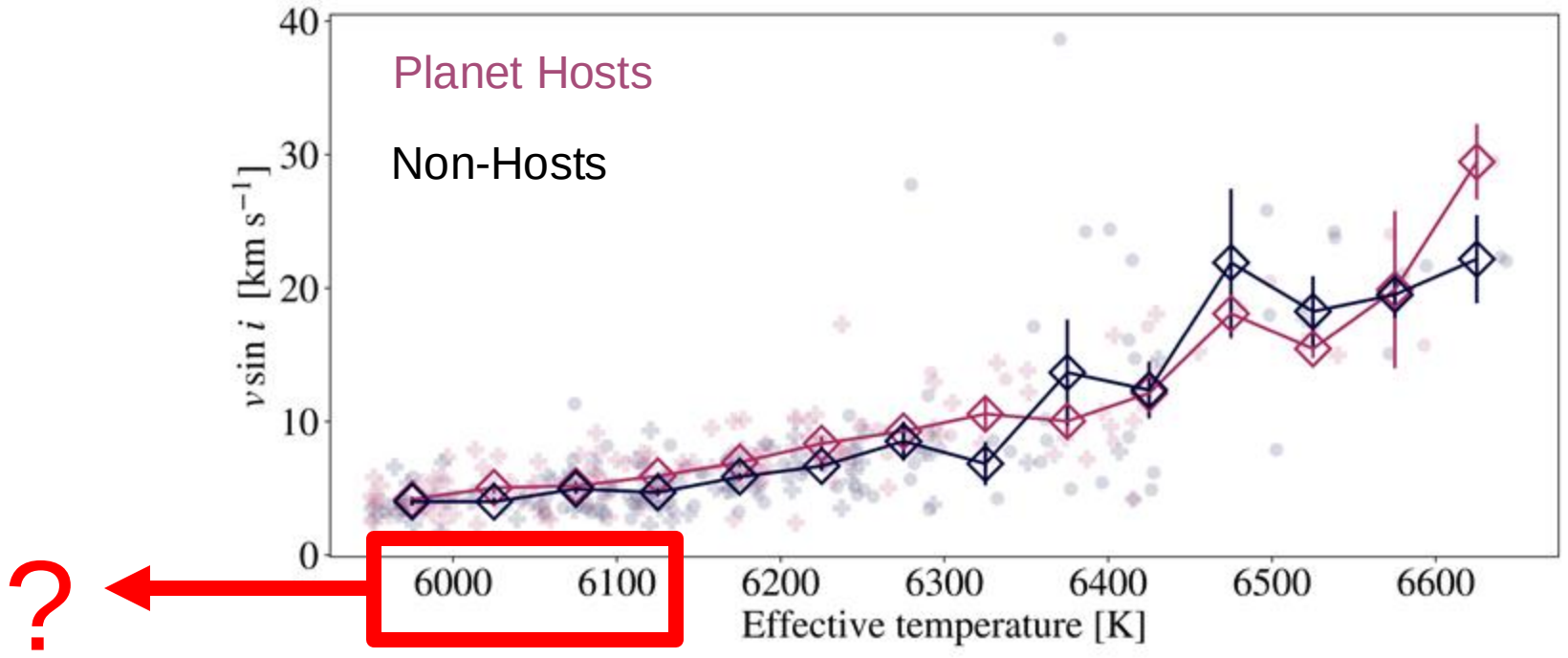


Inclination Comparison*

Sky-Plane Obliquity

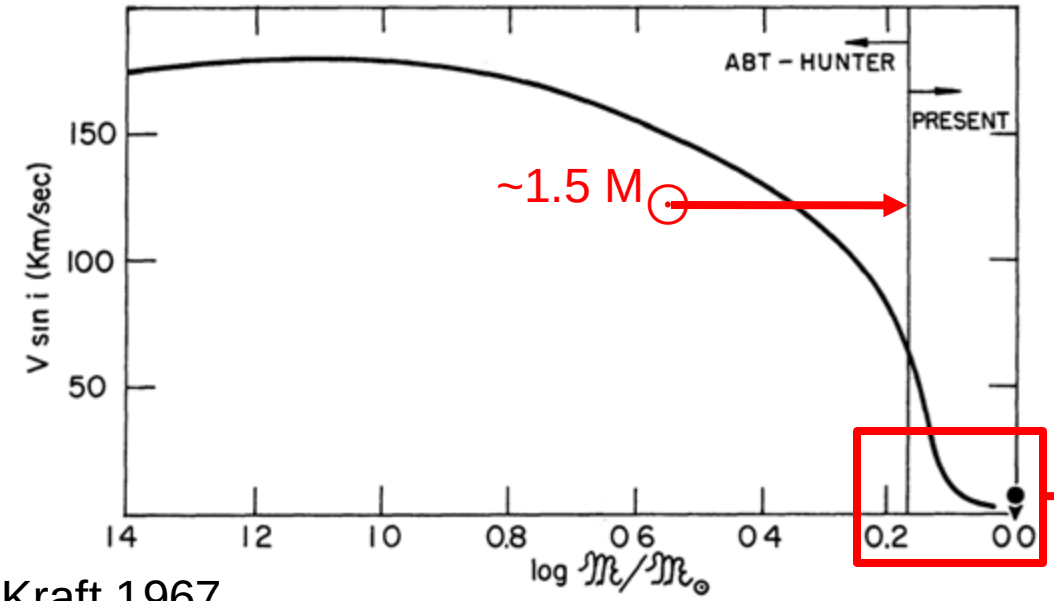
*Need rotion period and *v*sin*i* value

Extend Tendency for Alignment?

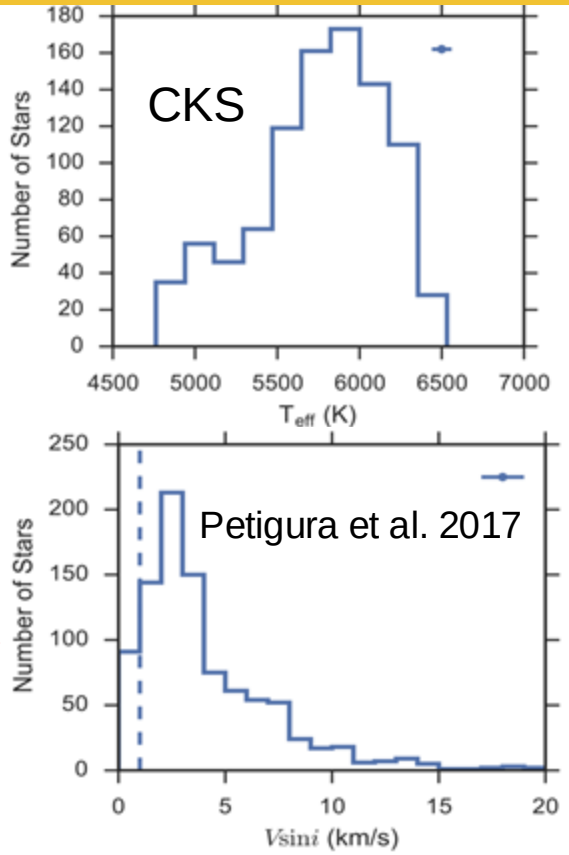


Seek to extend Louden et al. 2024's study down to cool hosts

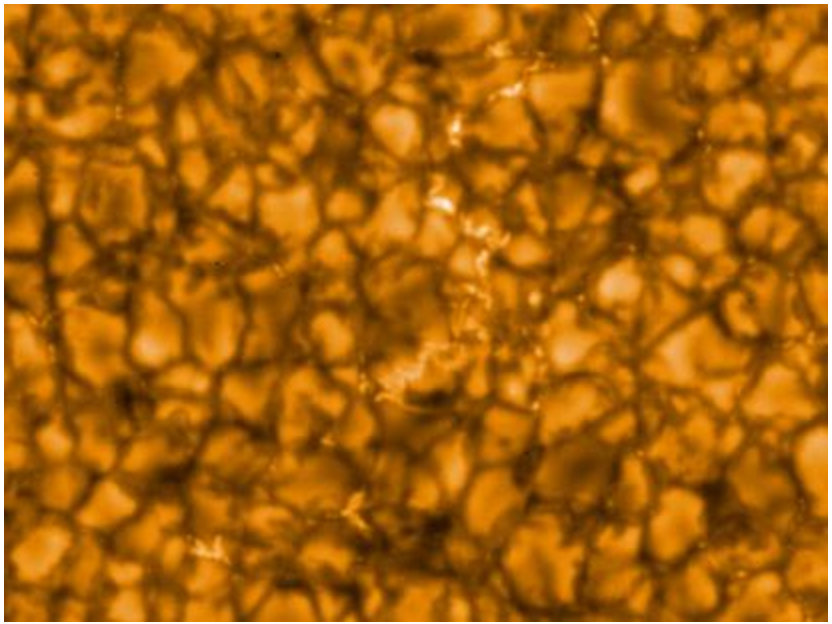
Sun-like stars are generally slow rotators



Kraft 1967



Macroturbulence Also Broadens Lines



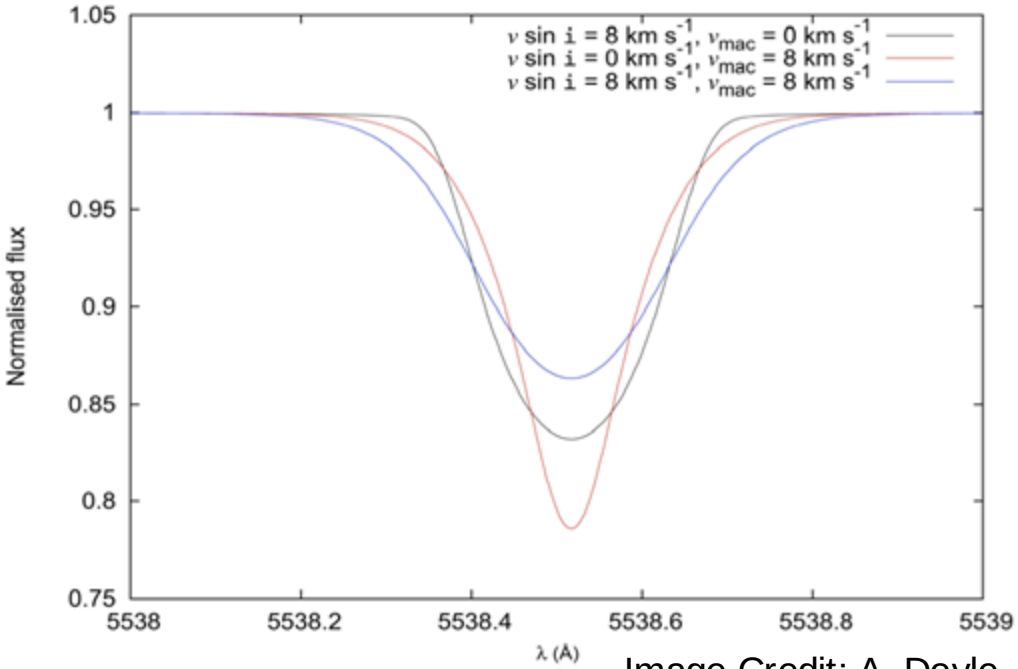
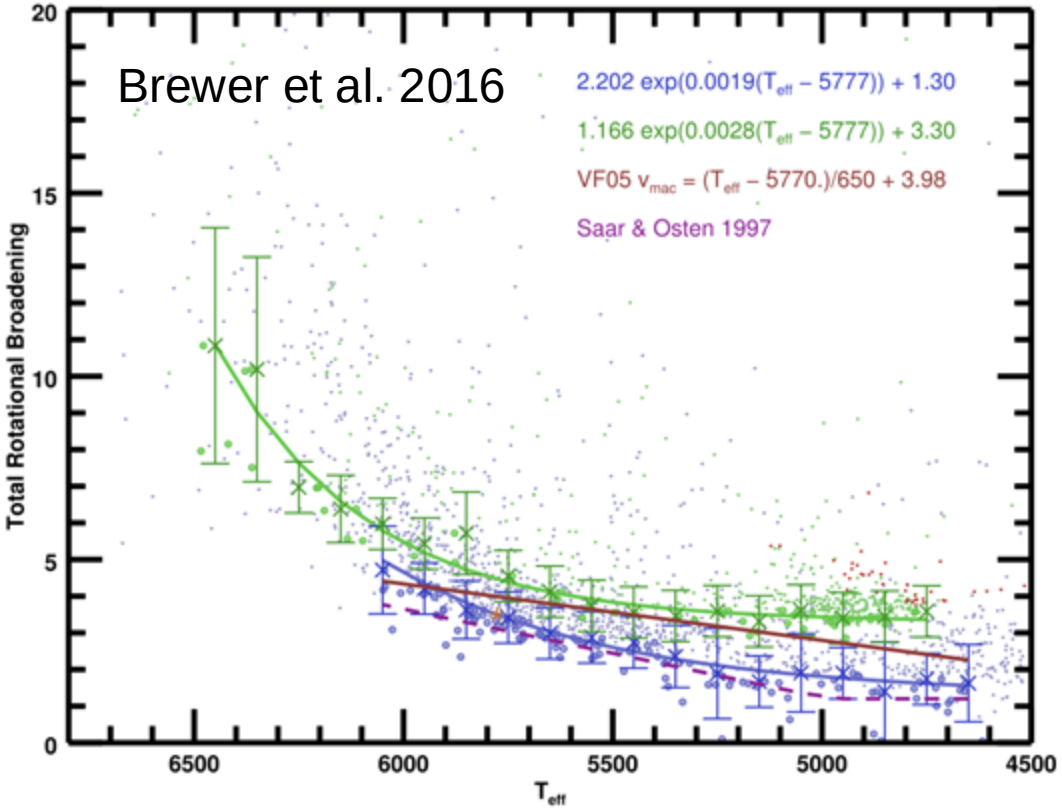


Image Credit: A. Doyle

Limitations of Current Methods

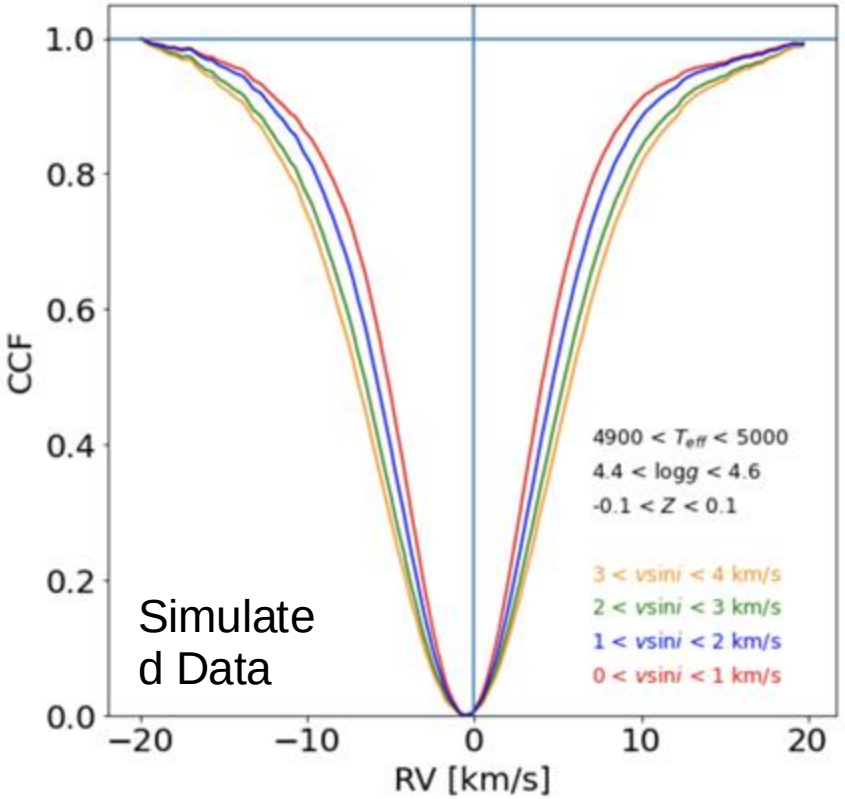


Total line broadening is a function of rotation and macroturbulence

At low rotational velocities, it is difficult to disentangle the two sources

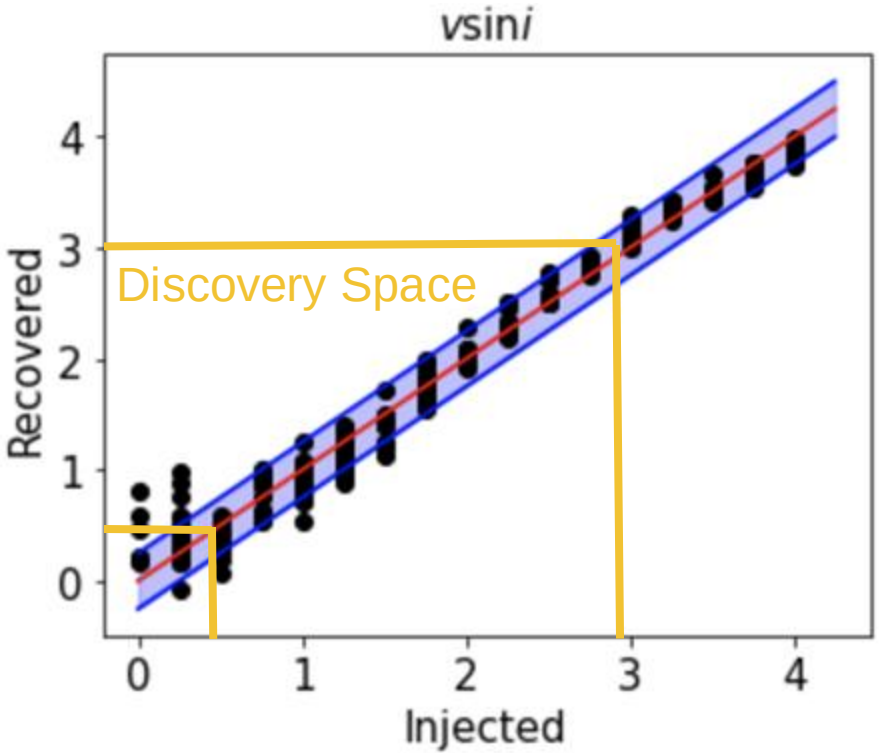
Building a Data-Driven Model

- The Cross-Correlation Function (CCF) of the spectrum encodes broadening information
- Newly stabilized spectrometers make instrument profile uniform
- Macroturbulence becomes a hidden parameter that the model learns



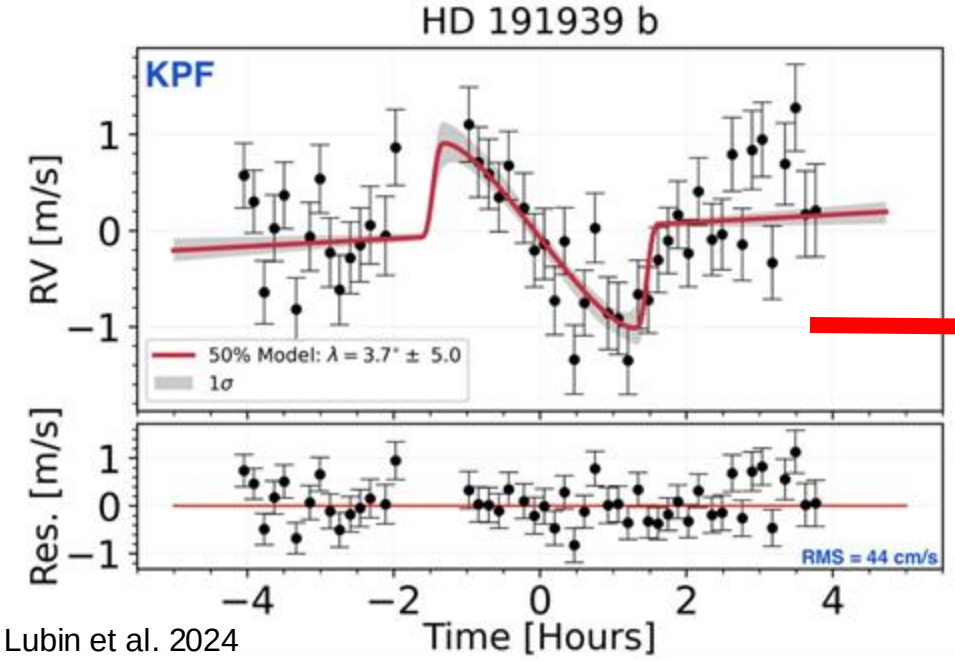
Simulated Data: Very Early Results

- Using simulated Phoenix spectra with specified Teff, logg, Fe/H
- Resampled to KPF wavelengths
- KPF instrument profile convolved
- Broadened to specified *v*sin*i*
- 800 training CCFs, 200 validation
  - Using The Cannon (Ness et al. 2014)

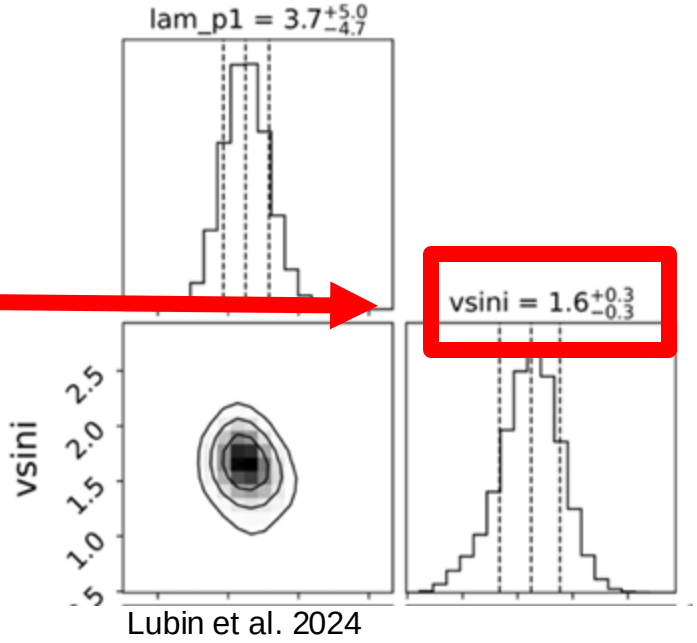


Obtaining Labels for Real Data: Help from RM!

Previously Lubin et al. 2022 found *v*sin*i* upper limit of 2.0 km/s from SpecMatch Synthetic for HD 191939, a 6 planet system



Lubin et al. 2024

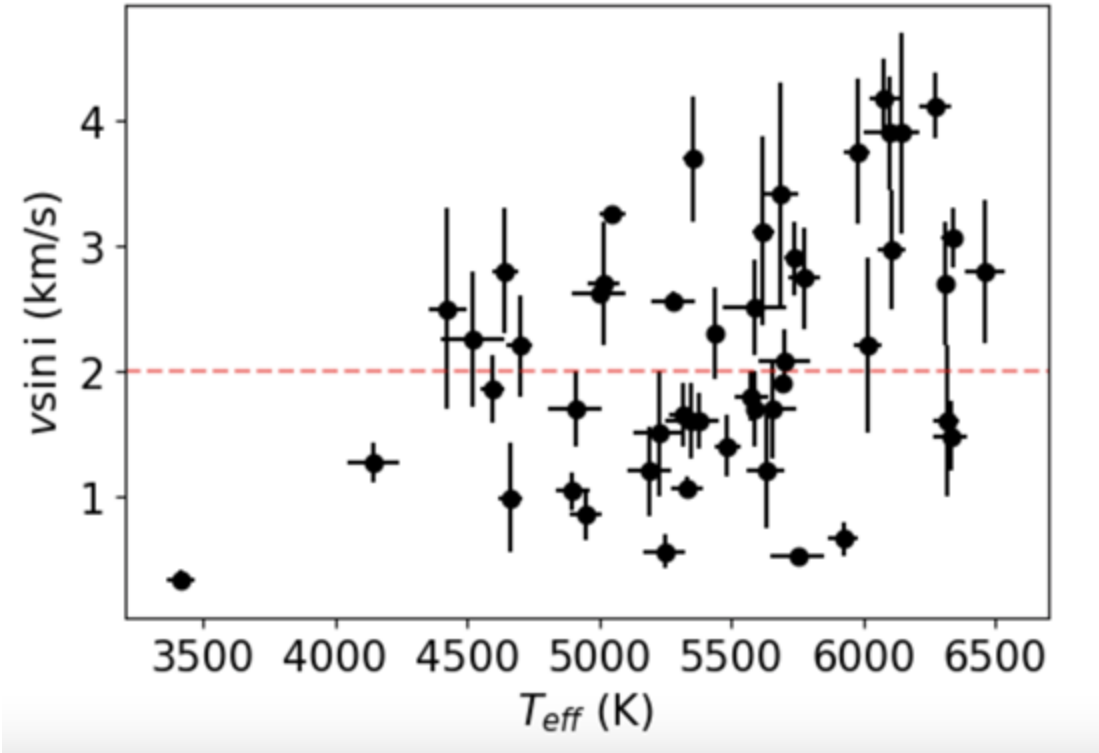


Lubin et al. 2024

Current Keck/KPF Observing Program

- 50 targets
  - 32 already in hand
- Published RM measurement
- Small *v*sin*i* value and error
- Obtain high SNR spectrum

Plans to expand sample and build a library of spectra



Example Data: HAT-P-22

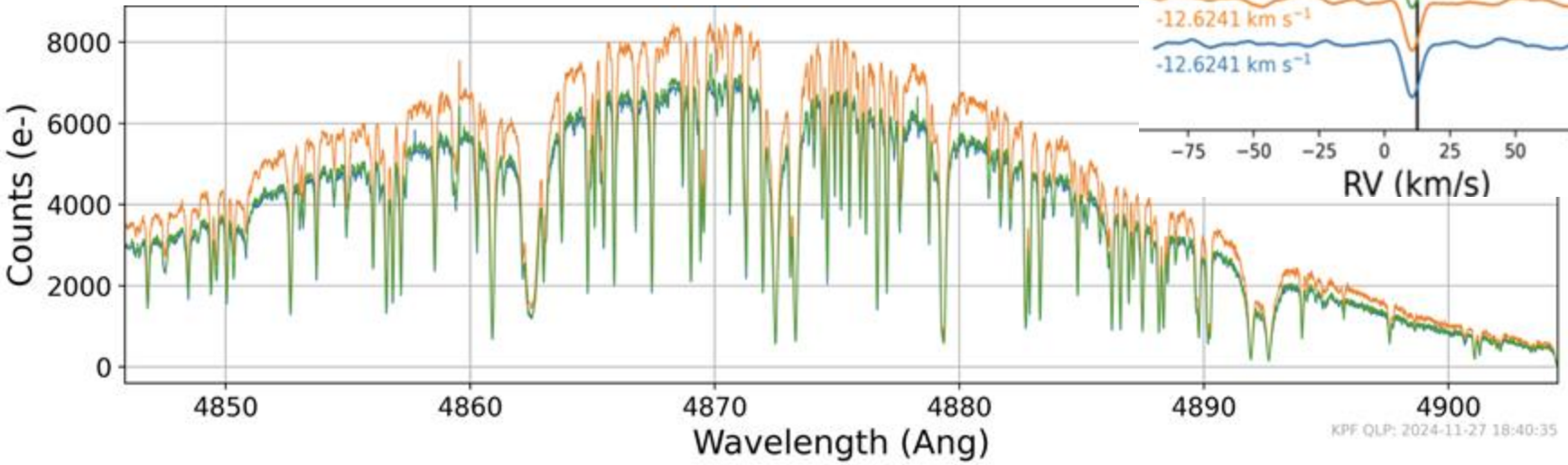
- Teff = 5314 +/- 50 K
- *v*sin*i* = 1.62 +/- 0.25 (Mancini et al. 2018)

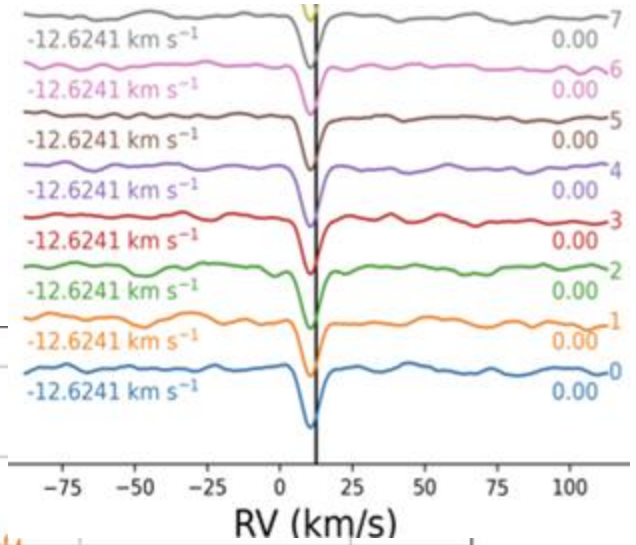
KPF Spectrum

Science Fiber 1

Science Fiber 2

Science Fiber 3





Conclusions

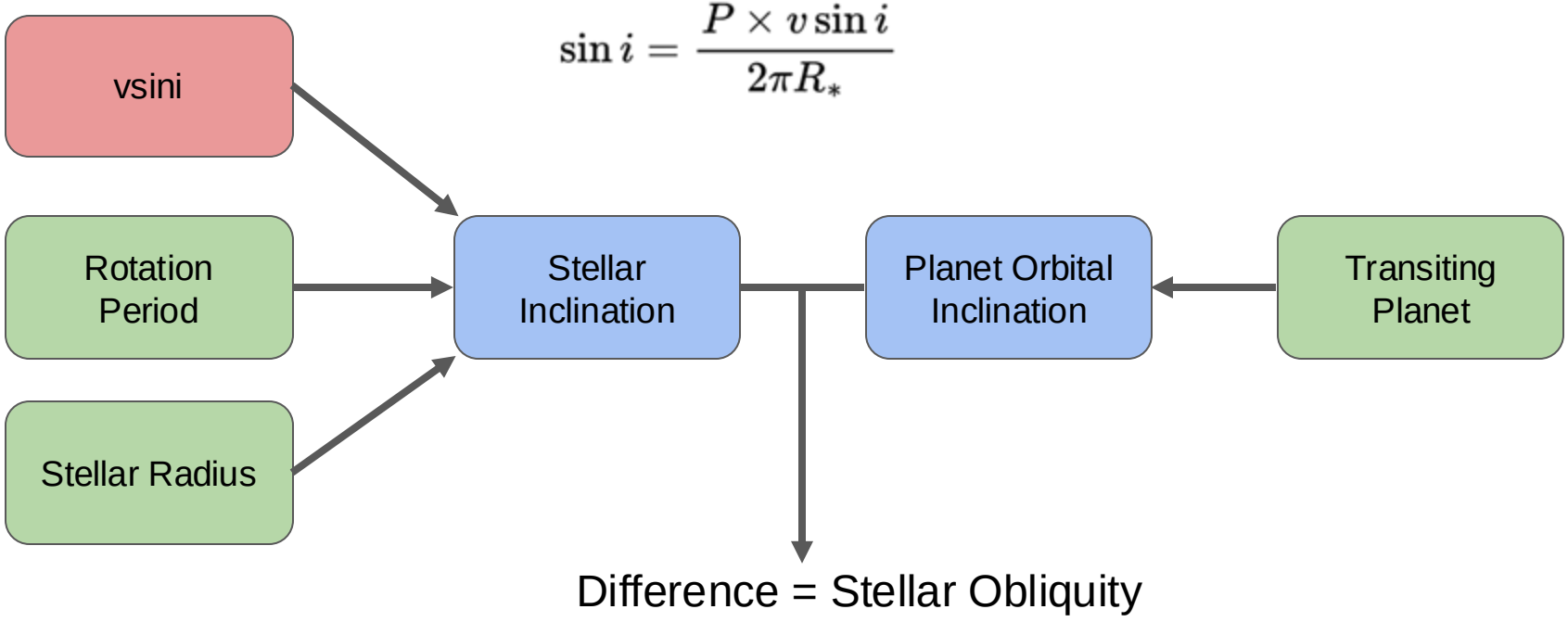
- Build a data-driven model, trained on CCF of high SNR spectra, to measure low *v*sin*i*
- Publish this as an open-source tool for the community:
  - Take a high resolution, high SNR spectrum with KPF and get *v*sin*i*
  - Can be extended to more instruments
- Seek to measure of small planet obliquities, and probe their formation

- ***<u>This is all in-progress, we want to hear from you!</u>***
  - ***Ideas/Thoughts? Alternative science application(s)?***

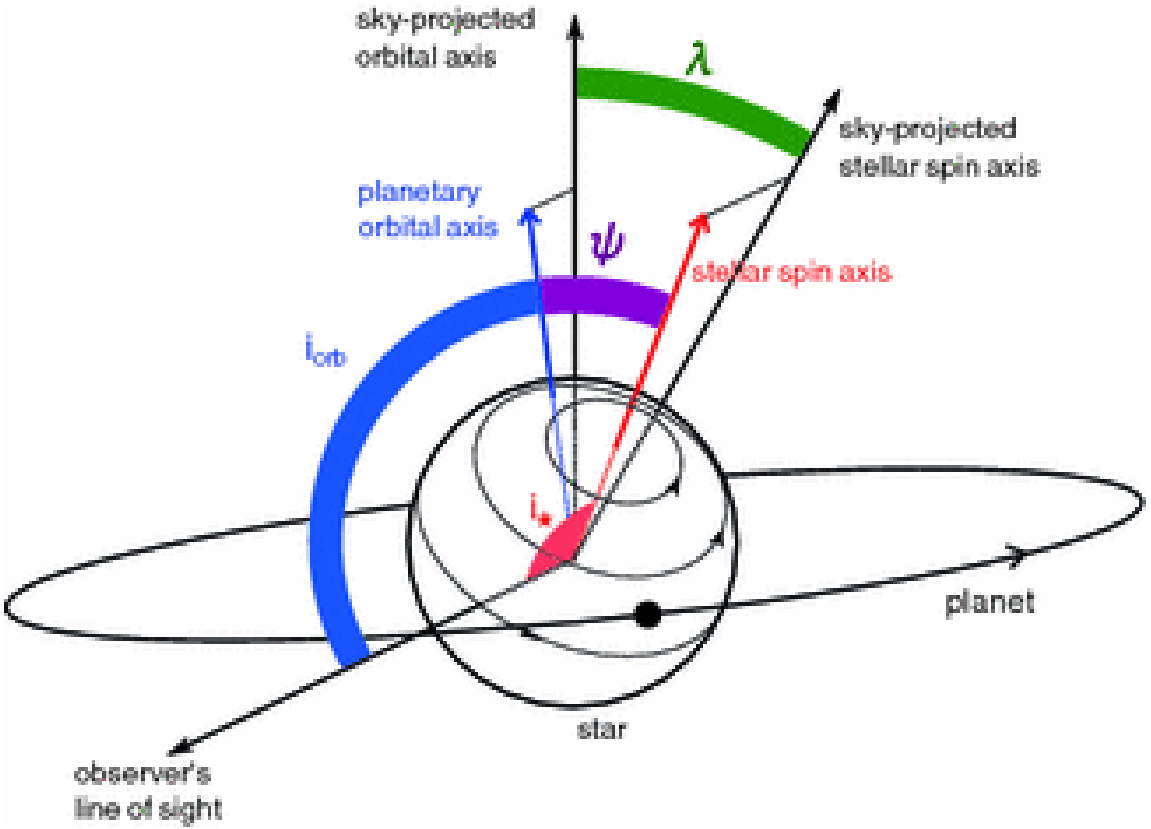
Backup slides

Measure Stellar Obliquity in Sky Plane

$$\sin i = \frac{P \times v \sin i}{2\pi R_*}$$



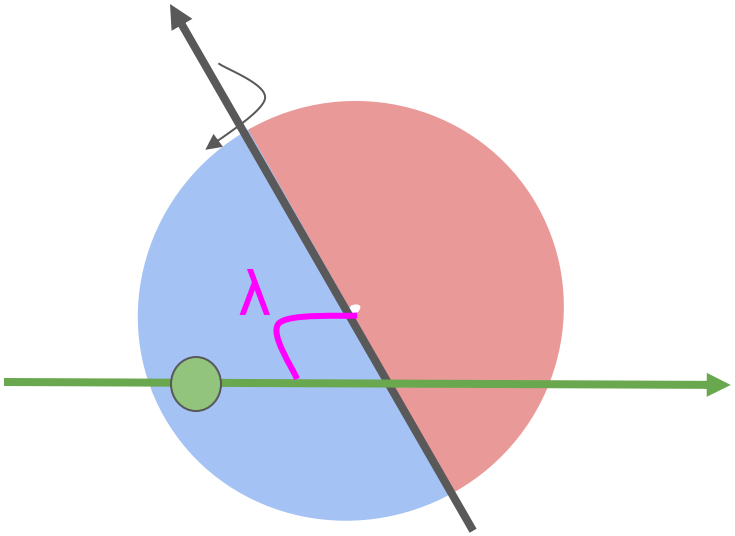
Angles


sky-projected
orbital axis
λ
sky-projected
stellar spin axis
planetary
orbital axis
ψ
stellar spin axis
i_{orb}
i_*
planet
star
observer's
line of sight

Primary Science Motivation: Obliquities En Masse

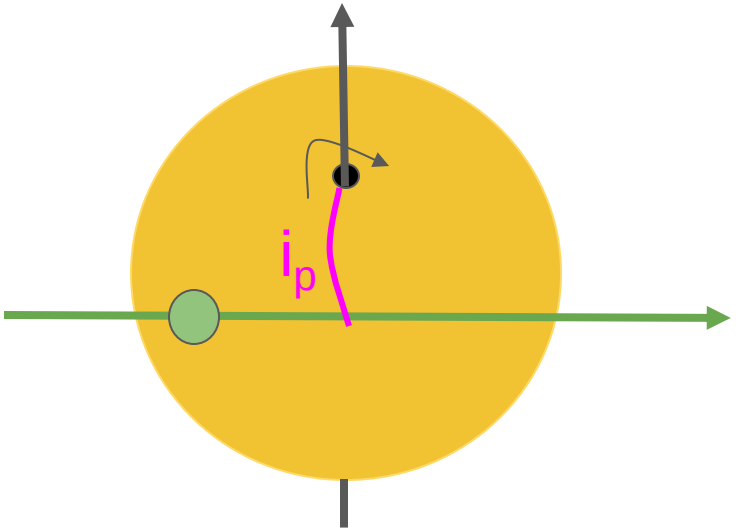
Sky Projected

RM Effect



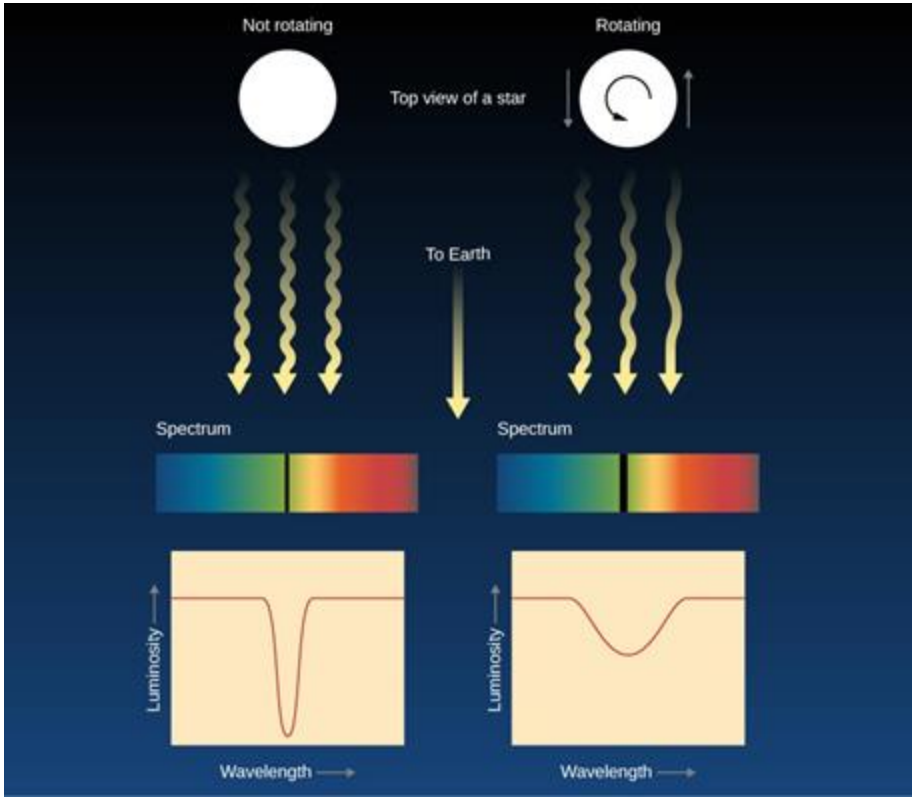
Sky Plane

Inclination Comparison*



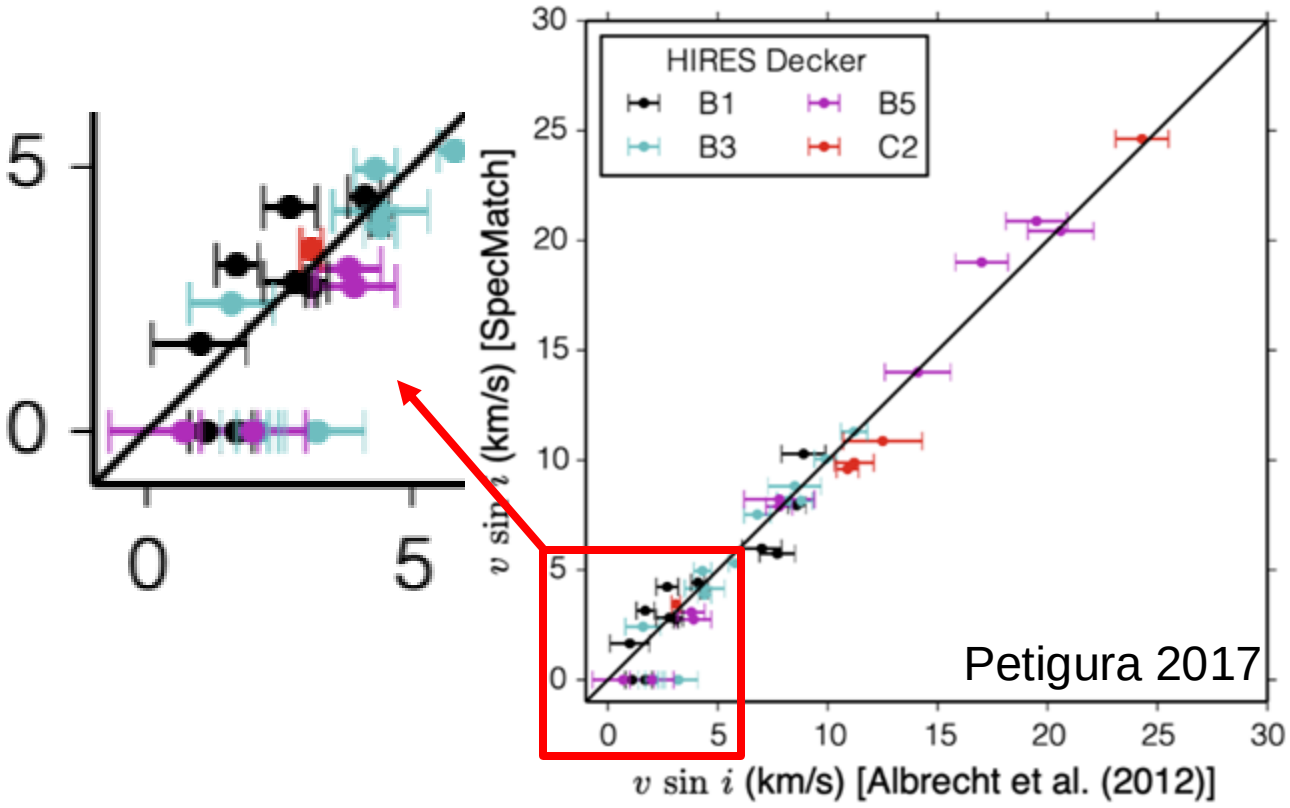
*Need *v*sin*i* value

Rotational Broadening

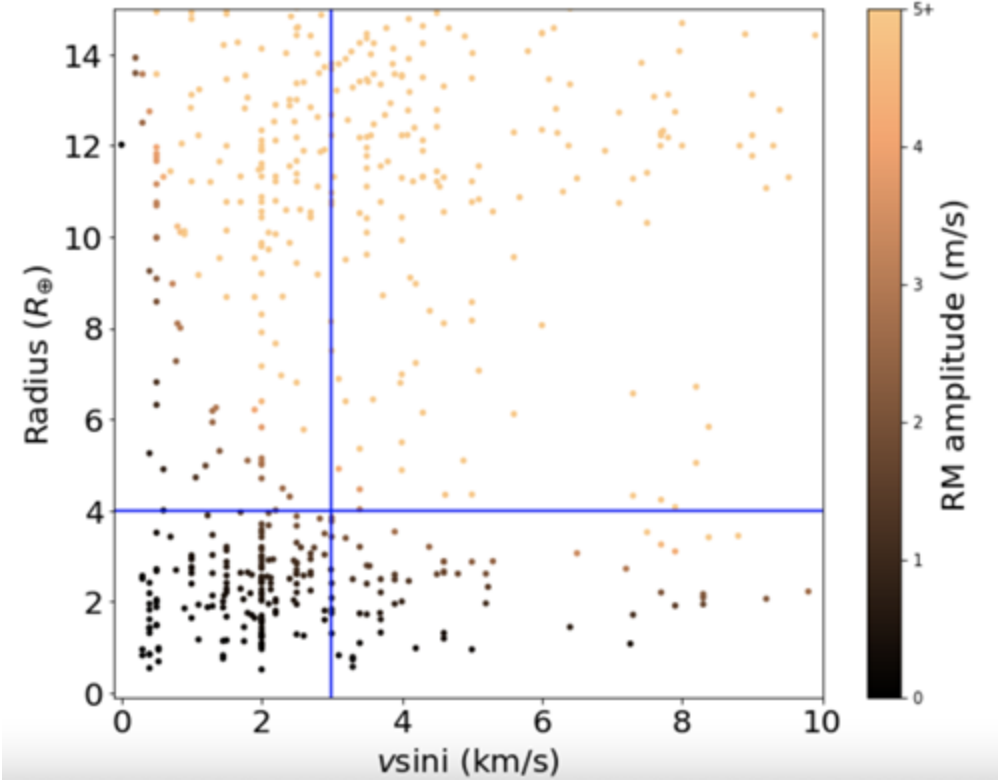


Limitations of Current Methods

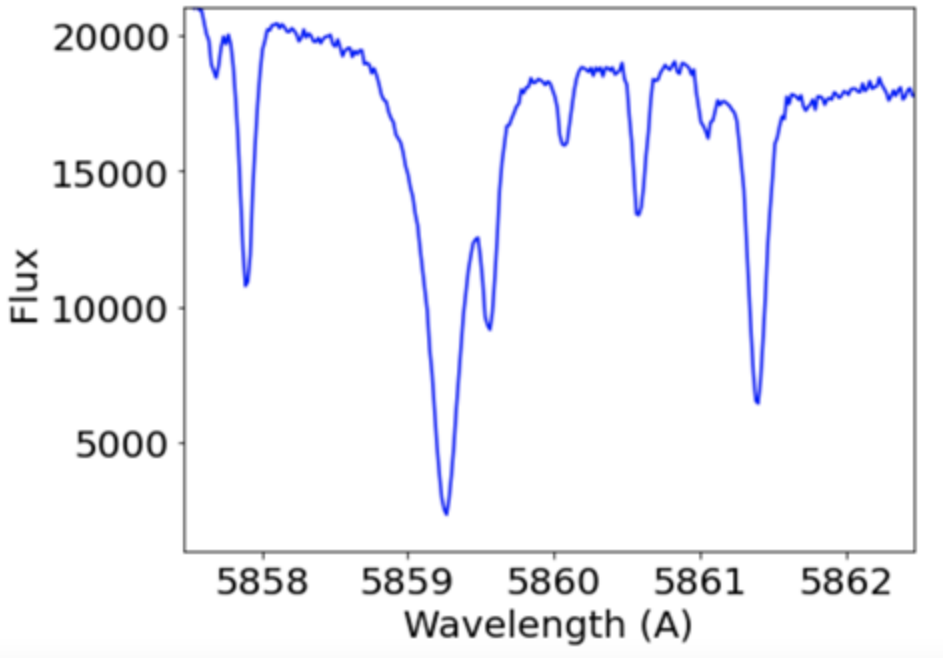
- Divergence is greater at the lowest regime
- How to make this measurement?

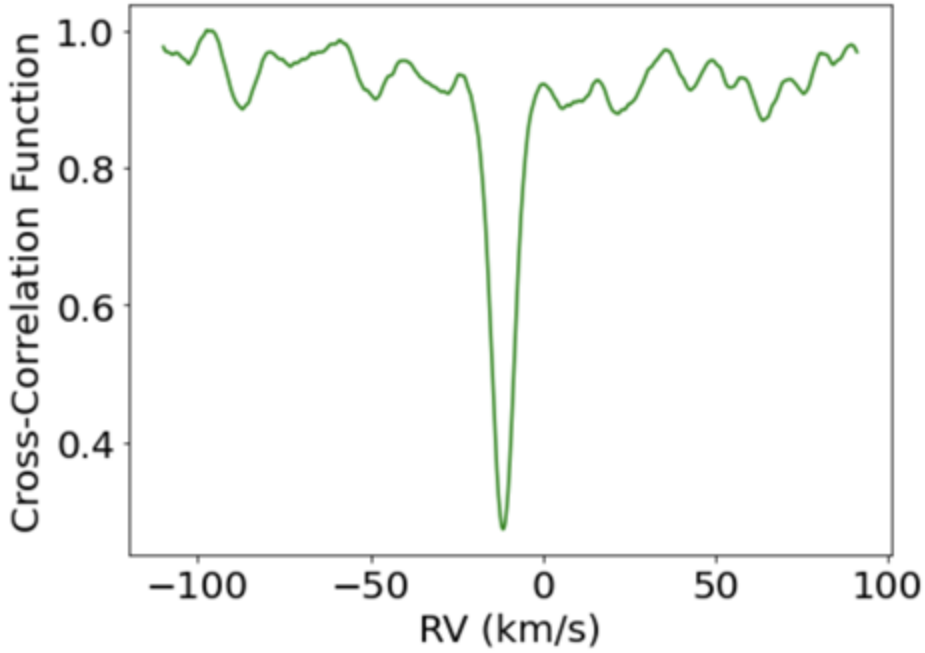


RM Possibilities/Restrictions



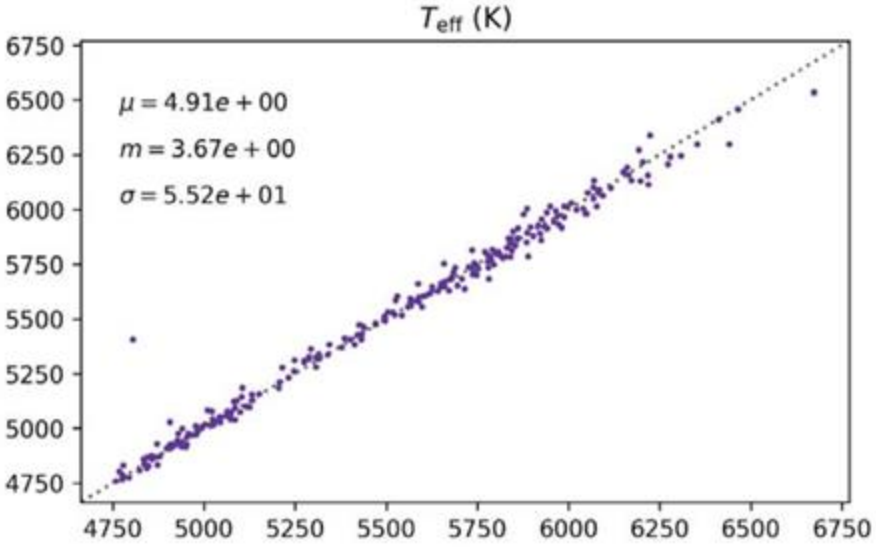
Example Data: WASP-69

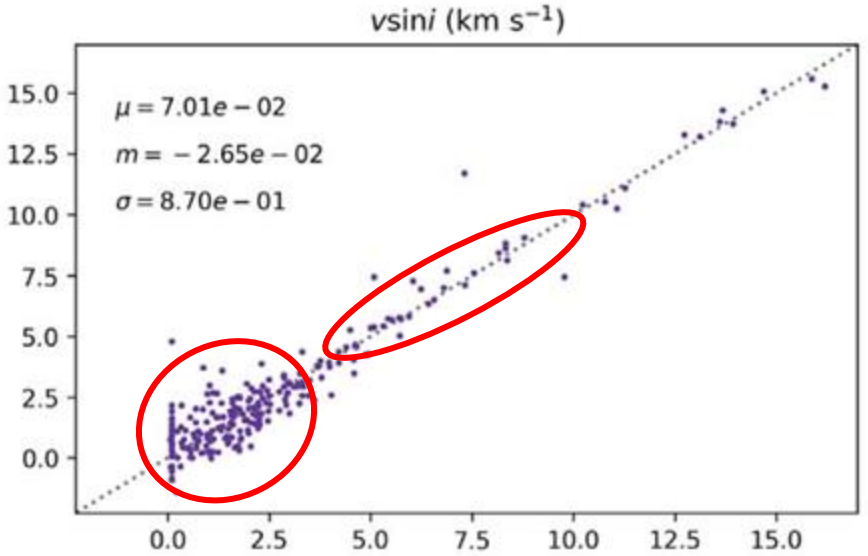




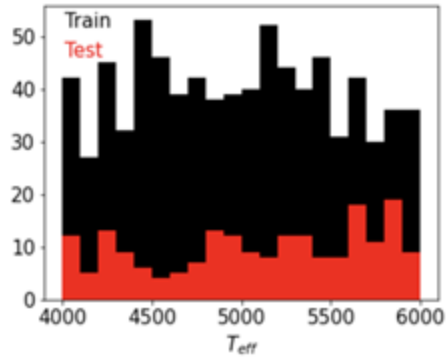
Successes of Data Driven Models

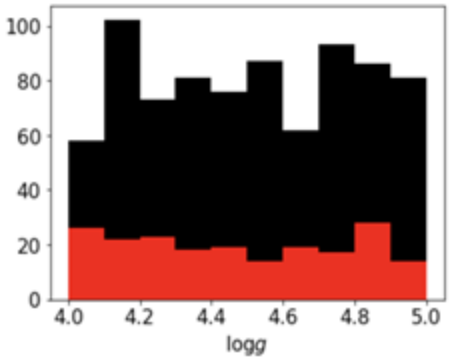
Rice & Brewer

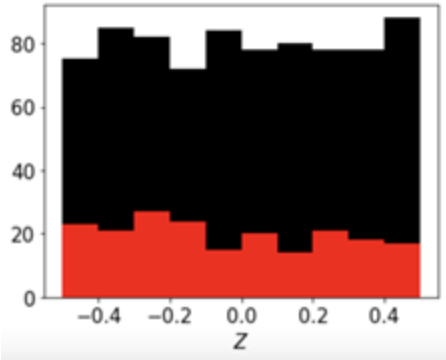


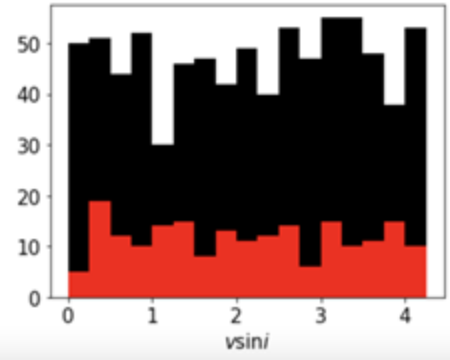


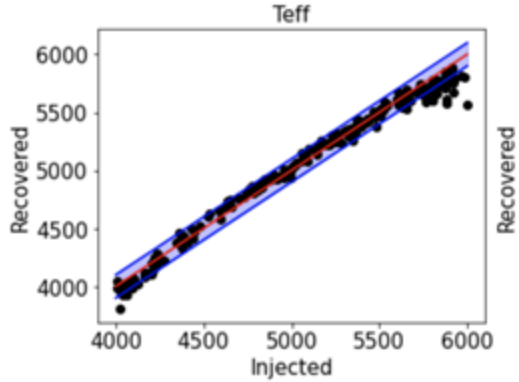
Full Inject/Recover Cannon Model

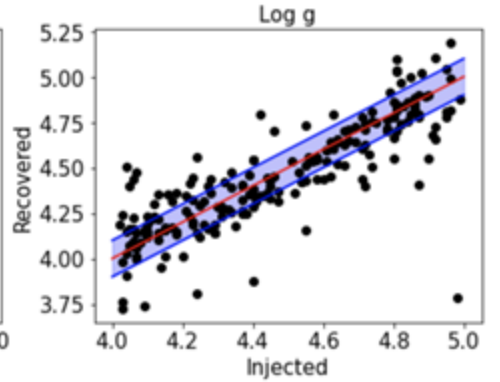


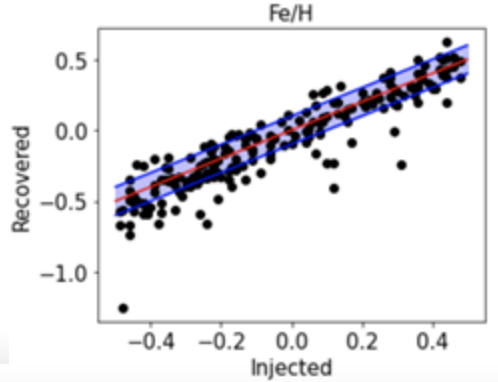


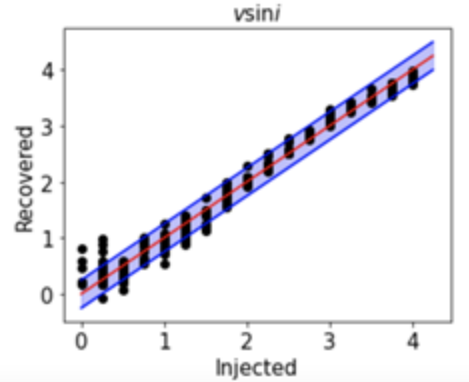






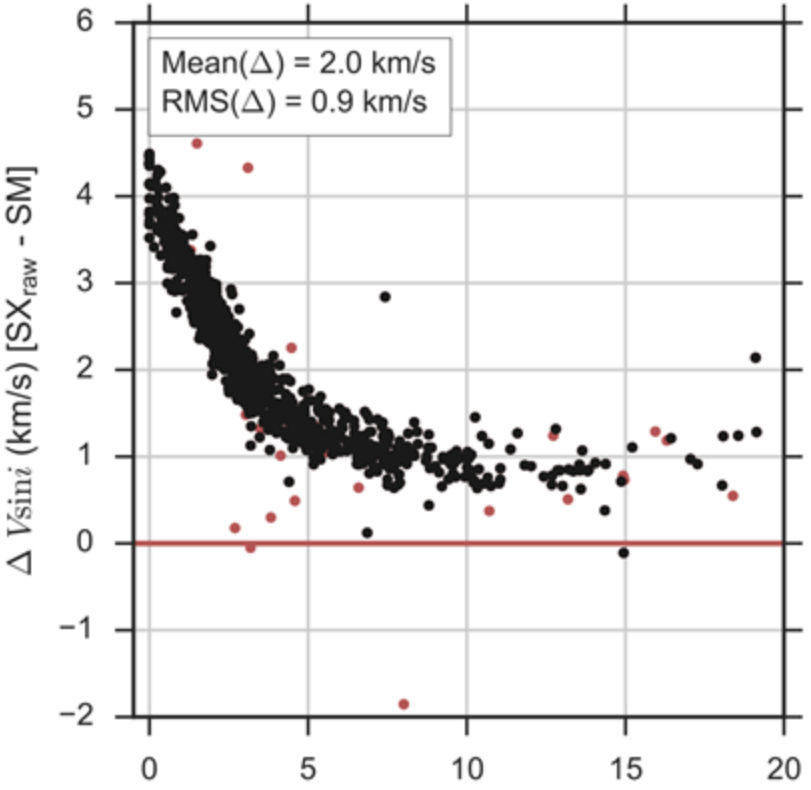






Limitations of Current Methods

- At low *v*sin*i*, spectral fitting methods diverge
- Divergence is greater at the lowest regime
- How to make this measurement?



Petigura et al. 2017