

The Metallicity Distribution and Hot
Jupiter Rate of the *Kepler* field:
Hectochelle High-resolution
Spectroscopy of 776 *Kepler* Stars

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HJ rate from RV

Fressin et al. (2013): $0.43 \pm 0.05\%$ around Kepler dwarfs

$\approx 2 \times$ HJ rate from transits

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(*SuperLupus, Kepler*)



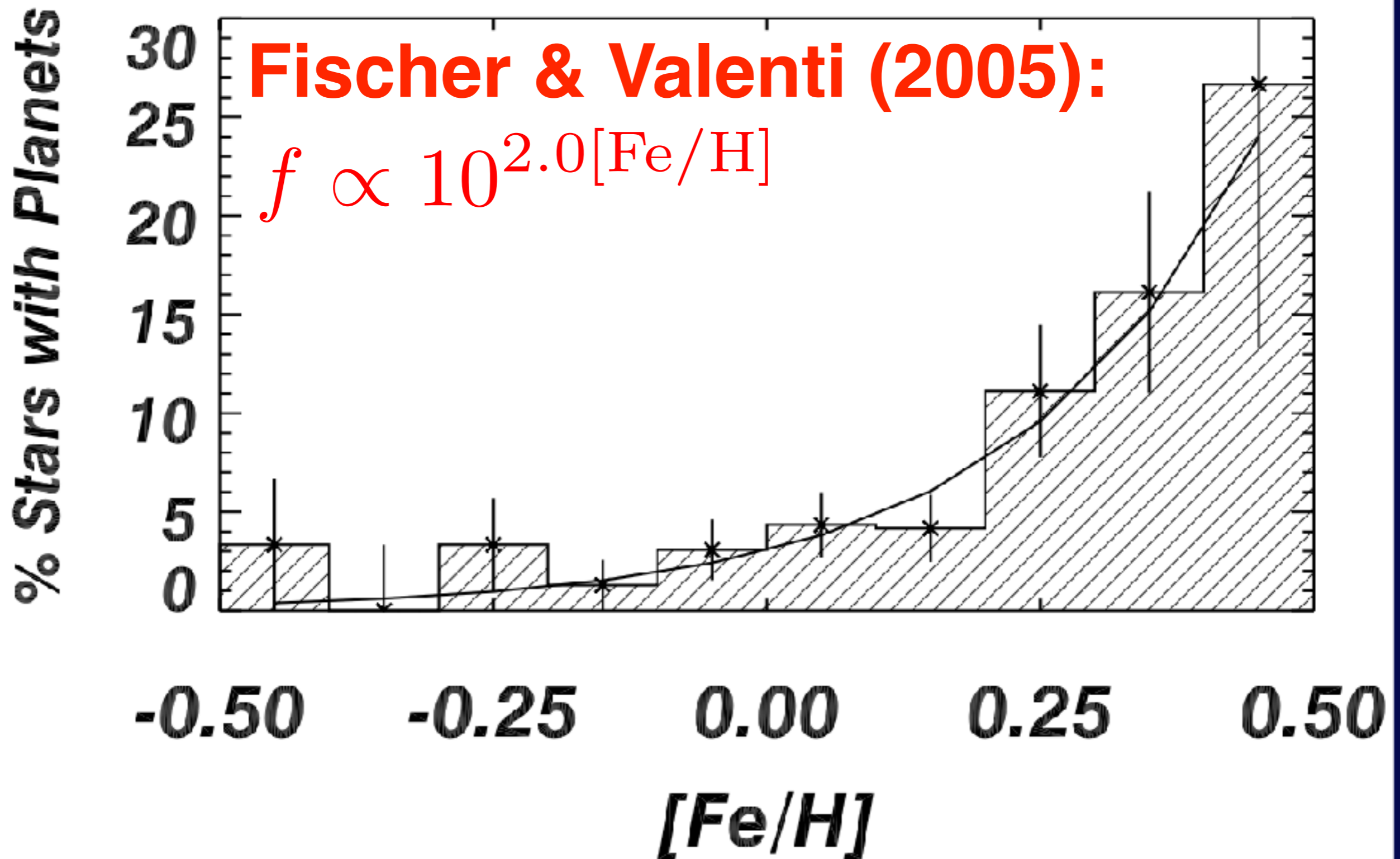
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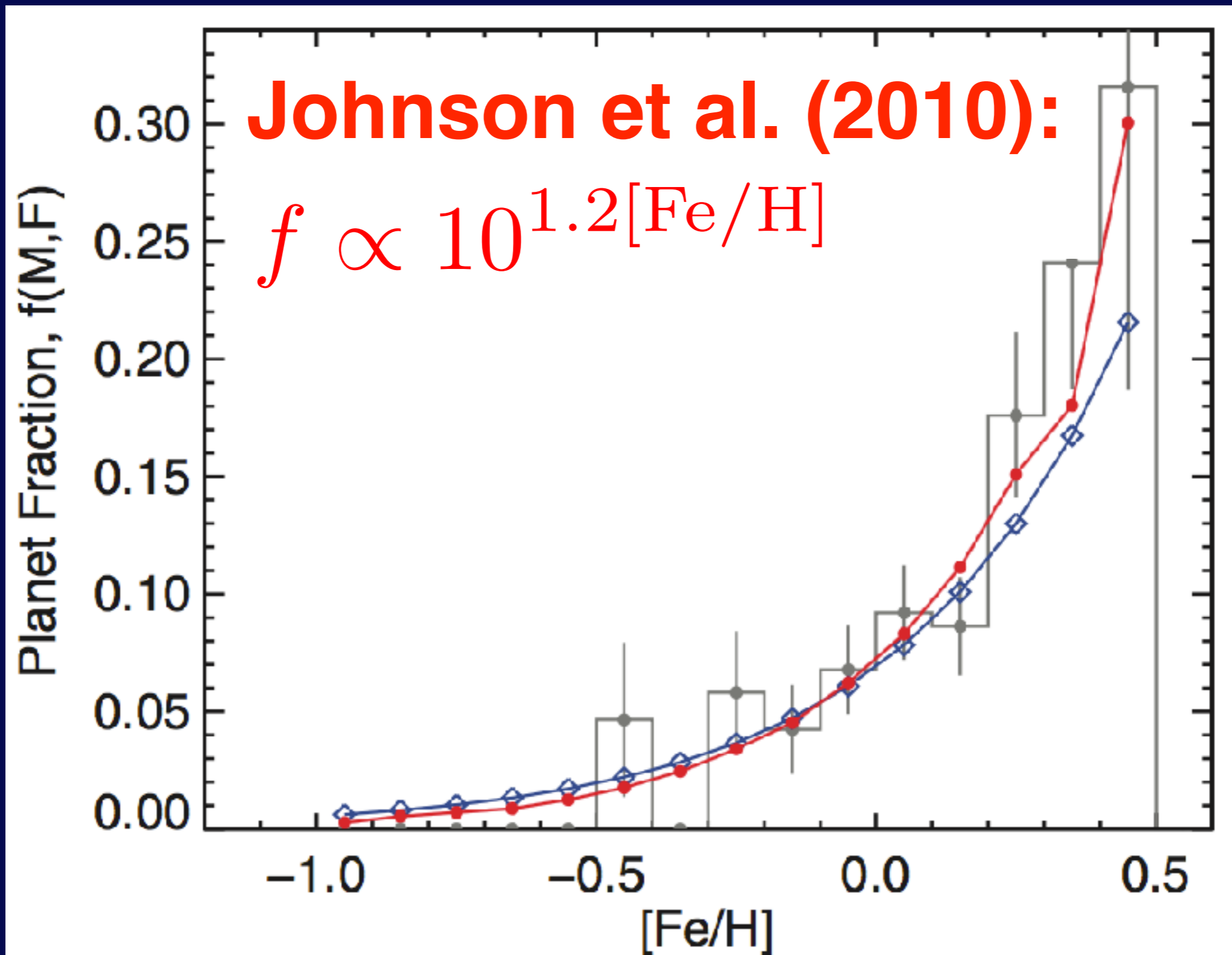
metal poor?

- **Stellar metallicity and HJ rate are positively correlated.**

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Transit surveys report lower HJ rate
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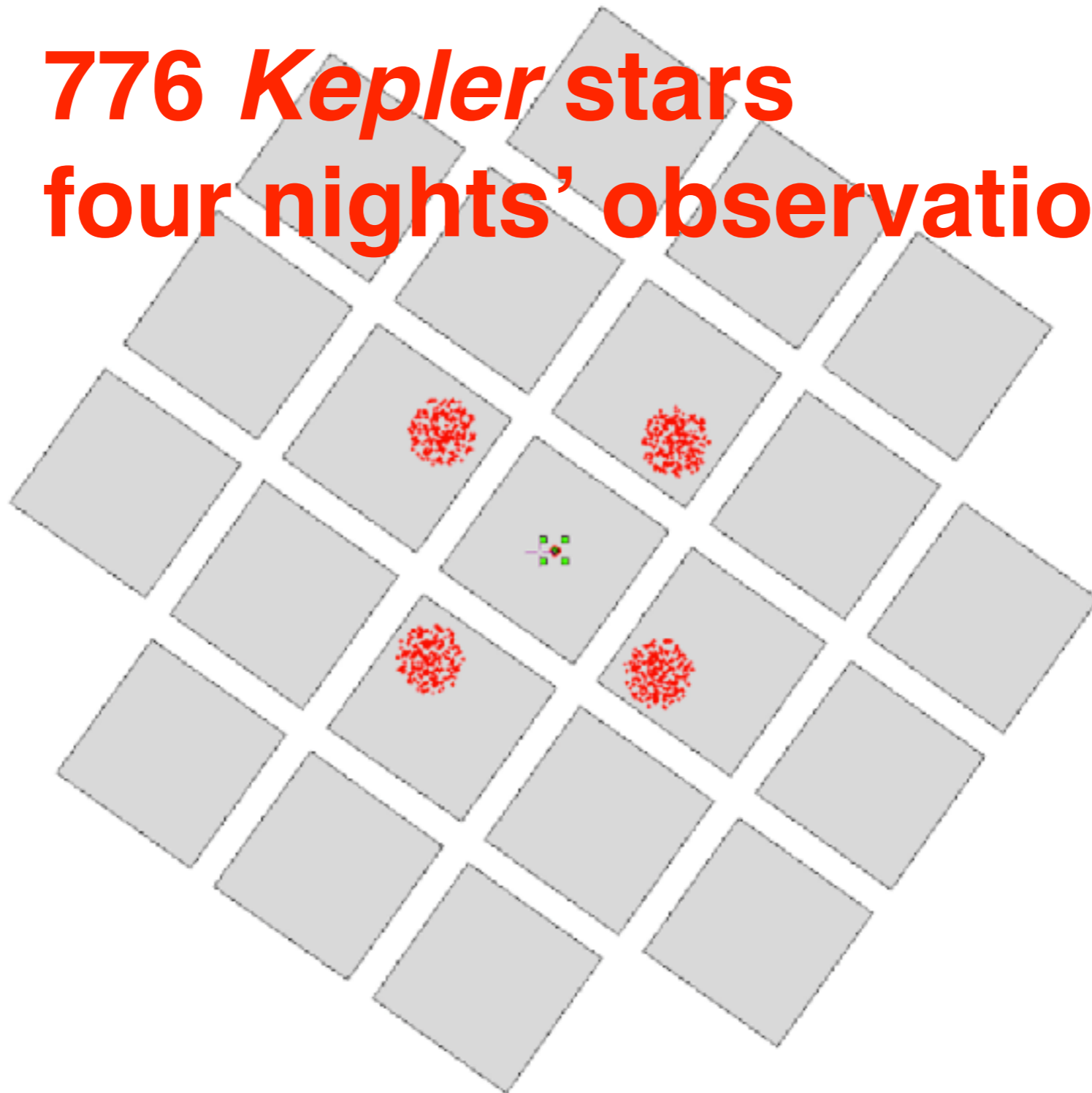
Test:

by measuring the stellar metallicity distribution of the *Kepler* field, and comparing with that of the solar neighborhood.

- **Sample**

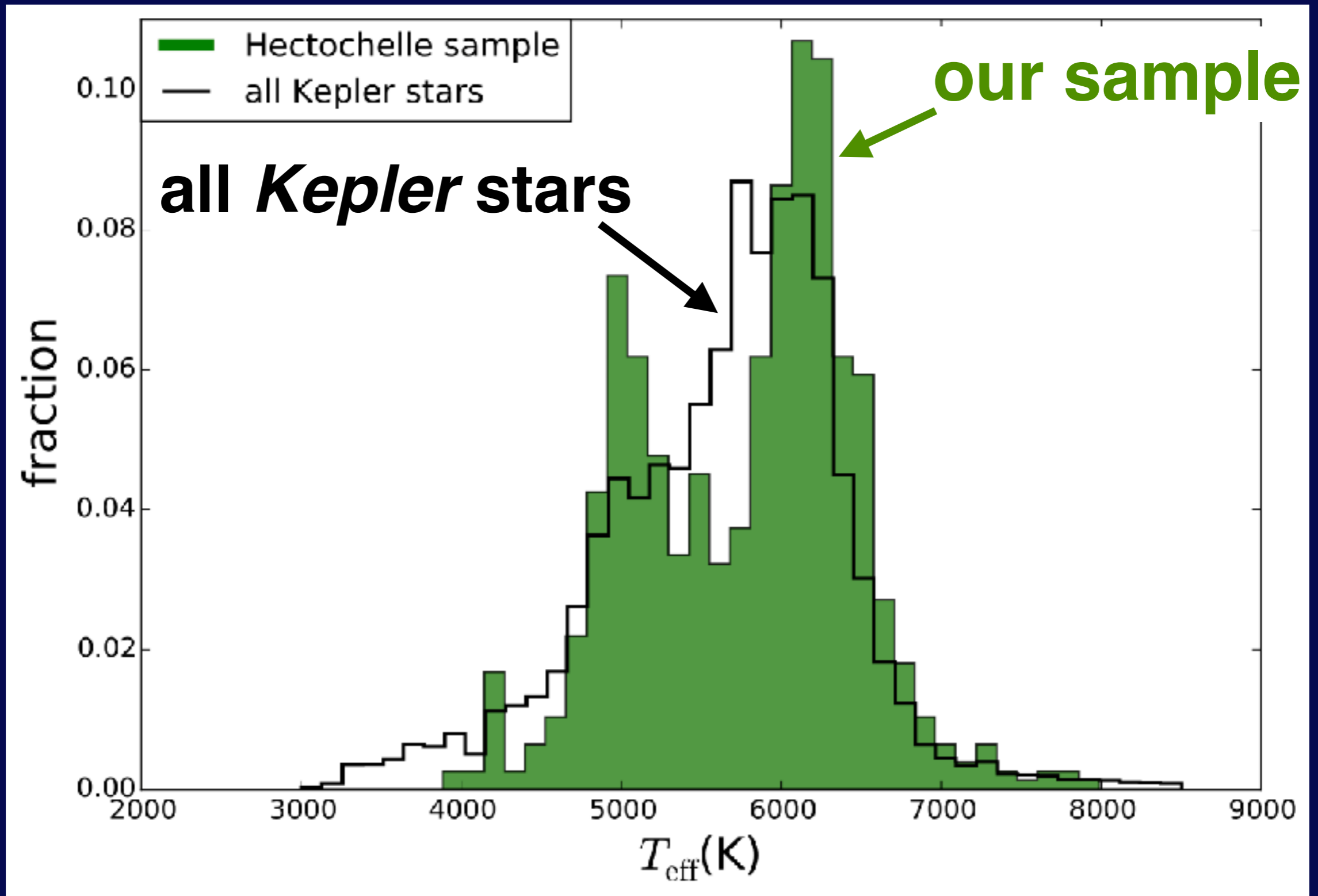
Instrument: Hectochelle(240 fibers) on MMT.

776 *Kepler* stars
four nights' observation



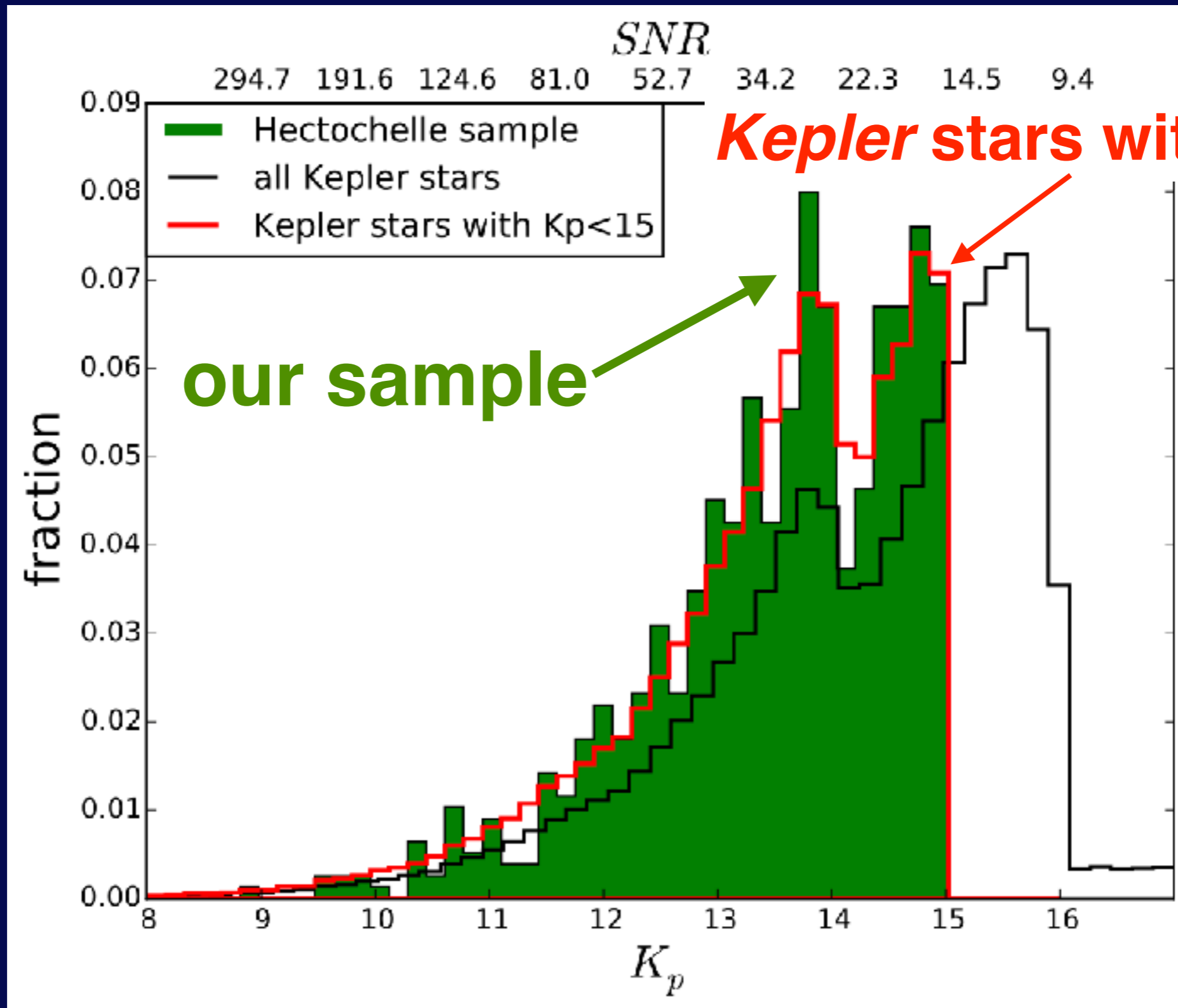
- **Sample**

F/G/K stars, 4000~7000 K



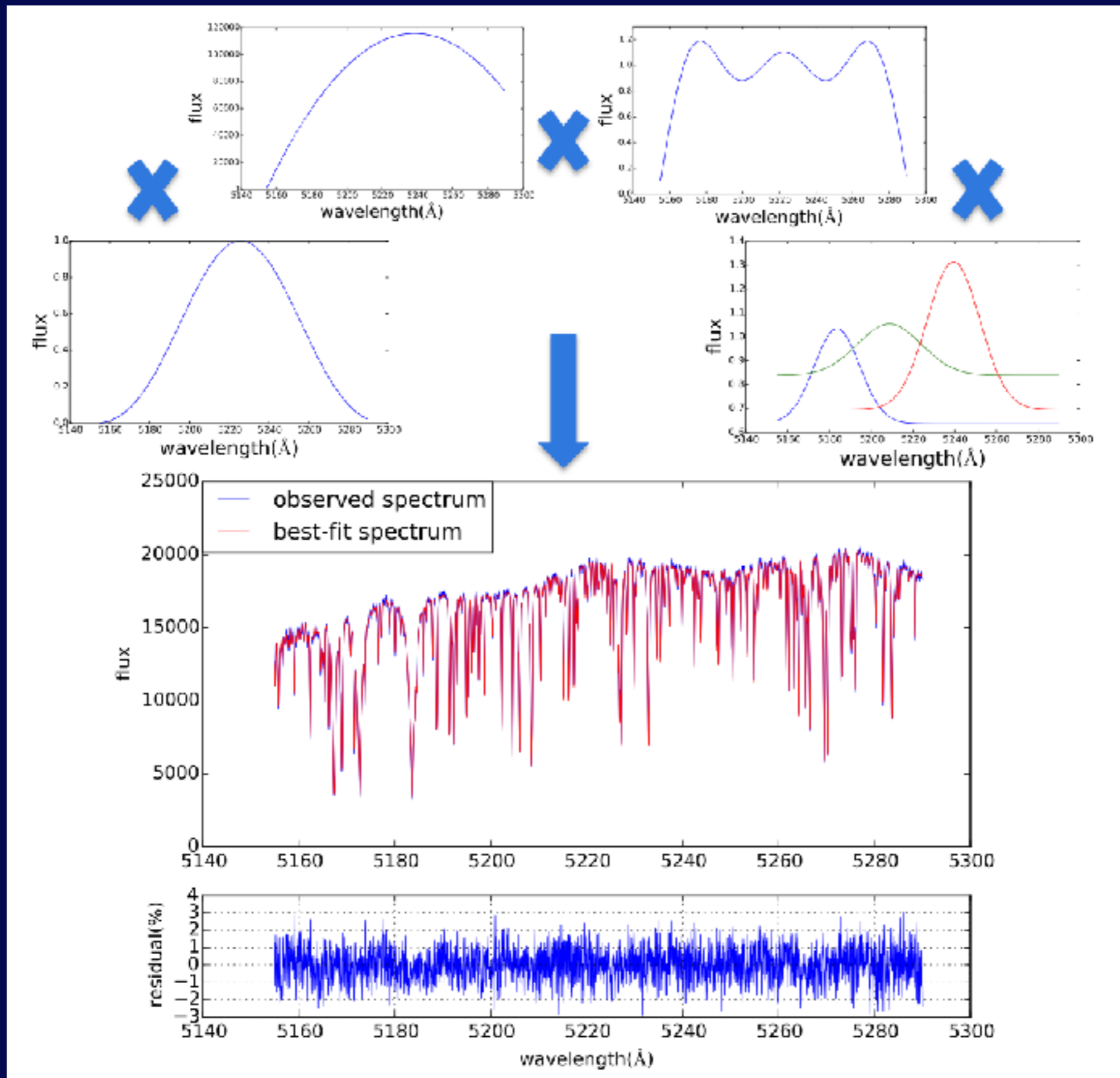
- **Sample**

$$K_p < 15, \text{ SNR: } 15 \sim 80$$



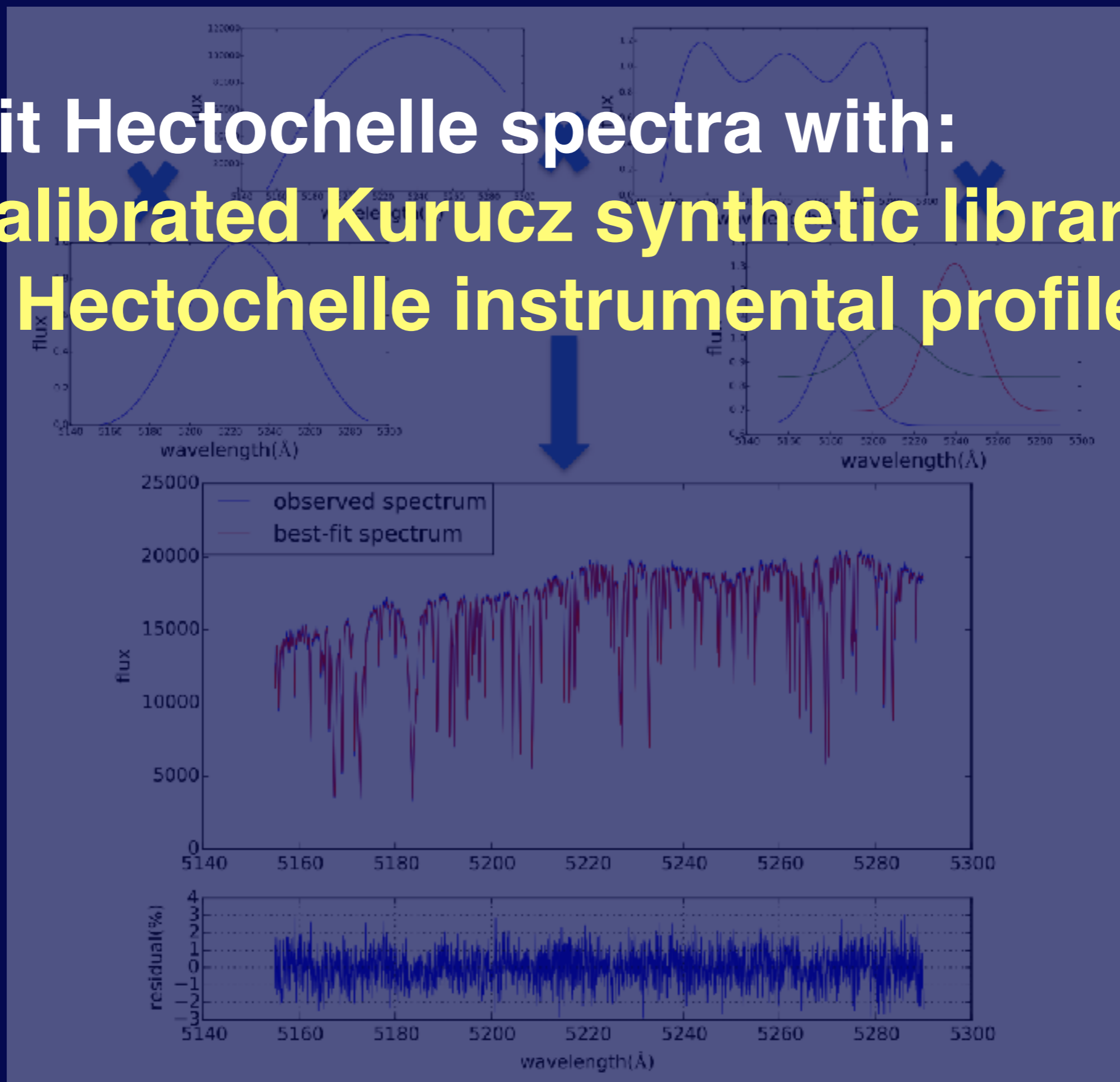
Kepler stars with $K_p < 15$

• Spectral fitting...



- **Spectral fitting...**

**Fit Hectochelle spectra with:
calibrated Kurucz synthetic library
+ Hectochelle instrumental profile**



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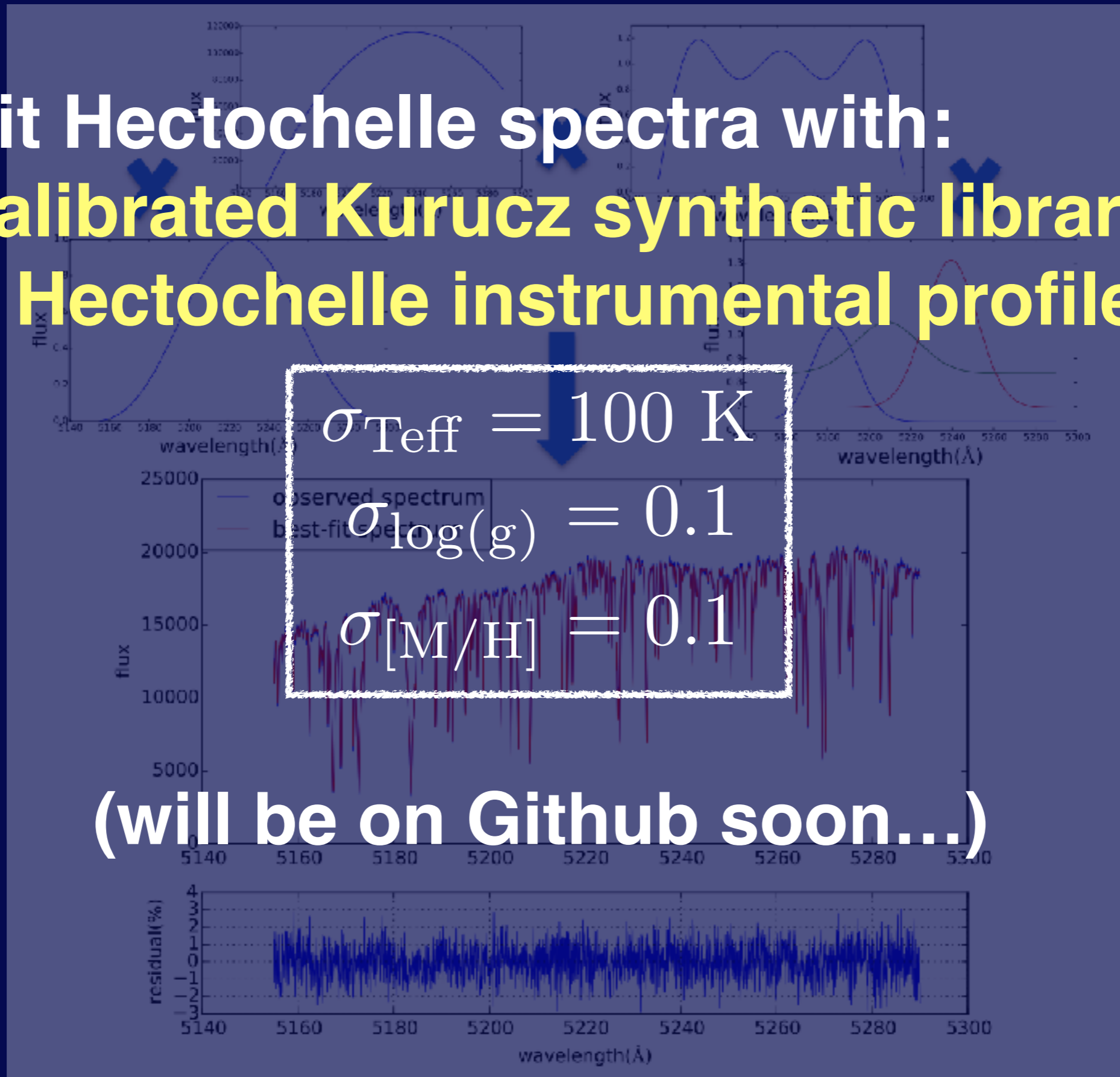
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$$\sigma_{T_{\text{eff}}} = 100 \text{ K}$$

$$\sigma_{\log(g)} = 0.1$$

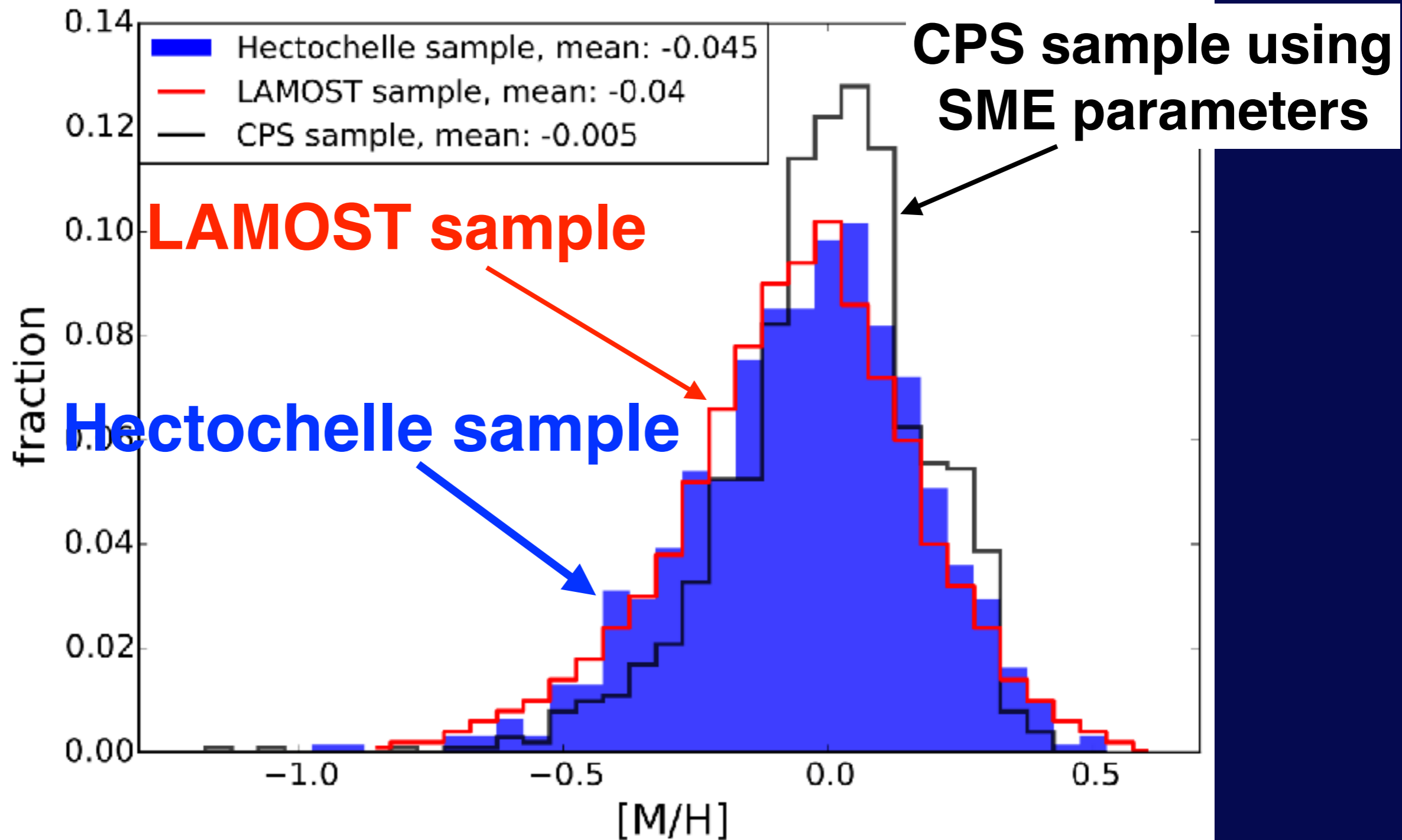
$$\sigma_{[M/H]} = 0.1$$

(will be on Github soon...)



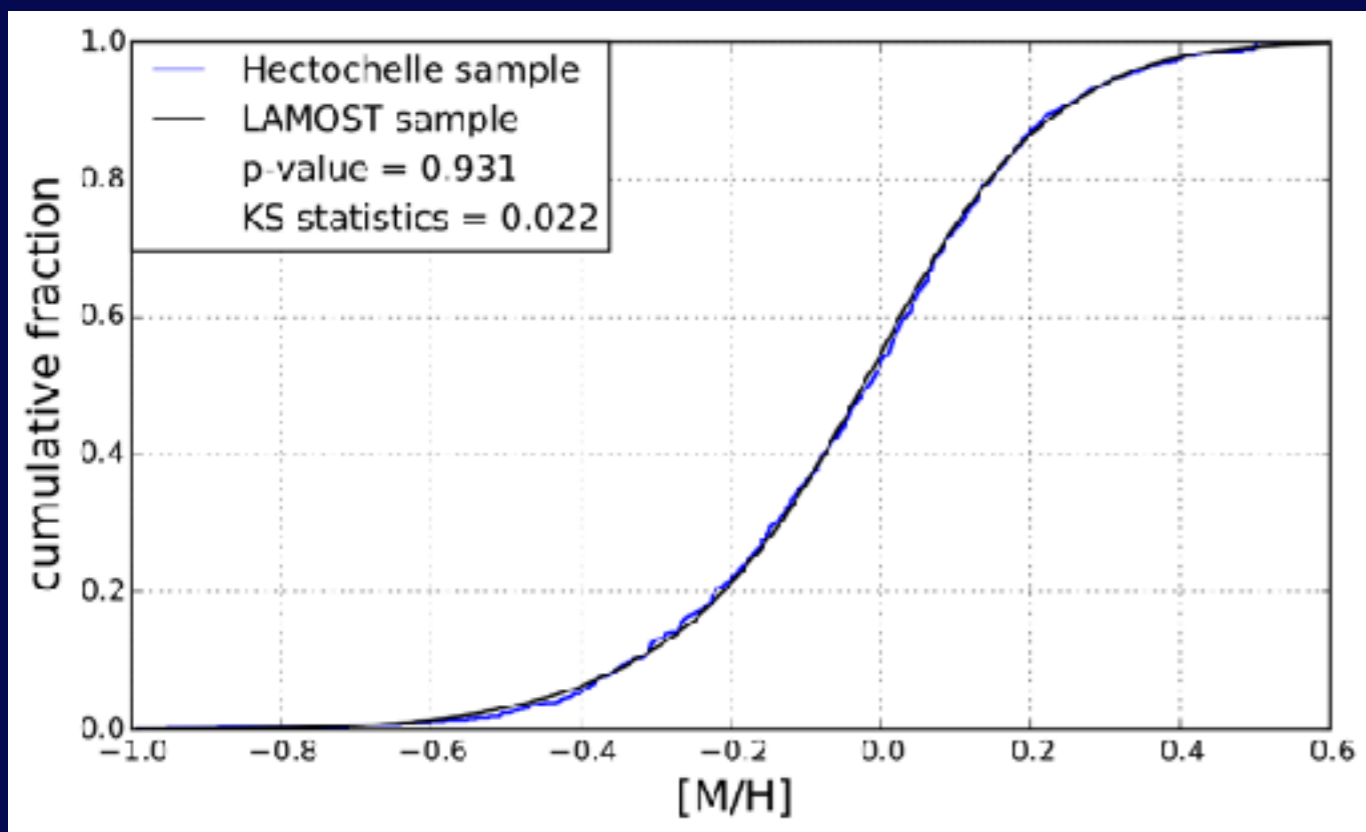
- Results

Metallicity distributions of the two populations are distinct



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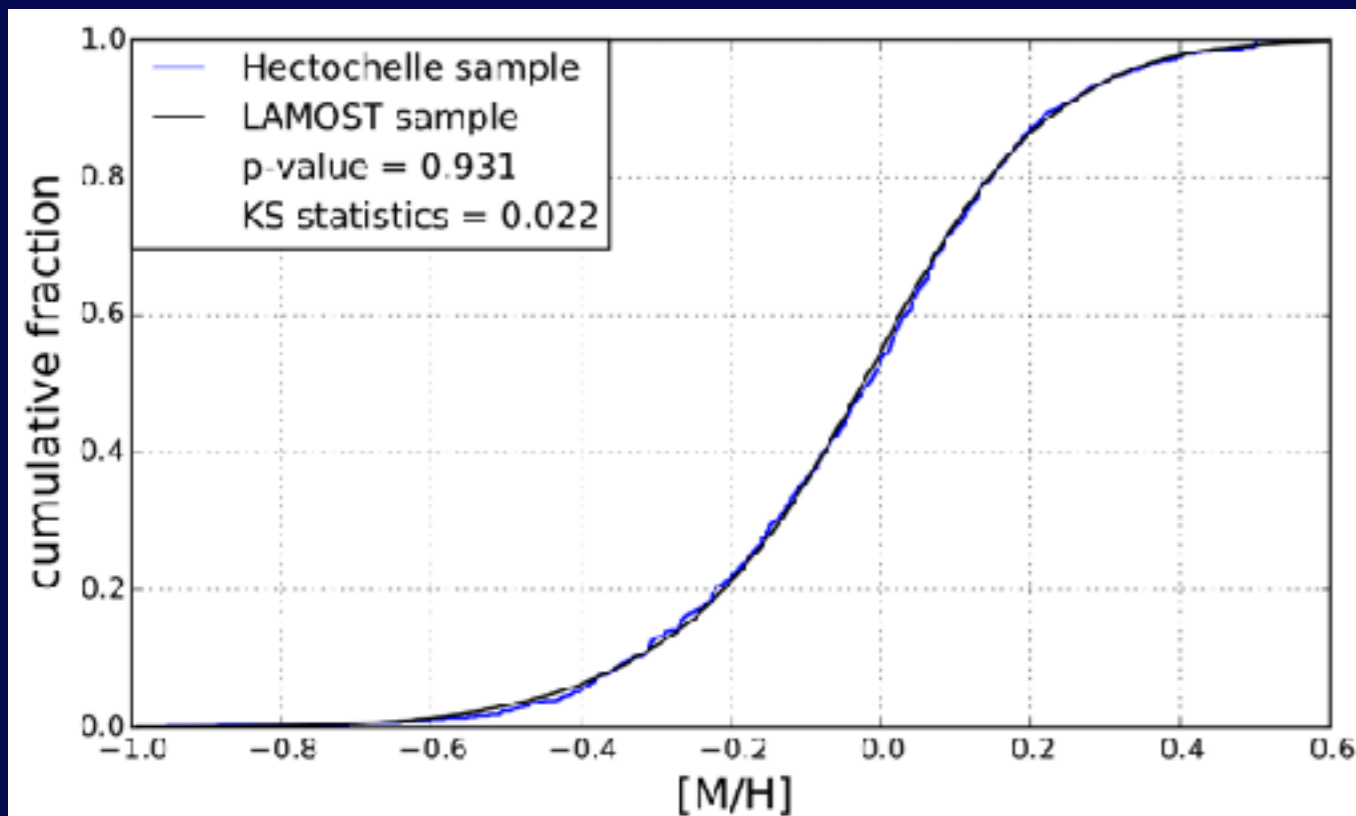
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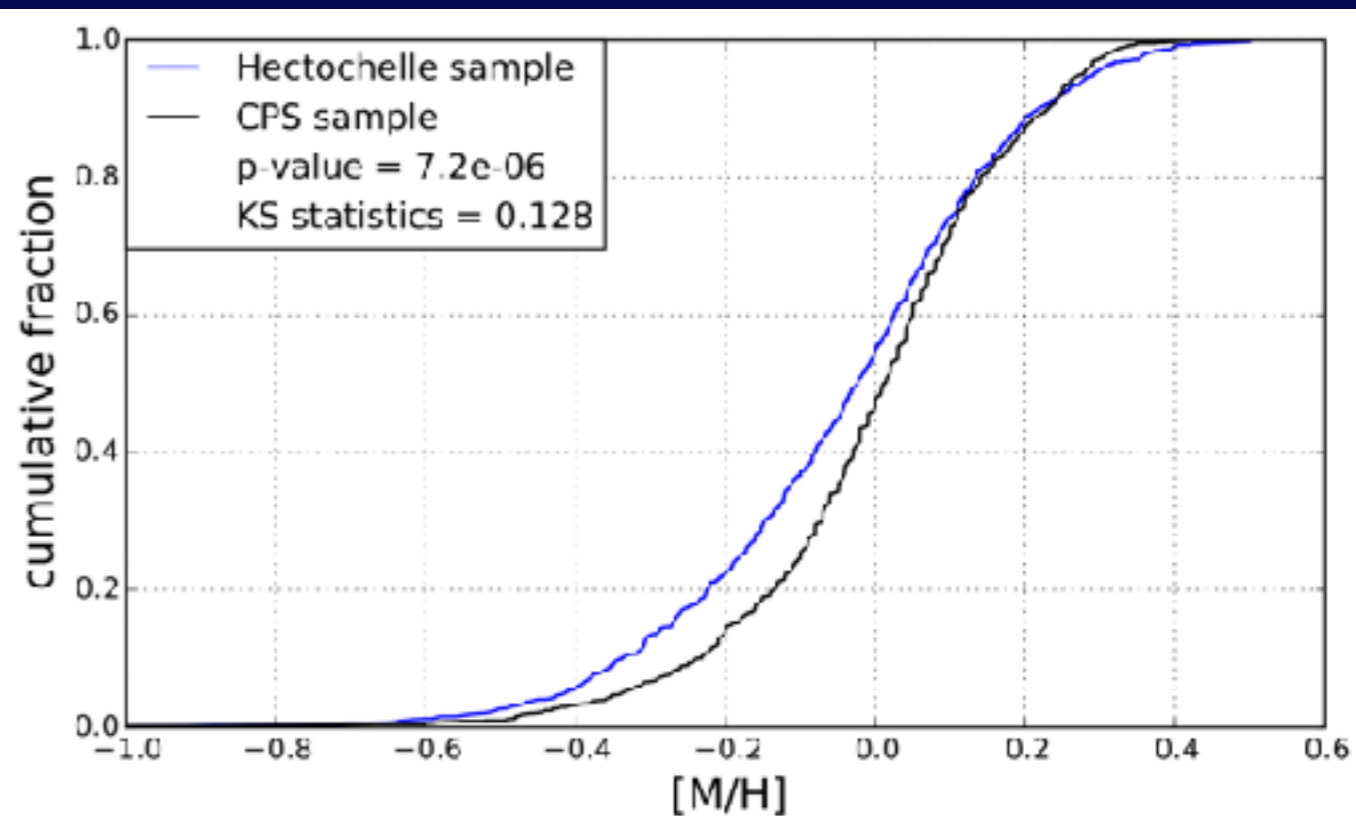
Hectochelle sample vs.
LAMOST sample
p-value = 0.93

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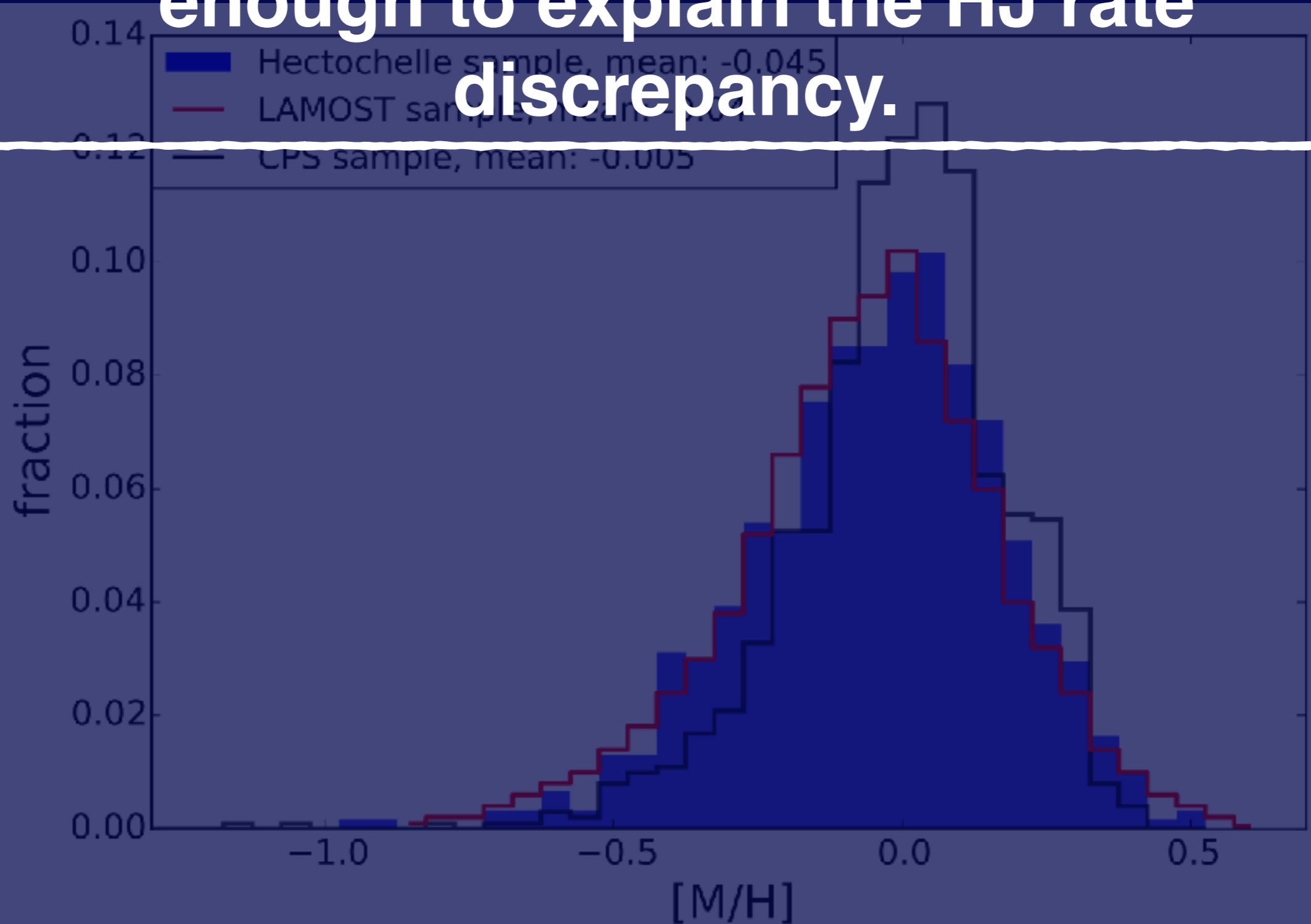
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Kepler stars vs.
solar neighborhood stars
p-value = 7.2e-6

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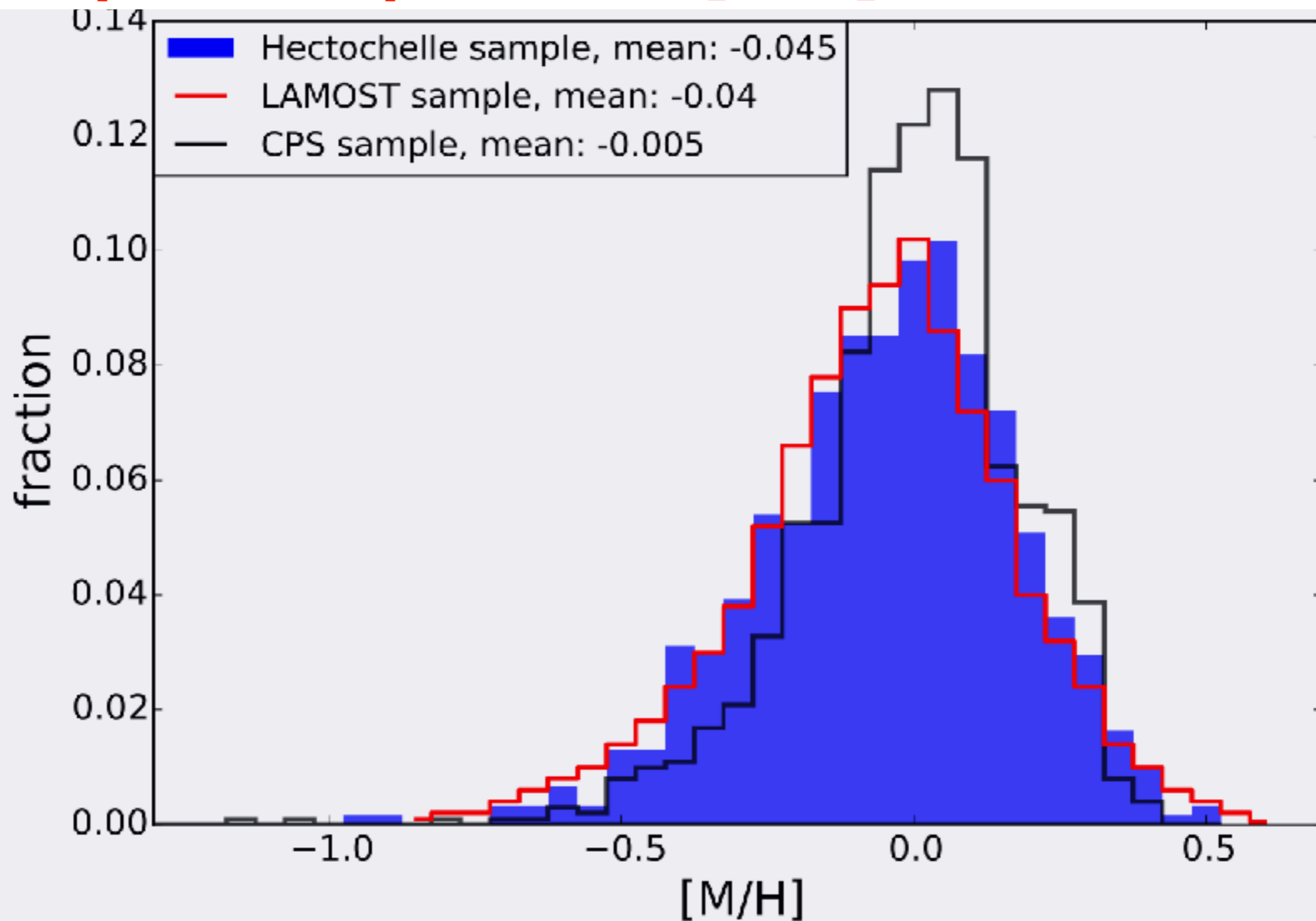
But, the metallicity difference is not big enough to explain the HJ rate discrepancy.



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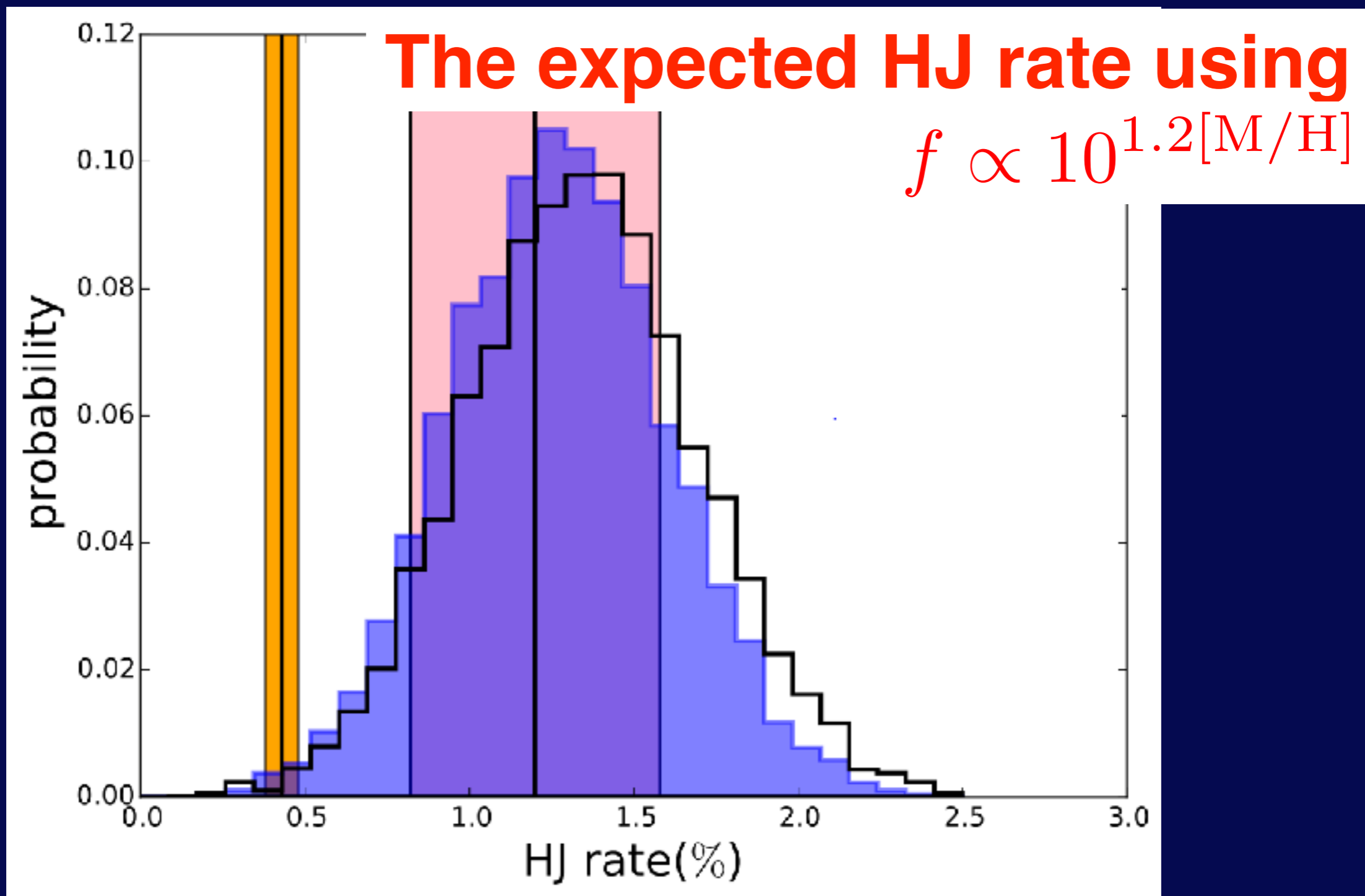
RV sample mean [M/H]: -0.005

Kepler sample mean [M/H]: -0.04



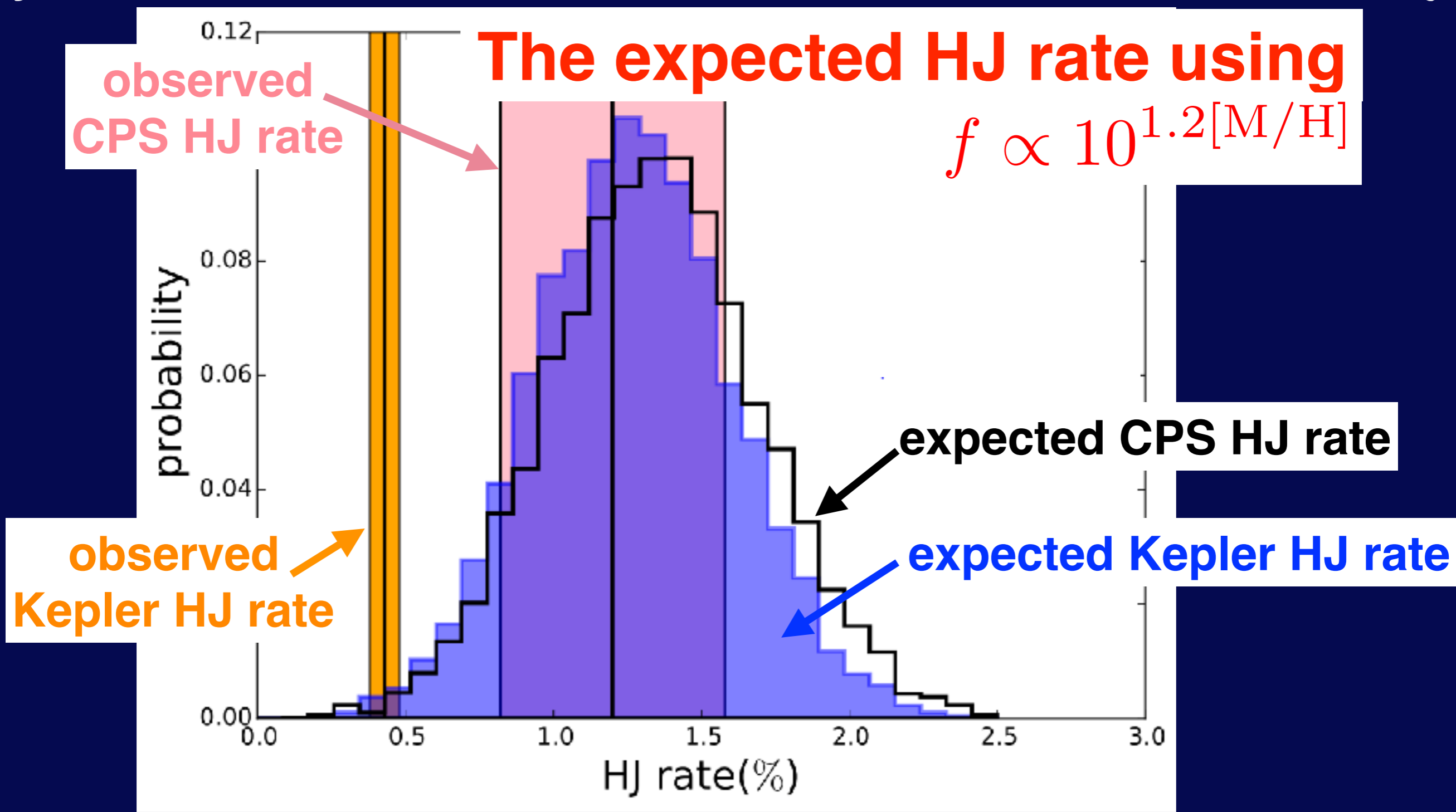
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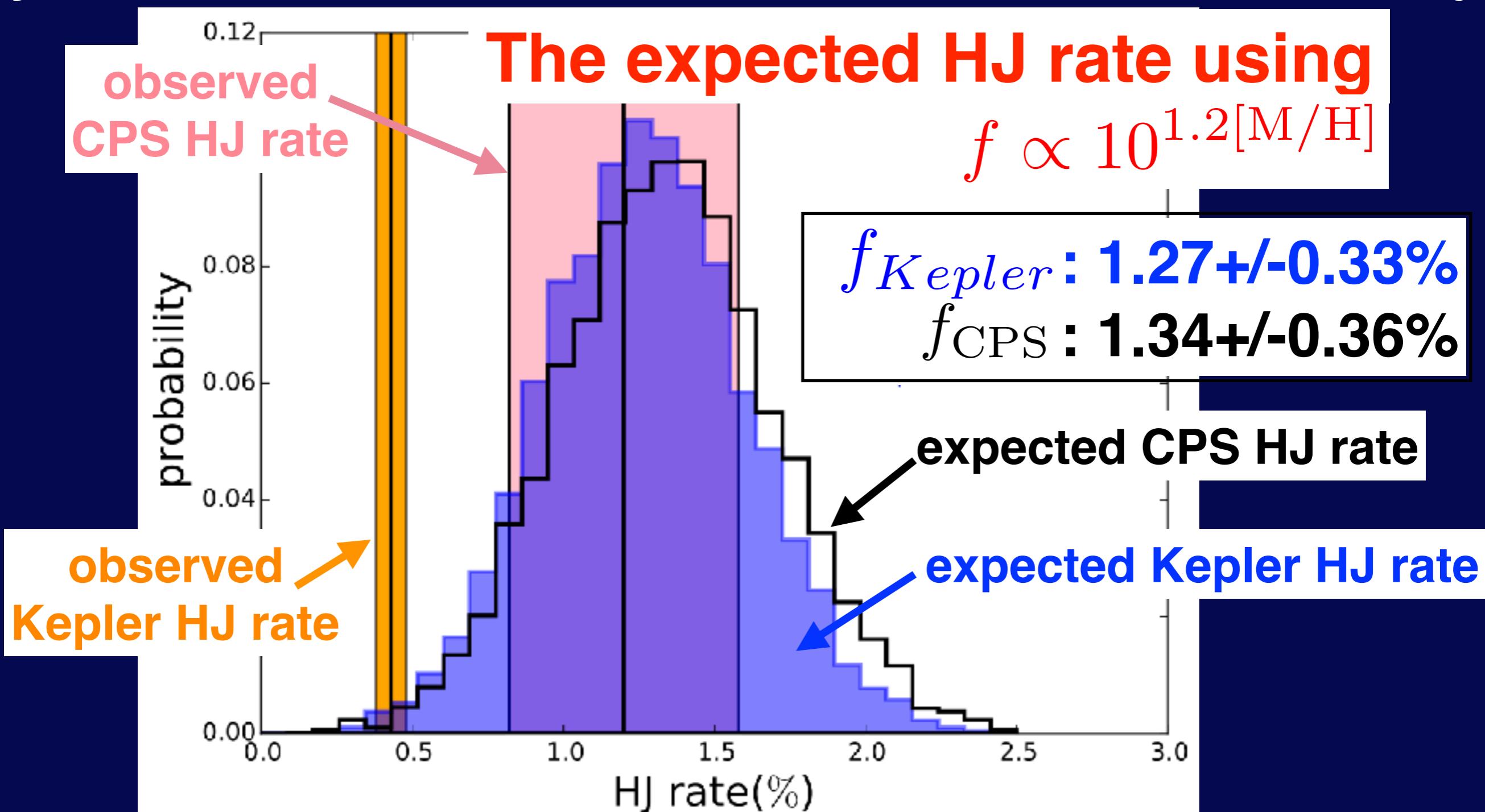
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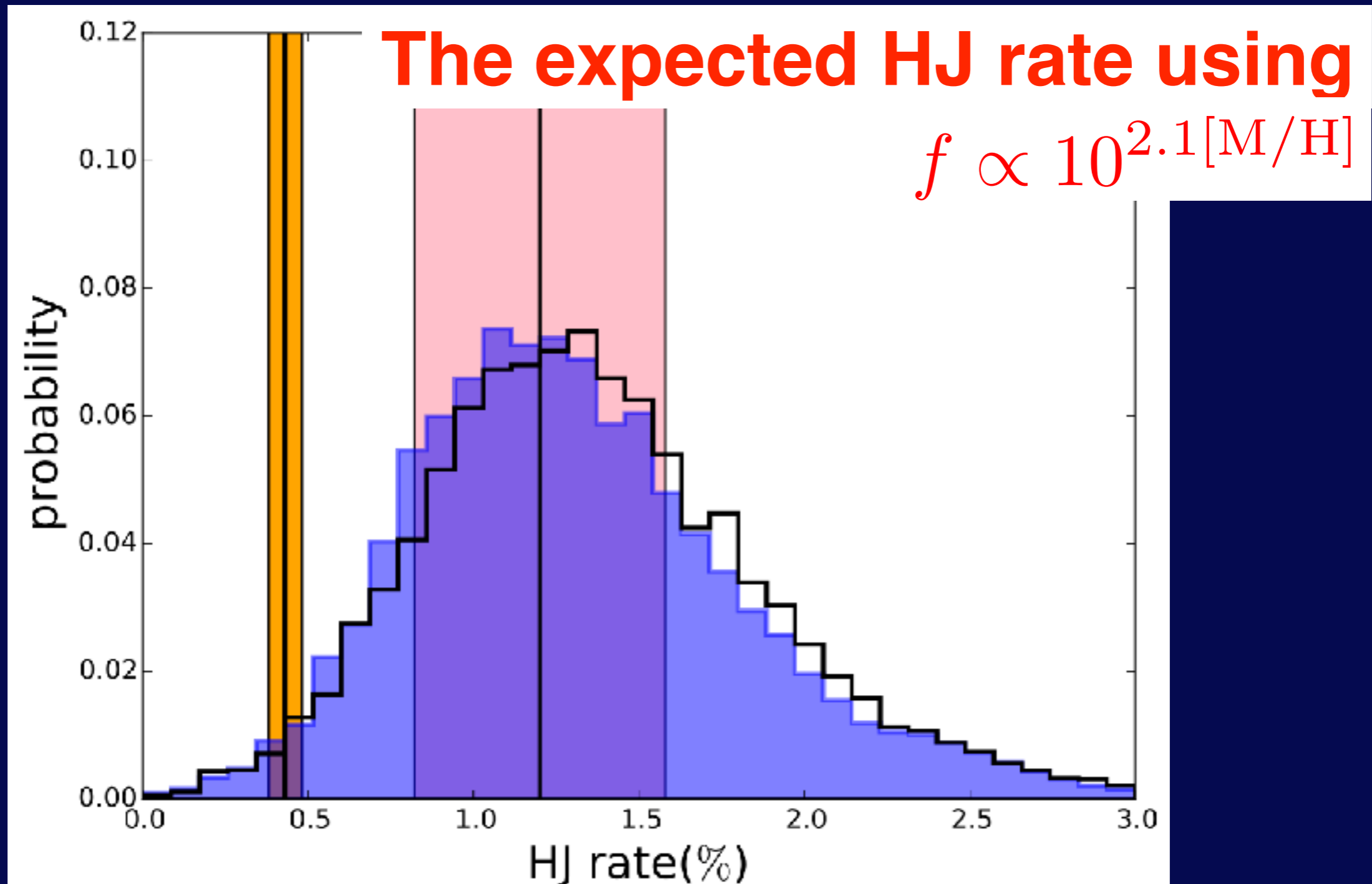
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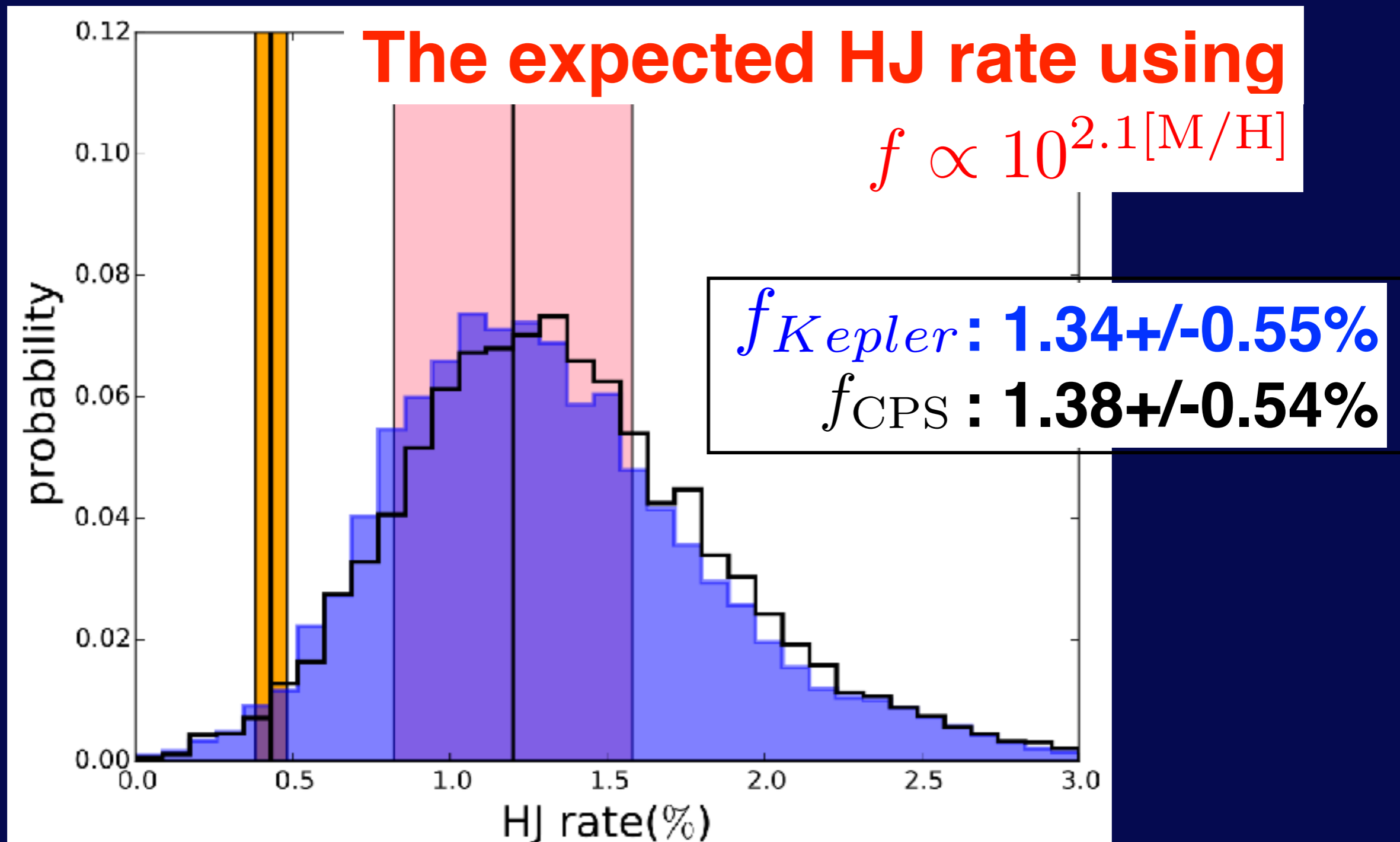
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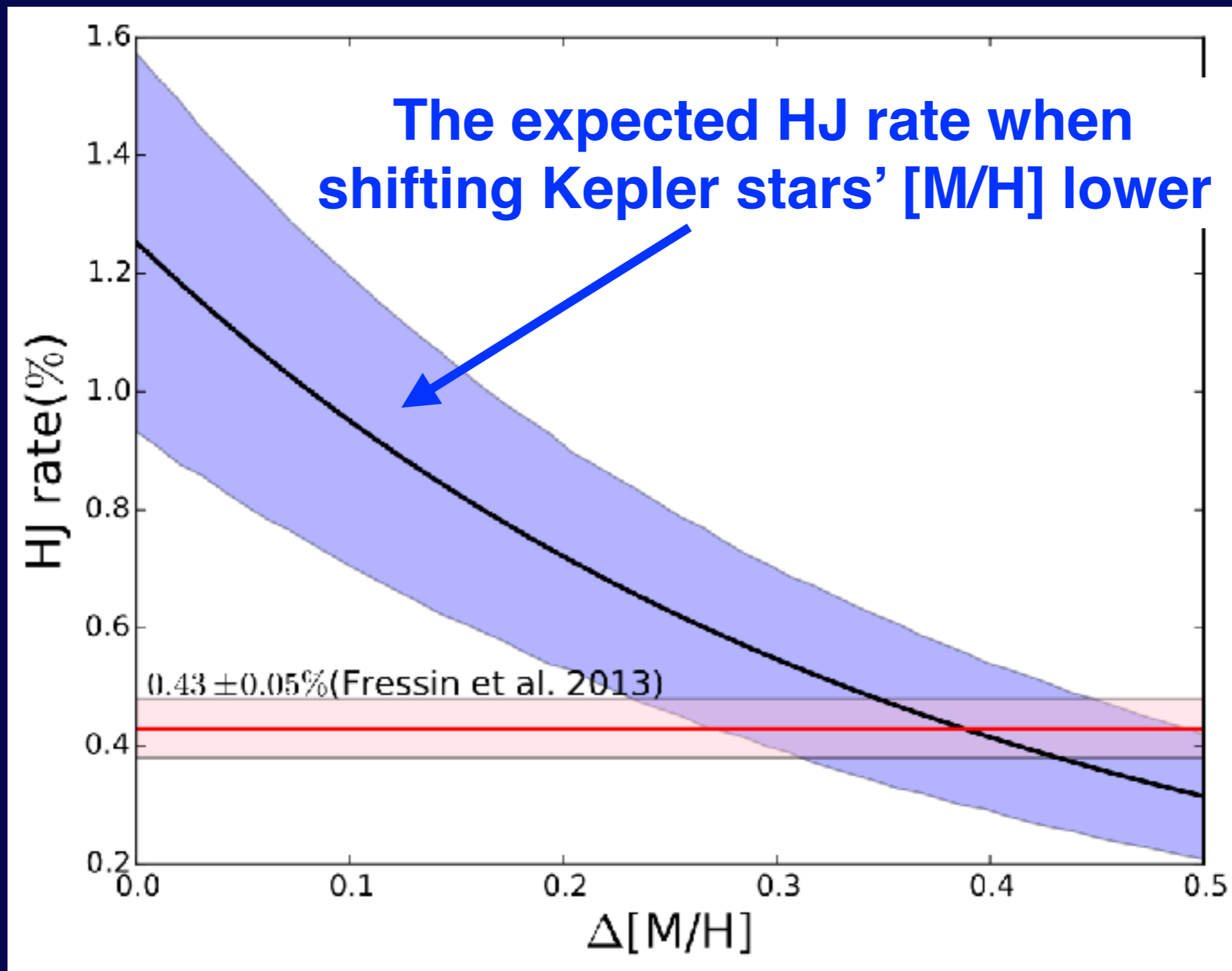
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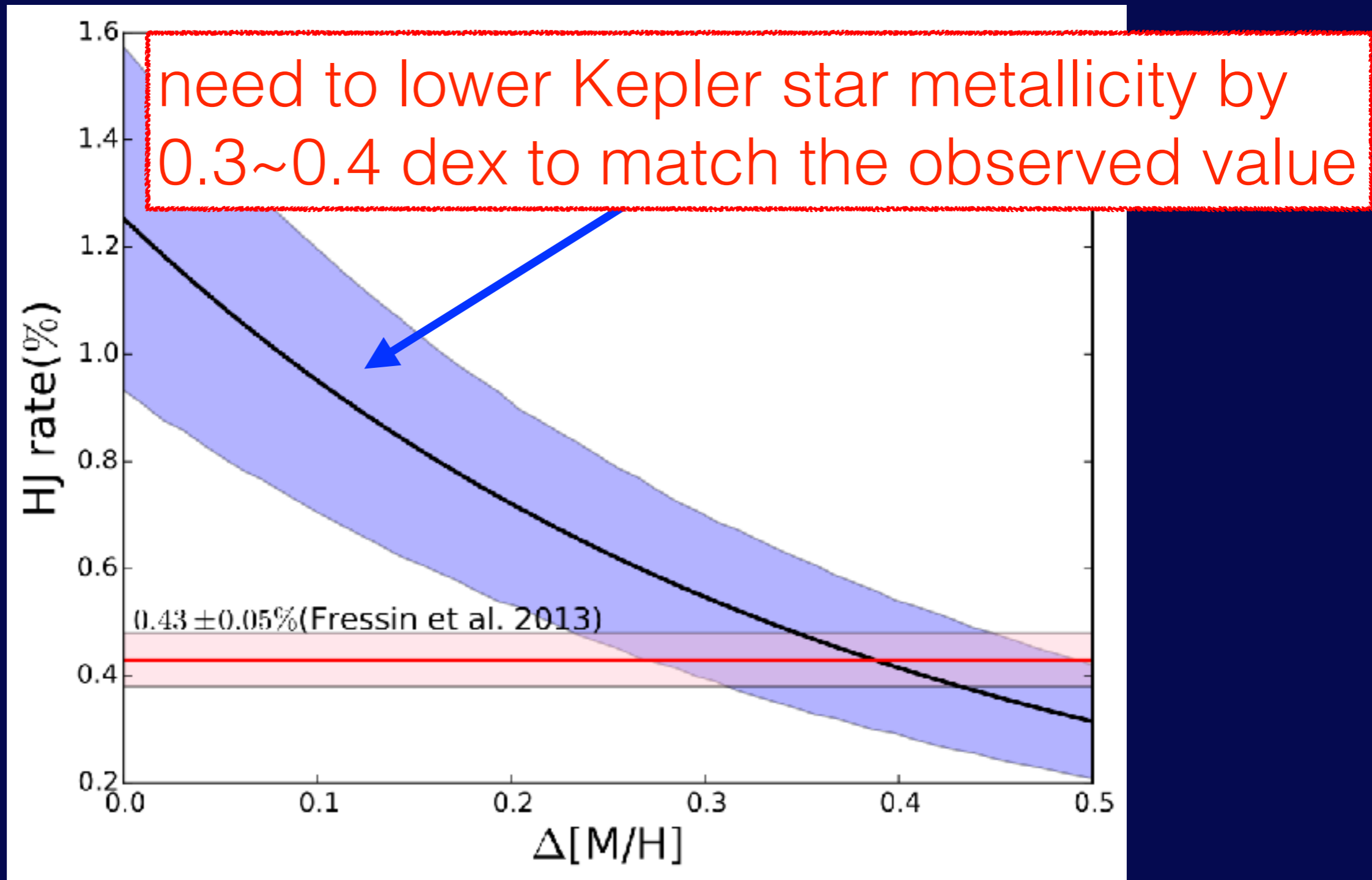
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- * Inaccurate occurrence rate measurements
 - “Inverse detection efficiency” bias occurrence rate estimate, etc.

Check out our paper! (2017APJ, 838, 25G)

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The Metallicity Distribution and Hot Jupiter Rate of the *Kepler* Field: Hectochelle High-resolution Spectroscopy for 776 *Kepler* Target Stars

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Abstract

The occurrence rate of hot Jupiters from the *Kepler* transit survey is roughly half that of radial velocity surveys targeting solar neighborhood stars. One hypothesis to explain this difference is that the two surveys target stars with different stellar metallicity distributions. To test this hypothesis, we measure the metallicity distribution of the *Kepler* targets using the Hectochelle multi-fiber, high-resolution spectrograph. Limiting our spectroscopic analysis to 610 dwarf stars in our sample with $\log g > 3.5$, we measure a metallicity distribution characterized by a mean of $[M/H]_{\text{mean}} = -0.045 \pm 0.009$, in agreement with previous studies of the *Kepler* field target stars. In comparison, the metallicity distribution of the California Planet Search radial velocity sample has a mean of $[M/H]_{\text{CPS,mean}} = -0.005 \pm 0.006$, and the samples come from different parent populations according to a Kolmogorov–Smirnov test. We refit the exponential relation between the fraction of stars hosting a close-in giant planet and the host star metallicity using a sample of dwarf stars from the California Planet Search with updated metallicities. The best-fit relation tells us that the difference in metallicity between the two samples is insufficient to explain the discrepant hot Jupiter occurrence rates; the metallicity difference would need to be $\simeq 0.2\text{--}0.3$ dex for perfect agreement. We also show that (sub)giant contamination in the *Kepler* sample cannot reconcile the two occurrence calculations. We conclude that other factors, such as binary contamination and imperfect stellar properties, must also be at play.

Key words: catalogs – methods: statistical – planets and satellites: detection – stars: abundances – stars: fundamental parameters – techniques: imaging spectroscopy

Supporting material: machine-readable table

Poster: Ensemble Atmospheric Properties of Earth-Analogs around Kepler M Dwarfs

Ensemble Atmospheric Properties of Small Planets around Kepler M Dwarfs

Xueying Guo¹, Sarah Ballard¹, Diana Dragomir¹

Affiliation: 1. MIT 2. Harvard Exolab

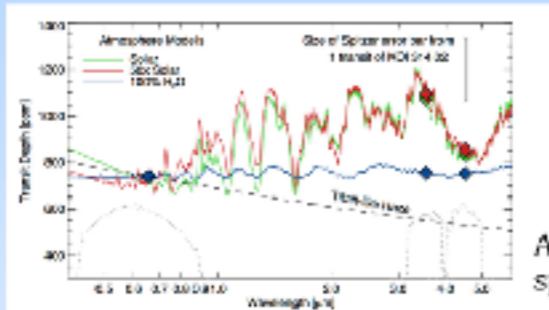
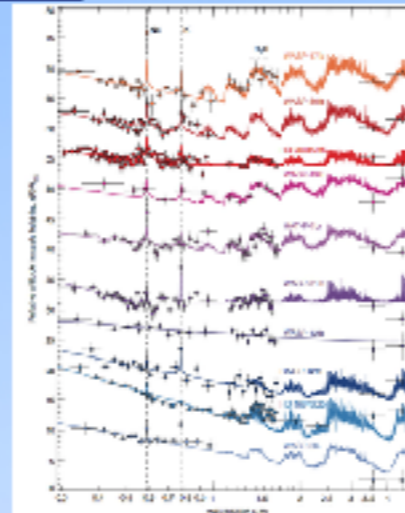


Contact: shryguo@mit.edu



1 Motivation and plan

- **hot Jupiters** exhibit diverse atmosphere composition with **both clear and cloudy/hazy atmosphere possible**. What about **small planets (Earth analogs)**?
—> studies on **clouds and hazes on small planets** have been held up due to the faintness of host stars.
- **our plan**: analyze an ensemble of *Kepler/K2* Earth analogs with *Spitzer* observations.
—> measure **effective radius on Spitzer band**. —> **Obtain haze slope distribution** for an ensemble of similar planets!



Sing et al. 2016, <Nature>: 10 hot Jupiters with well fitted haze/cloud slopes.

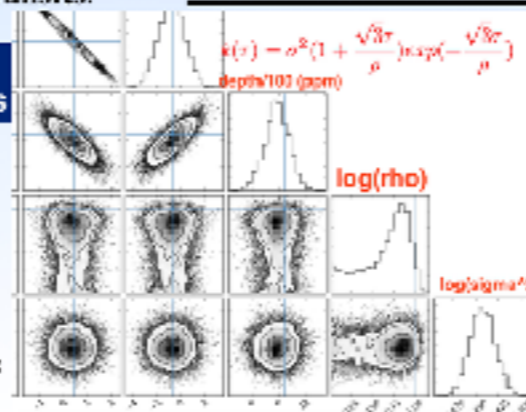
Anchor haze slope with spitzer transit depth

2 Sample planets

- Radius: 1-3 R_Earth
 - Temperature: 300-500 K
 - Host star: M Dwarf
 - Observed by both *Kepler/K2* and *Spitzer*
- 28 planets in total:
- 19 Kepler planets
 - 9 K2 planets
 - 2 of the 28 also have Spitzer ch1 transits.

3 Spitzer transit depth measurement: Pixel Level Decorrelation + Gaussian Process

- **PLD free parameters**: weight of each pixel (c_j), **transit depth**, **transit epoch**, temporal ramp.
- **Gaussian Process**: use Matern-3/2 Kernel function, correlation time scale = rho (see right figure)
- **Test**: simulate light curves with correlated noise. —> our GP reproduced the correlation time scale correctly.
- run on real light curves: **real Spitzer light curve noises show very mild time correlation.** (<3 sec)



4 Result: transit depths

- We have calculated the Spitzer transit depth with uncertainties for 28 Kepler/K2 planets.

- **Figure 1**: Spitzer depths of different observations of a same planet are consistent.
- **Figure 2**: Kepler and Spitzer depth differences are: < 1 Sigma for 88% planets; < 3 Sigma for 95% planets.

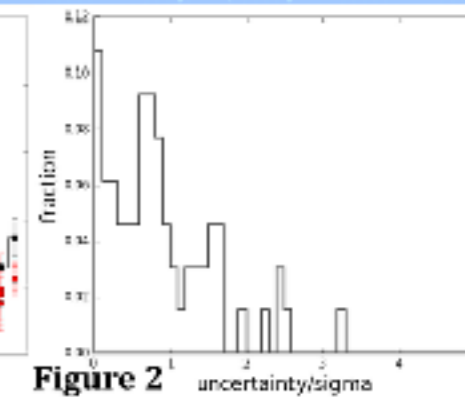
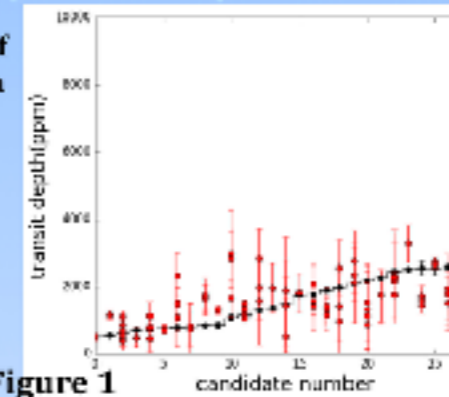


Figure 1

Figure 2

5 Result: atmosphere Slopes

- * Larger slope: no haze/cloud + higher H2O absorption
- * Smaller slope: hazy/cloudy + lower/obscured H2O absorption

Figure 3:

- **Smaller planets (1-2 R_Earth) show larger slopes than bigger planets (2-3 R_Earth).**
- **K2 planets' trend traces Kepler planets' trend.**

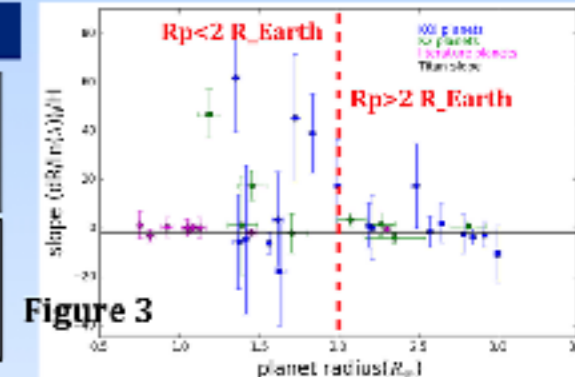


Figure 3

Fit the slope probability distribution with:

- One Gaussian (Figure 4)
 - Two Gaussians: one for R_p<2 R_Earth, one for R_p> 2 R_Earth.
- The probability that smaller and bigger planets follows 2 different Gaussians is around 88%.

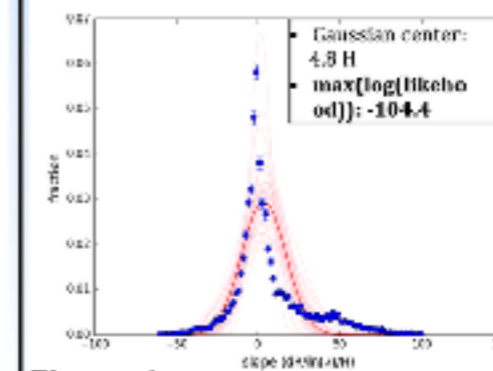


Figure 4

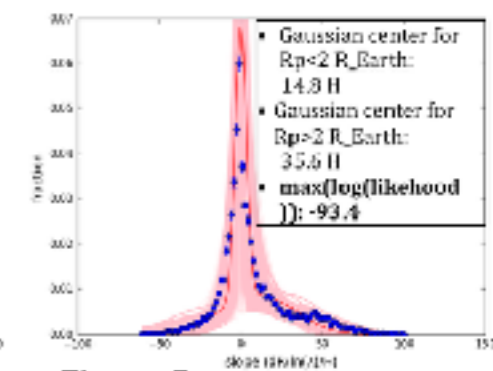


Figure 5

