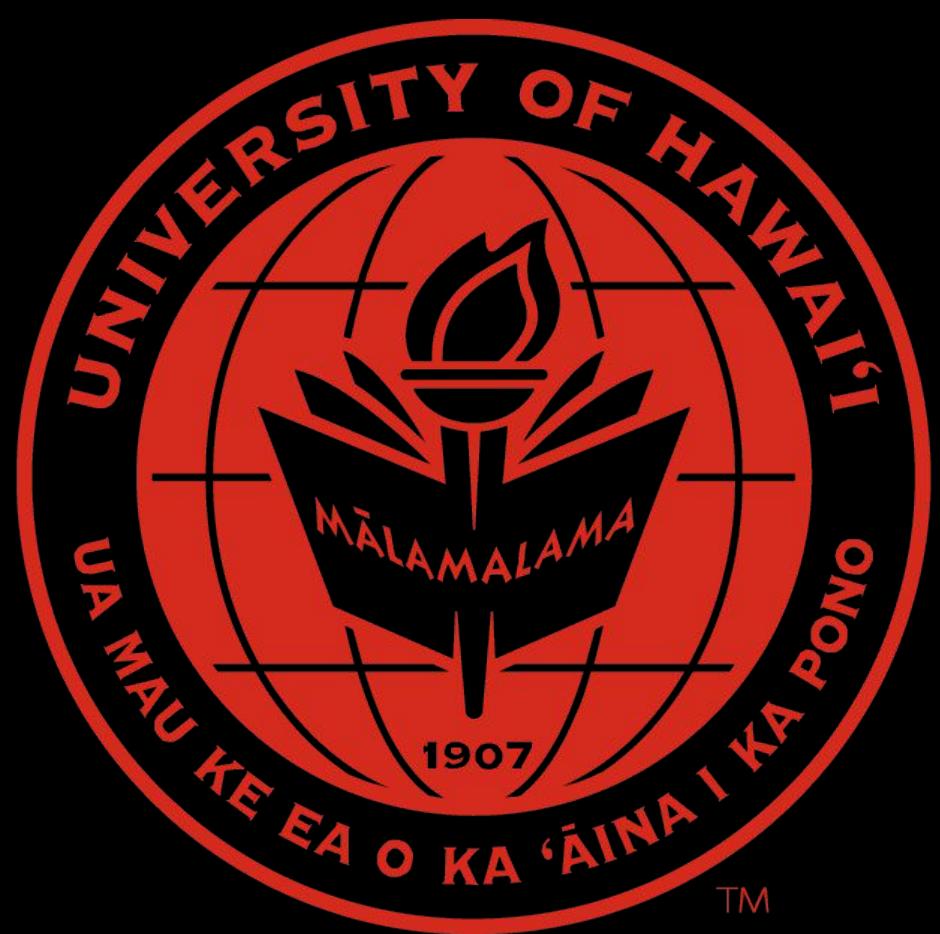
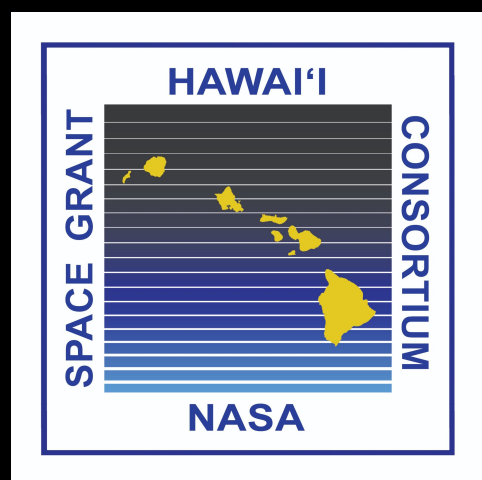
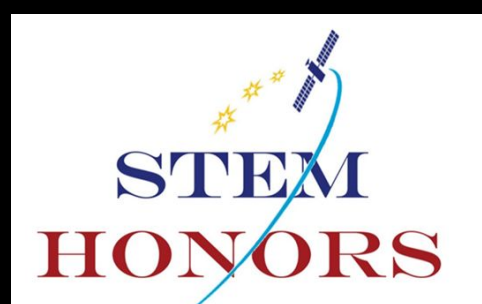




# Measuring the Mass of the Youngest Sub-Neptune, K2-33b, with 3 Years of VLT/CRILES+ Spectral Data



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## Introduction

Approximately, only a third of the discovered exoplanets have mass measurements due to the difficulties in detecting their Doppler shift signals on their host star's spectrum. Young exoplanets, specifically, are difficult to parameterize because their host stars are usually magnetically active and convective. Using the Doppler shifts to measure the radial velocity of a young exoplanet is important to constrain its mass proportions. Thus, the goal of this research is to determine the mass of K2-33b, the youngest sub-Neptune exoplanet, by measuring its radial velocity signals from the time-resolved spectrum of its host star, K2-33, an M-type pre-main sequence star. This project will use three years of spectral data taken by the CRILES+ instrument on the VLT, predicting a mass value between 4-40  $M_{\oplus}$  (RVs of between 2-21 m/s).

## The Data

900s exp time  
3 chip detectors  
SNR: K ~ 48 | J ~ 22

| Date         | # of Obs | Cell Used       | Bands | Orbital Phase |
|--------------|----------|-----------------|-------|---------------|
| Mar 25, 2022 | 8        | 4 SGC<br>4 FREE | K     | 0.72          |
| Mar 27, 2022 | 8        | 2 SGC<br>6 FREE | K     | 0.08          |
| Aug 9, 2022  | 2        | SGC             | K     | 0.93          |
| May 26, 2024 | 4        | FREE            | J     | 0.89          |
| Jul 8, 2024  | 4        | FREE            | J     | 0.79          |

## Data Reduction

The data reduction was used with EsoRex, a recipe tool for ESO's telescopes and their instruments. EsoRex was executed using a Linux environment on a Microsoft computer via the Windows Subsystem for Linux (WSL).

### Segment of Reduced Spectrum

With SGC



Without SGC



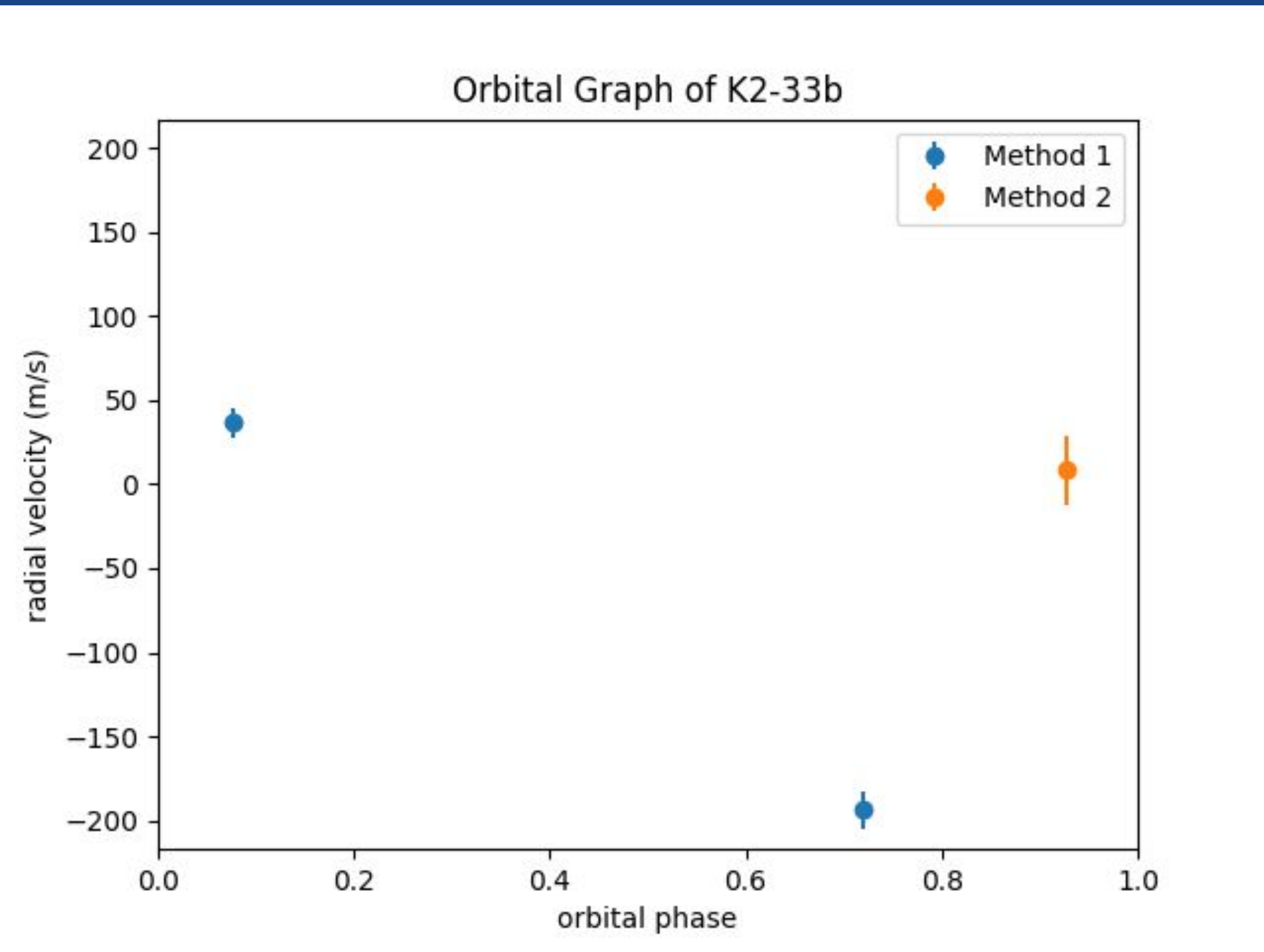
A comparison between data taken with SGC and without SGC for a fragment of the reduced spectrum of K2-33 in the K band. There are more prominent absorption lines in the SGC data which allows for an accurate wavelength reference and can limit the error of RV estimations to as low as 3 m/s.

## Telluric-free Template

A forward modeling of telluric lines is required to remove absorption impurities in the spectra caused by the Earth's atmosphere, allowing for errors as low as 10 m/s. Using VIPER, a telluric-free template was created for each spectrum. By making a new template with the previous as a reference, the new template becomes more precise, resulting in higher quality RV measurements. VIPER then cross-correlates the template with the observed spectrum to measure the RV shifts. The method of template creation that returned the smallest errors was an initial iteration of the SGC spectrum followed by three iterations of the FREE spectrum (Method 1).

Note: VIPER is a relatively new RV estimator and is prone to bugs. While experimenting, it was discovered that VIPER currently only compatible with the K and H band. Therefore, RVs from the J-band data must be estimated with another method.

## Radial Velocity Graph



A graph of K2-33b representing its RV estimated from VIPER at different points of its orbit. The RV estimations for Mar 25 and 27, 2022, were calculated using Method 1, with an error range of 8-11 m/s. Because the datasets on Aug 9, 2022, were all taken with the SGC, Method 2 was used, where the telluric-free template was created with six iterations of the SGC spectrum.

## Conclusion

### Takeaway

Detecting the Doppler shifts of young exoplanets is challenging due to their host star's magnetic activity and convection. Measuring the radial velocity of young exoplanets is important for mass constraints.

### What Was Done

All raw spectra of K2-33 has been reduced. Telluric-free templates and RVs of the K-band datasets have been created and estimated.

### Future Steps

Estimate the RVs for the J-band datasets. Create a Keplerian orbit model to fit the measured radial velocity signals of the K2-33 system. Do some MCMC sampling to estimate the mass of K2-33b.