We Didn't Start the Fire: A T-Dwarf Kinematics Survey

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Background

Brown dwarfs can be useful age tracers, but their ages must be accurately quantified. We would expect the coldest objects to be the oldest, but the temperature of a brown dwarf is also dependent on its mass, resulting in a degeneracy between mass, age, and temperature [1]. We can break this degeneracy by finding an independent measure of either mass or age; population velocity dispersion, which increases over time as individual objects dynamically interact with each other and with large-scale Galactic structures (giant molecular clouds, spiral arms, bars, etc.)[2]. These interactions scatter stars in velocity space, leading to well-established age-velocity dispersion relations [3]. Quantifying a population's velocity dispersion requires measuring the 3D velocity components of all stars in the population, necessitating distance, proper motion, and radial velocities (RV) for a complete sample. Precise RV measurements in-turn require high resolution spectroscopy which can be a challenge for cold and faint brown dwarfs.

Data Set

We are working with **spectroscopic data taken with the Folded-port InfraRed Echellette (FIRE)** on the Magellan telescope [4] (1-2.5 μm, R = 6000). 55 Targets were selected out of all known T dwarfs that have estimated or measured distances within 20 pc of the Sun. Fewer than half of these sources have previously reported RV measurements [5][6], and only 9 have reported rotational velocities [7][8]. **We are prioritizing the brightest object J0718-6155.**

Reduction

We are using FireHosev2 [9], a modified version of the FIREHOSE [4] reduction pipeline. Once extracted from FireHosev2, the individual order spectra of the target goes through a process of blaze and continuum correction to prepare it for forward modeling.

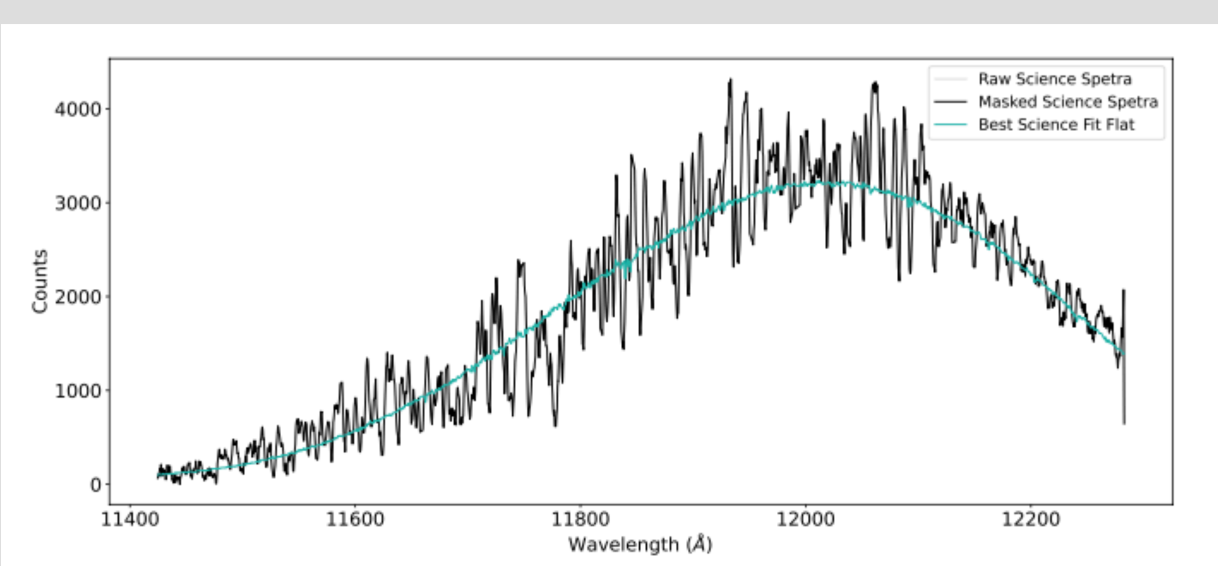
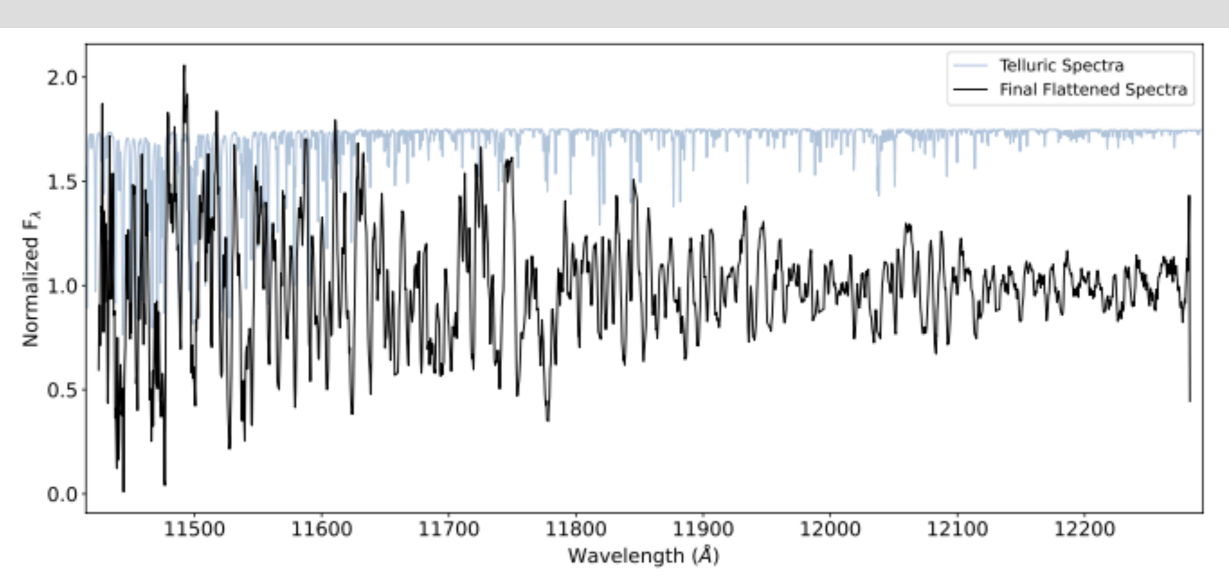


Figure 3: (Top) The extracted science spectrum (black line) and its corresponding fit flat (teal line) to the standard star as determined by the Nelder Meade optimization.



(Bottom) The final flattened spectrum (black line) with a model of telluric(blue line) absorption plotted for reference.

Modeling

We are using an adapted version of Spectral Modeling Analysis and RV Tool (SMART) [5], a Markov Chain Monte Carlo (MCMC) forward-modeling framework for spectroscopic data, to determine properties such as radial velocity, effective temperature, and surface gravity. We employed the BT-Settl08 models [10] on orders 7,9,10,11,14,15,19, and 20.

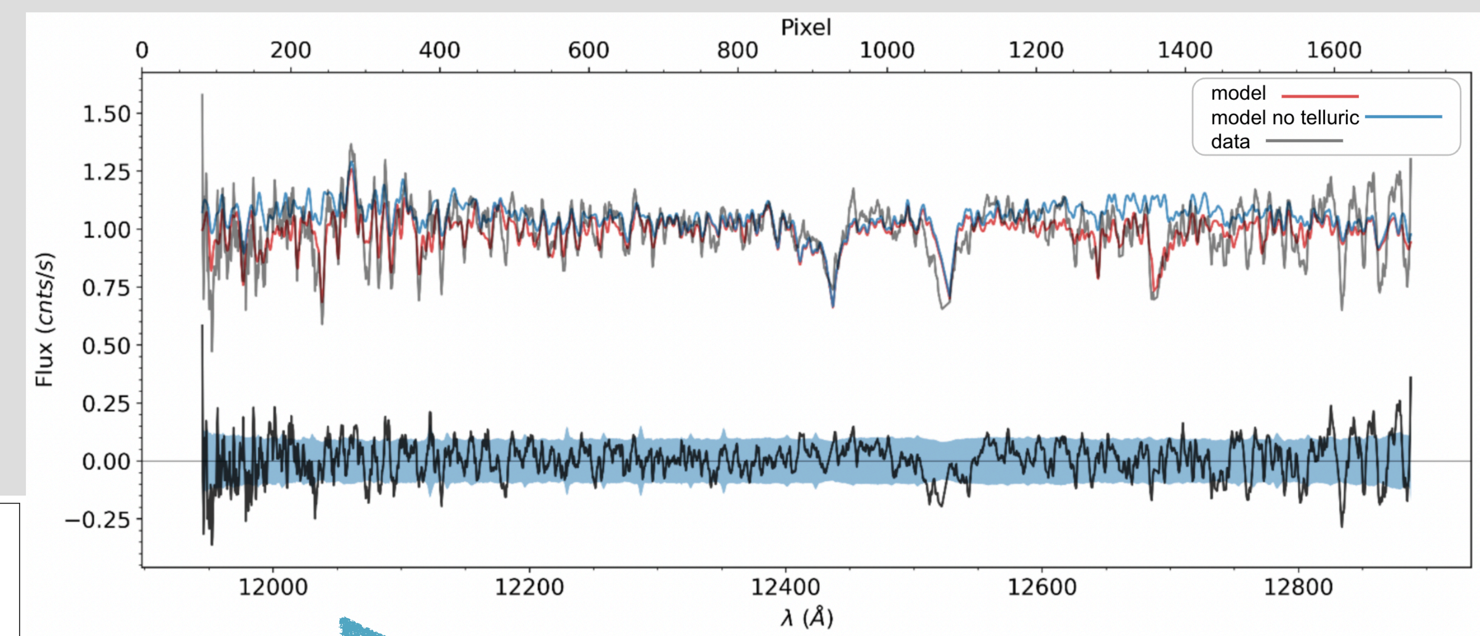
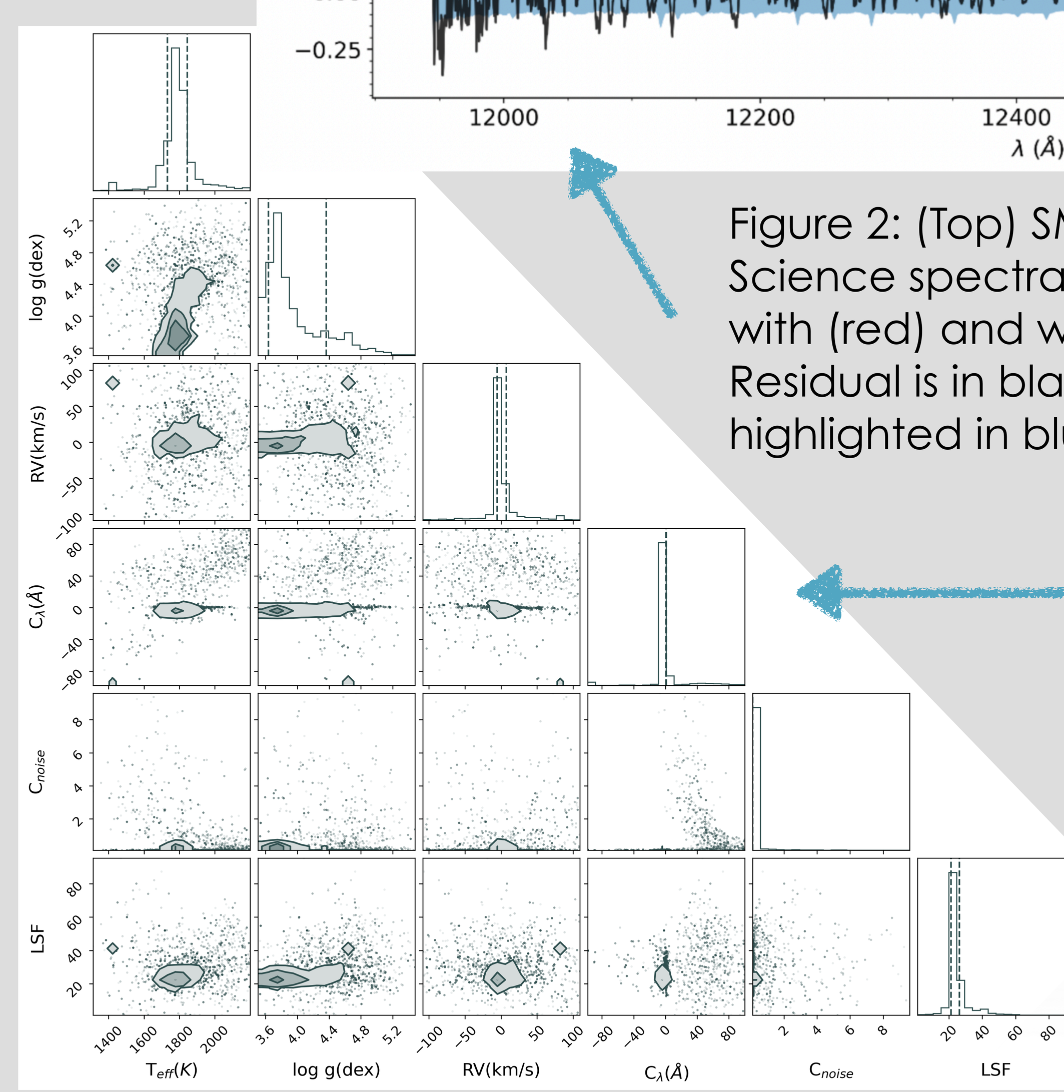


Figure 2: (Top) SMART spectral fits for order 10. Science spectra is in grey. The best fit model with (red) and without (blue) tellurics included. Residual is in black below, with uncertainty highlighted in blue.



(Left) Corner plot demonstrating the correlation between Temperature, specific gravity and Radial Velocity, Flux offset, Noise offset and the Line Spread

We first calculated the average weighted value for each parameter and corresponding χ^2, the error s provided by SMART are vastly underestimated, so we scaled all the uncertainties so that we achieved a reduced $\chi^2 \sim 1$. We also inspected the values across orders to eliminate obvious outliers, which for the purposes of this experiment are points that fall outside of 3σ of the weighted average. If an order was removed, the average was recalculated and the cycle repeats until only values that fall within 3σ remained.

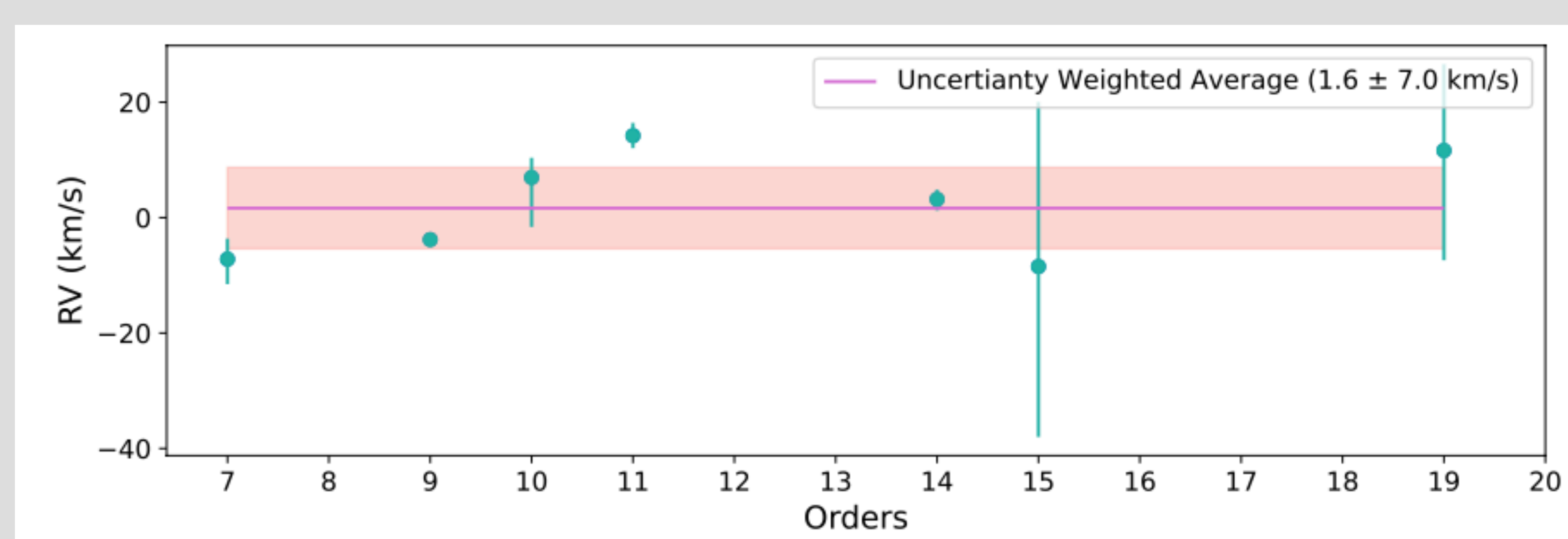


Figure 3: Best fit parameters for radial velocity, with associated error bars. Purple line is the weighted average of the fits with the shaded pink region indicating the uncertainty.

Discussion

We measured an **RV of 2 ± 7 km/s** for the T6 dwarf J0817-6155 which was previously found to have an RV of 6.1 ± 0.5 km/s [6]. We are in agreement with these previous measurements. For a spectrograph like FIRE (R=6000)[4] we would expect a precision of ~ 4-5 km/s, so our results are within reason, however we can still improve our model fits.

There are several next steps I intend to accomplish in the near future.

- Add **fit for vsini**, which should improve the fit and possibly shift RV.
- Adjust the spectral range over which we are fitting models to exclude strong water, methane or telluric bands which dominate the overall shape of the fitting.
- **Integrate and test the Sonora Diamondback and ElfOwl models with SMART** to strengthen the validity of the final fit parameters and improve the quality of the fits.

References

[1] Burrows et al. 2001a ,
[2] Spitzer&Schwarzsschild 1951,
[3] Wielen et al. 1977,
[4] Simcoe et al. 2008,
[5] Hsu et al. 2021,
[6] Tannock et al. 2022,
[7] Schmidt et al. 2010,
[8] Berger et al. 2021,
[9] Gagne et al. 2015,
[10] Allard et al. 2012