Abstract

Nathaniel Kerman's Thesis:
Improving the Wavelength Calibration for the EXPRES Spectrometer

Nathaniel Eden Baird Kerman
2020

Goals: We present a new and improved catalog of Thorium and Argon (ThAr) lines across the breadth of the visible, near infrared, and near ultraviolet spectrum to allow wider-range calibrated spectra, the tighter characterization of EXPRES spectra and more precise measurements of radial velocity (RV). We base this catalog on a subset of the National Institute of Standards and Technologies (NIST) ThAr Line List which extends from 3500 – 8500 Å. We present corrections to these lines specific to the EXtreme PREcision Spectrograph (EXPRES) based on spectra of a laser frequency comb (LFC) produced through EXPRES. The wavelength range of the corrections extends from 4570 - 7230 Å.

Methods: We use a series of 701 ThAr spectra taken throughout 2019 and collect a total of 4142 LFC spectra taken within $\pm$30 minutes of each ThAr exposure (with a median of 5 LFC exposures per ThAr exposure) and the collective LFCs are fit with a smooth spline to assign a new wavelength to each ThAr line's central pixel.

Results: We update 2383 ThAr lines of the catalog with values assigned by the LFC wavelength solution. These corrections are confined to the maximum 2019 wavelength range of the LFC output, yet this represents a significant increase in wavelength range compared to the current LFC limit (with an additional 356 Åon the blue end). The updated catalog values have order-of-magnitude uncertainties of 10^{-4} Å and produce **FILLER** results within EXPRES' calibration pipeline.

Nathaniel Kerman's Thesis:
Improving the Wavelength Calibration for the EXPRES Spectrometer

Presented to the Astronomy Department
of
Yale University
for the Bachelor's Degree in Astrophysics

by
Nathaniel Eden Baird Kerman

Thesis Director: Debra Fischer

May 2020

Acknowledgments

Insert acknowledgments here. {Same line
Different Line}
I am deeply indebted to the continuous research advice and help I received from Dr. Debra Fischer and Ryan Petersburg, as well as the help and advice from Lily Zhao.

I am also grateful to my fellow undergraduate students who gave me help and support working through so many little mysteries.
changes

I am deeply indebted to the continuous research advice and help I received from Dr. Debra Fischer and Ryan Petersburg, as well as the help and advice from Lily Zhao.

Contents

List of Figures

List of Tables

Chapter 1

Introduction and Motivation

1. What is the EXPRES Spectrograph?
    - Echelle Spectrographs (See Eversburg)
2. What are RV Data?
3. Why are RV Data important?
    - Exoplanet Detection via the RV method
    - Small exoplanets require extremely precise RV measurements
4. Such precise meaurements require equivalently exacting calibration.

Chapter 2

Wavelength Calibration

1. Why do we need to calibrate wavelength?
    - The spectrograph's detector can only record intensity (*I*) as a function of pixel location
    - We need some method to transition from this I(x,y) $\rightarrow I(\lambda)$
    - A Wavelength Solution converts (x,y) $\rightarrow \lambda : \lambda_{soln} = f(x, y)$
    - In the EXPRES instrument's case, this x corresponds to the calculated One-Dimensional pixel value of a given Echelle Order and y corresponds to the Echelle order itself
2. How *precise* do we need to be?
    - $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta v}{v}$
    - A change in wavelength of 1 Å at 5000 Å equates to an enormous RV of m s $^{-1}$
3. In order to convert from $(x, y) \rightarrow \lambda$ we need a series of fixed reference wavelengths.
4. EXPRES' Wavelength Calibration Methods
    - **Thorium Argon** cathode lamp (*ThAr*) produces atomic spectral lines
        - Current catalog gathered from NIST, the lines are not specific to EXPRES
        - Wide wavelength range from between 3500 and 8500 Å
        - Used to generate a course wavelength solution λ_{ThAr}(order, pixel) which then assigns mode number to the LFC lines
    - **Laser Frequency Comb** (*LFC*) produces a "picket fence" of sharp lines at even spacing within frequency space
        - If the mode number of a line is known (from the ThAr solution), its central wavelength can be very precisely characterized

- Produces an abundance of lines, one every $\sim$ 10 pixels

5. -

Chapter 3

LaTeX Learning

Here I am learning to LaTex:

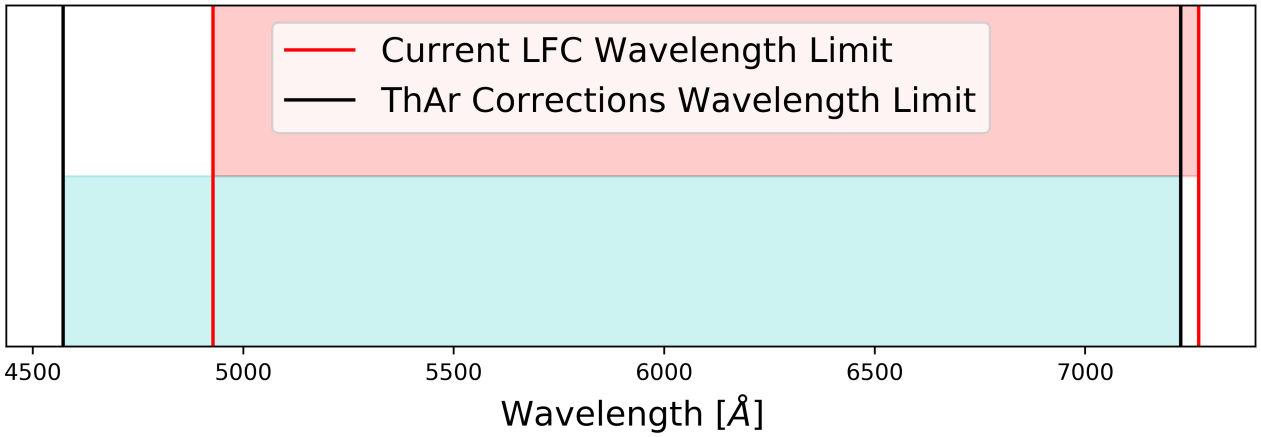

Figure 3.1: Test Plot 1

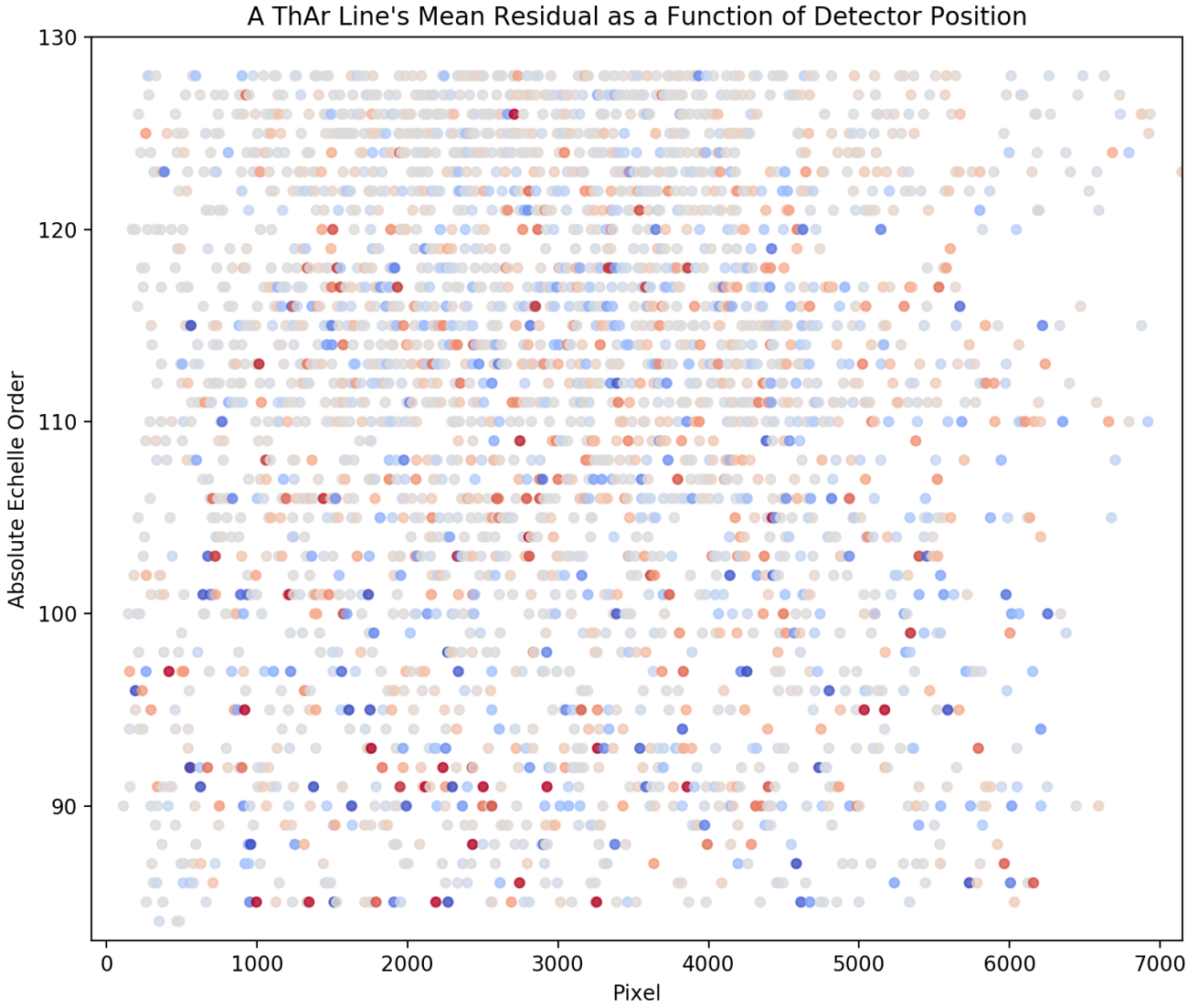

Figure 3.2: Test Plot 2