Temperature Dependence of Focus Position is Controlled by Thermal Expansion of Optics, not Refractor Tube

In an attempt to improve my astroimaging by deriving robust statistics for temperature compensation and filter offsets, I conducted a **months-long set of experiments** in winter 2018-2019. In all, I collected **nearly 1000 individual data points consisting of paired focus position and temperature** across a range of more than 35 Celsius (63 Fahrenheit).

TL;DR: Temperature compensation works great unless you use a dew heater!

Conclusions:

Details are provided below, but here are **two major conclusions**:

1) Holding FL and focuser constant, more than 95% of the variation in focus position is explained by a **linear relationship with temperature**, with very robust and consistent estimates of both slope and intercept; and
2) Both the refractor tube and the optics (especially the large objective lens) change size in response to temperature change, but **variations in the focus position were dominated by thermal expansion and contraction of the objective, not the tube**.

Implications:

There are **three practical implications** of these results for my imaging:

a) Temperature compensation works very well as long as the refractor tube and objective lens cool at approximately the same rate;
b) **Temperature compensation fails completely when I use a dew heater** to control the temperature of the objective lens. In this case, the tube and lens cool at different rates;
c) ***I routinely use a dew heater on my 5-inch refractor, so I no longer use temperature compensation at all*.**

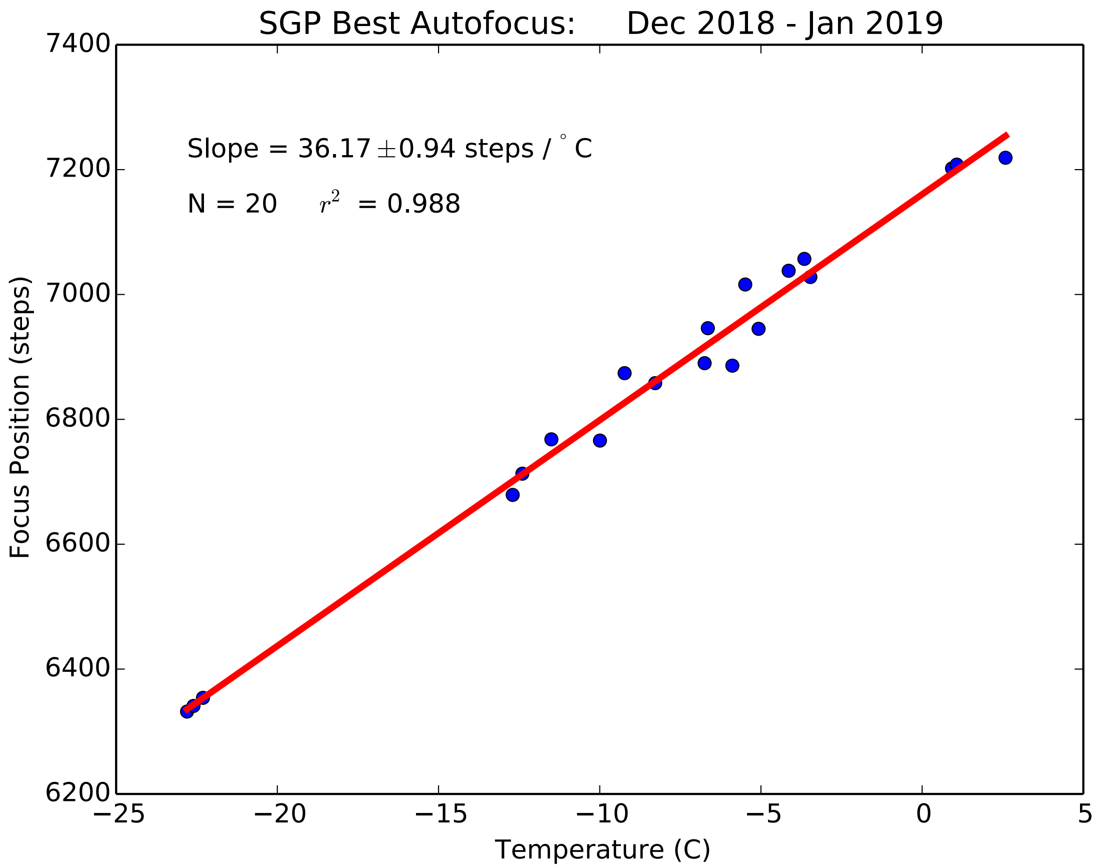
Methods:

All my experiments were performed with a Borg 125 SD refractor (native FL = 650 mm). The data were collected with a one-shot color imager at two different focal lengths (488 mm with a reducer and 1050 mm with a telecompressor), and two different motorized focusers (a FeatherTouch with an Optec QuickSync motor, and an Optec TCF-Si 3-inch focuser). Both focusers used a temperature probe attached to the refractor tube (insulated from the air with polyurethane) to measure focus temperature.

I built my own **analysis scripts in python to extract tube temperature, and focus position directly from FITS image files**. Data included actual light frame subs from real imaging runs as well as dedicated data collection runs. Mostly these were done when the Moon was too bright for imaging and involved performing repeated autofocus runs. Doing this across many nights and seasons allowed me to collect many hundreds of data points across a very wide temperature range.

Results:

Here's a plot of 20 pairs of focus position vs tube temperature spanning a temperature range of more than 25 C on the Borg 125SD f/3.9 with the FeatherTouch/QuickSync system. The linear



relationship explains almost 99% of the variance in focus position. The focuser stepsize is about 1.2 microns, so the entire variation in focus position across this temperature range (almost 60 F) is just over 1 mm.

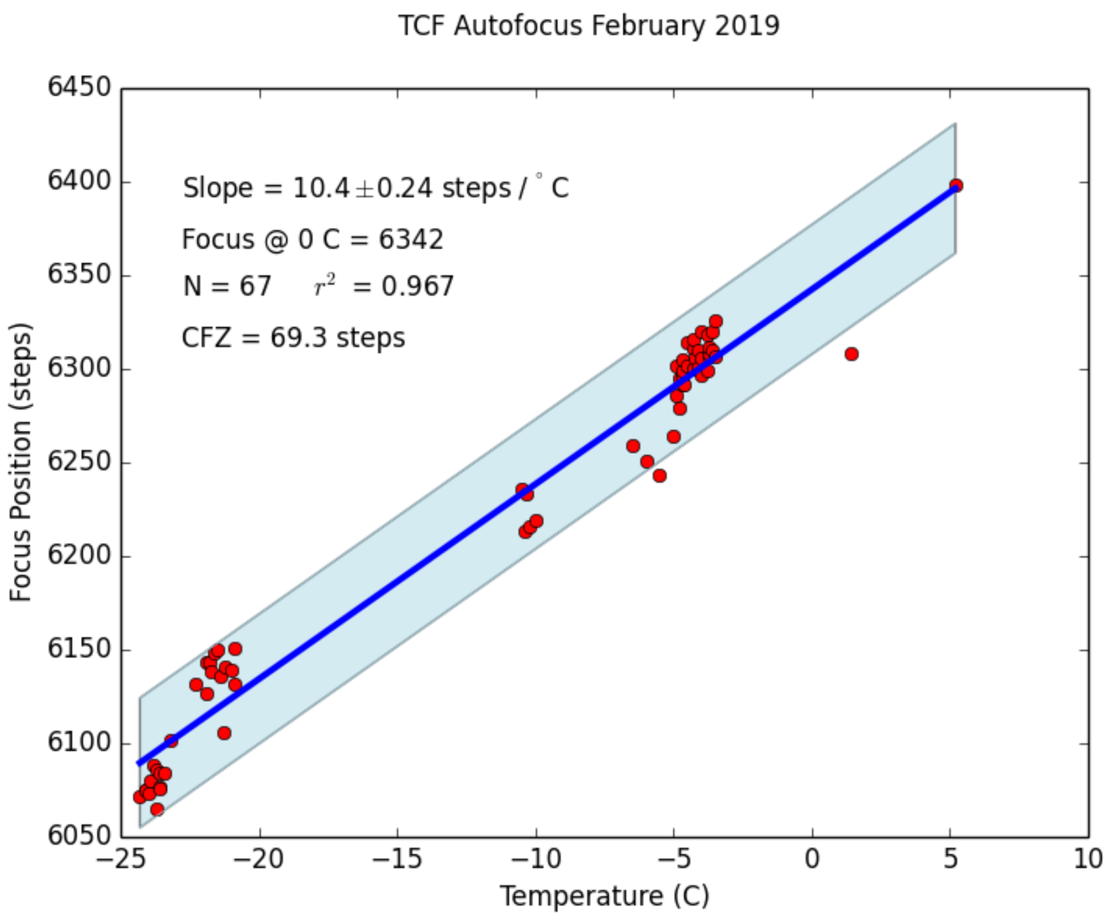
Later, I switched to a heavier imaging package with a monochrome CCD, filter wheel, and on-axis guider. The FeatherTouch is not strong enough to support this heavier imaging train without slippage, so I installed a much more robust Optec TCF-Si 3-inch focuser.

Here are results from a few nights (Luminance only) with the heavy focuser. The slope and intercept are of course different than with the earlier imaging train, but again the linear relationship with temperature explains more than 95% of the variance in focus position across a range of more than 30 Celsius.

The light blue band shows the critical focus zone (CFZ) for this optical system, computed as

$$CFZ = 4.88 * wavelength * f^2$$

where CFZ and wavelength are in microns and f=8.4 is the ratio of focal length to aperture. The plot shows that simply using the temperature compensation would result in a focus position within the CFZ for 65 of the 67 data points.



Discussion:

Note that for both imaging systems, the slope is positive. I verified by watching carefully as I moved the focusers in and out that larger numbers correspond to a longer optical path through the focuser and vice versa.

This means that as the temperature increases, the focuser must move outward to increase the distance between the objective lens and the imaging chip. Conversely, when the temperature drops, the focuser moves inwards to decrease the focal distance.

I had always assumed that the physical reason for temperature compensation of telescope focus was thermal expansion and contraction of the long metal refractor tube. I think this is a common assumption, and it's the reason we use temperature probes attached to the tube rather than air temperature to determine temperature compensation.

My results suggest that the actual behavior of my refractors is precisely the opposite of this common expectation!

If tube contraction was the physical mechanism causing temperature-related focus shifts, the focuser should move outward during the night to compensate for the cooling (shortening) tube and vice versa. But over many months of taking many hundreds of these measurements, I always observed the opposite. The temperature relationship is very robust, but the sign of the slope is opposite of what we'd expect based on tube expansion and contraction.

What I think is happening is that the linear relationship between focus position and tube temperature is due to the objective lens in expanding and contracting.

In my case the measured temperature is that of the lightweight aluminum Borg tube (not the air). The 125 mm diameter air-spaced doublet lens is much heavier than the tube. Recall that the focus position varies by only about 1 mm over a huge temperature range (around 60 F).

I hypothesize that both the lens and the tube expand and contract as the temperature changes. As the lens cools it contracts more than the tube and as it warms it expands more than the tube. Because lens contraction dominates, the optical path of the scope expands as the temperature drops, which is why the focuser must move inward during the course of the night.

Both the telescope tube and the objective lens cool by thermal radiation and so are generally colder than the air. This is a good reason to perform temperature compensation based on measured tube temperature rather than air temperature. It's also the reason we can suffer from dew or frost on our objectives even when the air temperature is above the dewpoint.

Even though I live in a relatively dry climate (Colorado), I occasionally lose most of a night of subs when dew or frost forms on the large objective lens of my refractor. In February, I finally purchased and installed a dew strap and controller to eliminate this problem.

Lo and behold, ***as soon as I started using the dew heater, the temperature compensation for my focusing system failed completely! This is because the refractor tube and objective lens no longer cool at the same rate during the night.*** This observation is completely consistent with the hypothesis that it's lens contraction rather than tube contraction that controls the optical path length of the imaging system. The tube still cools and I'm still measuring the tube temperature. But there's no longer any significant linear relationship between tube temperature and focus position!