

# On the Fading of the STIS Ultraviolet Calibration Lamps

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## ABSTRACT

With plans to continue operating *Hubble* through 2022 and beyond, yet with no more servicing missions to improve or replace the existing instrument suite, it is critical for the future science return of the observatory that data remain able to be calibrated at the same fidelity as earlier observations. Unfortunately, as the Space Telescope Imaging Spectrograph (STIS) has been in orbit for over 20 years, its calibration lamps are fading, risking the precision of future science opportunities. I analyze here the fading of these lamps in the ultraviolet and suggest possible mitigation strategies. In particular, I suggest moving from the LINE lamp to the HITM2 lamp for wavelength calibrations in the most far ultraviolet settings. For the NUV and FUV flat fields, I show that the strategy of alternating years to obtain deep flats appears to have slowed the fading of these lamps, but the modes in which the flat fields are taken may have to be changed again in future cycles to obtain enough counts for robust flat fields.

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## 1. Introduction

As ultraviolet astronomy *cannot* be done from the ground and there are no currently planned space facilities to provide future access to the UV, the ultraviolet spectrographs aboard *Hubble* are a precious resource to the community. Unfortunately, with STIS having been in orbit for 20 years, its calibration lamps are fading, risking the precision of future science opportunities.

I analyze here the current status of the ultraviolet STIS calibration lamps. Though the primary calibration lamps are all well short of their nominal usage lifetimes (as compared to pre-launch ground-based measurements), they are fading more rapidly than expected based on these nominal lifetimes (Kerber et al. 2005, Nave et al. 2012). Of particular concern are the wavelength calibration lamps, as these are used in every GO observation taking spectral data in order to determine the wavelength calibration zeropoint (Section 2). I find, as did Pascucci et al. (2010), that these lamps are fading achromatically, losing flux at the blue end while retaining it at the red end. The thus far barely used HITM2 lamp, however, should serve for obtaining robust STIS/FUV wavelength calibrations through 2022. Flat fields, on the other hand, are much more stable; in the last few cycles, these have been taken less frequently in order to extend the lamp lifetimes. I show in Section 3 that this strategy has worked, and that the lamps should last until 2022.

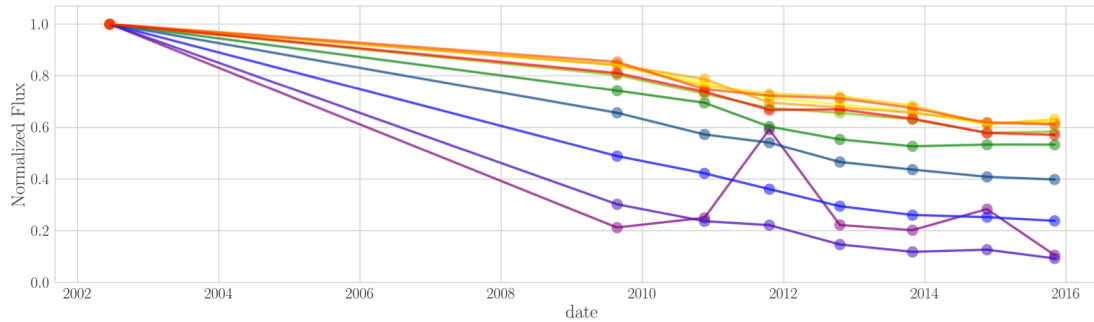
## 2. The Pt-Cr/Ne Lamps and Wavelength Calibrations

STIS has three Pt-Cr/Ne lamps: the LINE lamp, in the Calibration Insert Mechanism (CIM), and two Hole-in-the-Mirror lamps, HITM1 and HITM2. The LINE lamp is typically used for UV wavelength calibration, while the HITM lamps are used for target acquisition, with HITM1 generally being favored over HITM2. A notable exception, however, is that GO wavecals in G140L/1425 use HITM1. As G140L/1425 is the mode most useful to tracking the overall fading of the Pt-Cr/Ne lamps in the FUV, tracking the FUV fading of the LINE lamp is therefore limited to the annual wavelength dispersion solution monitors. To further complicate matters, in nearly all cases the Pt-Cr/Ne lamps are operated at the “medium” current of 10mA, but through Cycle 23, the G140L/1425 observations of the LINE lamp have been with a lower current of 3.8mA, which leads to a factor of  $\sim 20$  less flux. As I show in Section 2.1, the LINE lamp is extremely faint at the bluest wavelengths at this low current; we therefore increased the current to 10mA for all settings for the Cycle 24 dispersion monitor (except the redder G230L/2376, which remains at 3.8mA; PID #14831). Unfortunately, the glow region was stronger than normal for these data, making them unsuitable for measuring the rate at which the lamp is fading. In the analyses that follow, all fluxes are net counts/s in reduced x1d’s and the dispersion solution is the only calibration performed; separate analyses have indicated that the time-dependent sensitivity (TDS) contributes only somewhat to the observed fading.

### 2.1 The LINE Lamp

Pascucci et al. (2010) examined the fading of the LINE lamp, finding that it was fading much more rapidly at the bluest wavelengths ( $< 1250\text{\AA}$ ) than at redder

wavelengths. In Figure 1, I show the achromatic fading of the LINE lamp in the G140L/1425 setting from the annual dispersion solution monitor; these data are all taken at 3.8mA and the 52x0.1" aperture. At redder wavelengths, the LINE lamp is fading less slowly, losing only ~40% of the 2002 flux at  $>1450\text{\AA}$  by 2015 versus the 80-90% at the bluest wavelengths. It is important to note that this lamp faded at *all* wavelengths during the ~5 years that STIS was offline, indicating that the fading is not exclusively tied to usage. Note that the bluest bin ( $1150 < \lambda < 1200\text{\AA}$ ) is faint enough that its total net counts are highly affected by Poisson noise; the recent move to 10mA has largely mitigated this effect.



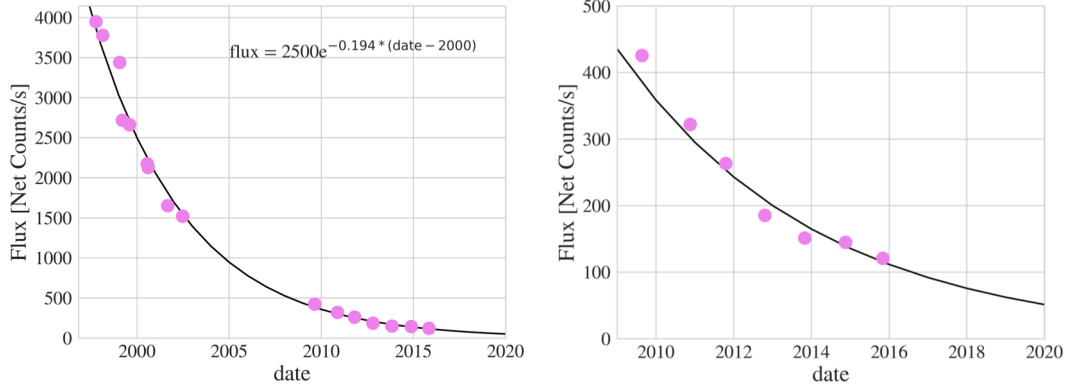
**Figure 1:** The achromatic fading of the LINE lamp from 2002 to 2015 in the G140L/1425/52x0.1 setting. Each line corresponds to a  $50\text{\AA}$  wide bin, from  $1150$  to  $1700\text{\AA}$ , from purple to red, normalized to the 2002 net counts/s (in the reduced x1d's) in that bin. The bluest wavelengths have been fading much more rapidly than the redder wavelengths.

#### *G140M/1218:*

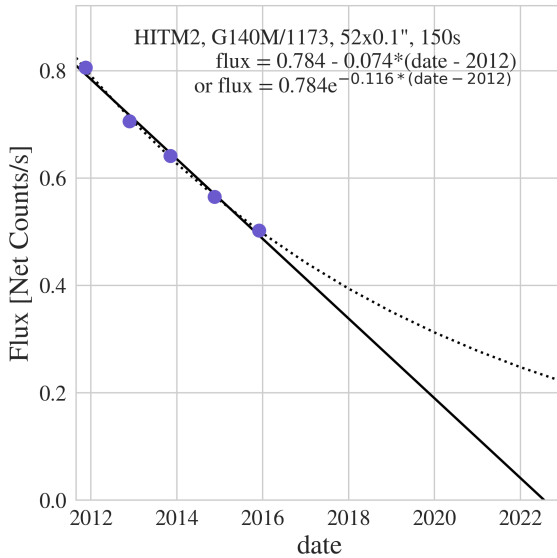
The annual MAMA dispersion solution monitor includes a G140M/1218 observation of the LINE lamp taken with a current of 10mA through the 52x0.1 slit; this is approximately the wavelength range of the second-bluest setting shown in Figure 1 (see also Figure 3). These observations provide a tracking of how the LINE lamp has faded at  $1190\text{--}1245\text{\AA}$  at the current used for GO wavecalcs. I show in Figure 2 that the decline in the LINE lamp's flux at these wavelengths has remained at a constant fractional rate (~20% per year), though should still be monitored going forward.

## **2.2 The HITM1 and HITM2 Lamps**

Clampin and Baum (1996) suggested that the HITM lamps might be useful in the event that the LINE lamp fades (or the CIM fails). In particular, the HITM2 lamp has barely been used, and is at only <2% of its nominal usage. Owing to the fading at the blue end of the LINE lamp, in 2012, GO wavecalcs for G140M/1173 were switched from LINE to HITM2. These data, shown in Figure 3, reveal that while the HITM2 lamp is currently bright enough to obtain robust wavelength zeropoint calibrations for this mode, at the current rate of fading, there will be no counts left at these wavelengths by 2023. It is currently unclear what, if any, possibly mitigation strategies may exist. Further monitoring, however, should reveal whether HITM2 is fading at a constant fractional rate (and thus more slowly than linearly).



**Figure 2:** The fading of the LINE lamp at 10mA in the G140M/1218 setting with the 52x0.1" aperture from the annual dispersion solution monitor; the right panel shows only the post-SM4 data; the fit is the same in both panels. The 2017 data are not shown as they fell on top of the glow region. The fading has remained at about 20% per year, including during the 5 years STIS was off.

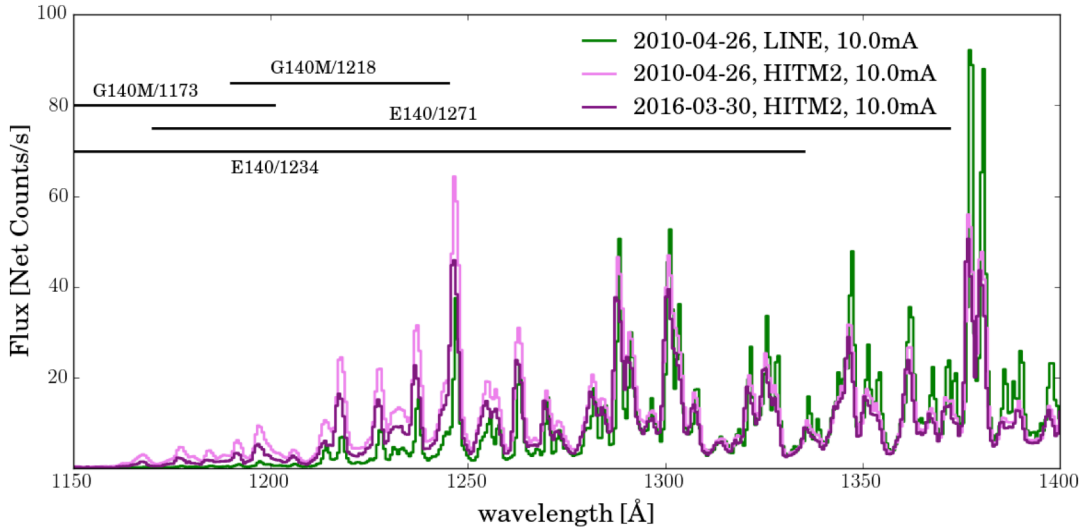


**Figure 3:** Fading of the HITM2 lamp in the G140M/1173 mode (1145 to 1201Å) with an 52x0.1" aperture at 10mA from the annual MAMA spectroscopic sensitivity and focus monitors (PIDs 12775, 13145, 13548, 13994, and 14429). At the current rate of decline, there will be no more counts at these blue wavelengths by 2023, though I note the flux is already quite low. There is not enough early HITM2 data to ascertain yet if, as with the LINE lamp, HITM2 is fading non-linearly (e.g., the dotted line).

To prepare for changing the GO-wavecal lamp from LINE to HITM2 in the E140H/1234 and 1271 modes, I executed a special calibration program (PID #14489) in April 2016 to look at HITM2 in these modes. Additionally, I took measurements of the lamp flux in G140L/1425 to measure how HITM2 has faded in the FUV since the 2010 observations. The observing plan for PID #14489 is summarized in Table 1; the odd exposure time lengths relative to PID #12079 were in order to keep the total observing length to only 2 orbits. These data are plotted relative to the 2010 data of both the LINE and HITM2 lamps from PID #12079 in Figure 4; note that, as with the LINE lamp, HITM2 appears to be declining achromatically.

Setting	Aperture	Exposure Time	Total Flux [counts/s]
E140H/1234	0.2x0.09	1000s	522.125
E140H/1271	0.2x0.09	865s	546.921
G140L/1425	52x0.1	100s	9462.03

Table 1: Exposures and total numbers of counts in the special calibration program PID #14489. All exposures were taken with the HITM2 lamp with a current of 10mA.



**Figure 4:** LINE and HITM2 lamps at  $<1400\text{\AA}$  in the G140L/1425 setting, from 2010 to 2016; the 10mA LINE lamp data taken in G140L/1425 in 2017 are unusable for this comparison owing to the brightness of the glow region. The black lines indicate the wavelength ranges of the blue modes discussed here. As can be seen by eye, at  $\lesssim 1300\text{\AA}$ , HITM2 IN 2016 was brighter than LINE was even in 2010, but at redder wavelengths, the LINE lamp was brighter than HITM2. Note that the 2010 LINE spectrum was taken with a narrower slit than the HITM2 data ( $52\times 0.05''$  versus  $0.1''$ ), affecting both the overall flux and sharpness of the emission lines.

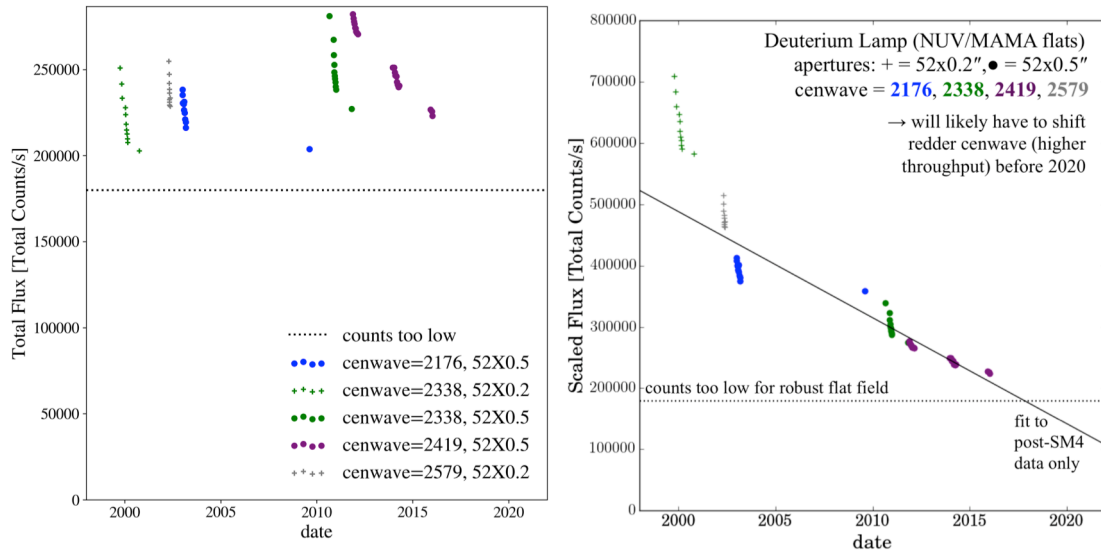
In June 2016, we switched the GO wavecal lamp for the E140H/1234 and 1271 modes from LINE to HITM2; HITM2 is brighter than HITM1 in the FUV (Pascucci et al, 2010; see also Table 10-1 of the STIS Systems Handbook and User's Manual). We kept the default exposure times the same at 16s for each. I calculated that this exposure time would suffice to give wavelength calibration zeropoints within the stated STIS accuracy of  $\pm 0.38$  pixels by doing a series of independent random resamplings of the counts from the long exposures from PID #14489, finding that at 16s SHIFTA1 changed by less than 0.38 pixels in more than 95% of the trials. The STIS team will continue to monitor the fading of the LINE lamp to anticipate other FUV modes that may need their GO wavecal switched to HITM2 (e.g., G140M/1222).

### 3. Flat Field Lamps

As the flat field lamps have faded, the flat field apertures have been increased and the cenwaves have been shifted in order to keep the number of counts high enough to obtain a robust flat field (while remaining low enough so as to not damage the detector). Here, for each of the flat field lamps, I review these past changes and extrapolate to 2020 and beyond. In short, I find that while each of these lamps is fading steadily, there remain brighter cenwaves and/or wider apertures to increase the throughput flux. In particular, I find that with the new alternating cycles between taking NUV and FUV flats, the rate at which the Deuterium and Krypton lamps is fading has indeed slowed.

### 3.1 The Deuterium Lamp (NUV Flat Fields)

Figure 5 shows the fading of the Deuterium lamp from the NUV flat field monitor. In the first panel, I plot the actual flux; it is evident that as the lamp has faded to have too few counts to obtain a robust flat field, the aperture and/or cenwave have been changed to increase the observed flux. In the second panel, I attempt to scale the flux to account for both the aperture size and the shape of the Deuterium lamp spectrum (see Figure 10-13 of the STIS Systems Handbook and User's Manual), keeping the most recent data to its unscaled value. Fitting a line to the post-SM4 data only, I find that another shift to a redder cenwave will have to be made before 2020 in order to maintain enough counts for a robust flat field. Since 2011, the annual STIS calibration plan has alternated between NUV and FUV flat fields, which has apparently slowed the fading of the Deuterium lamp.

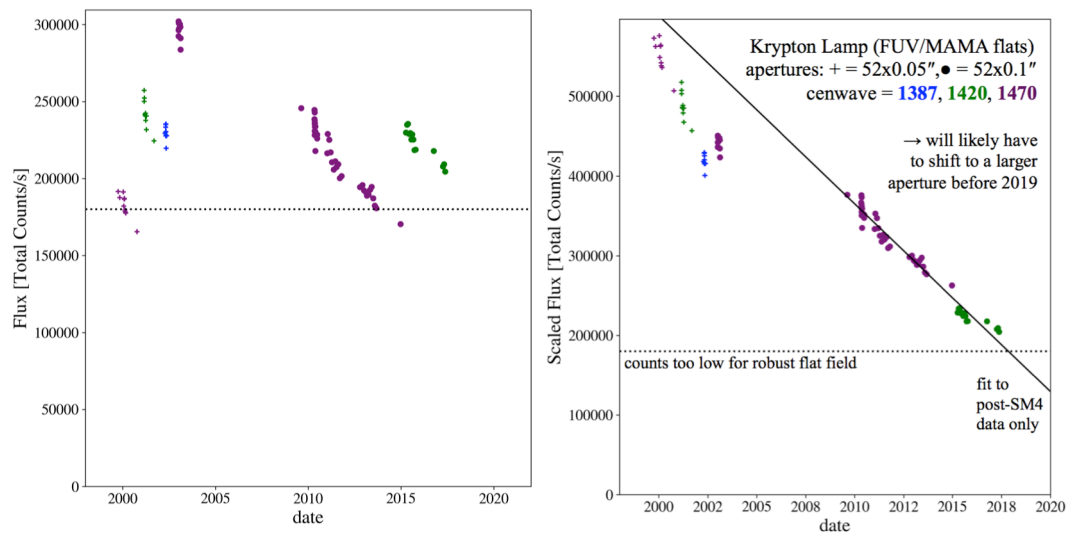


**Figure 5:** The fading of the Deuterium lamp used for NUV flat fields. Left: total flux. Right: flux scaled for changes in aperture size, throughput, and detector sensitivity. The dotted line in each panel is an approximate flux corresponding to how many counts/s are required for a robust flat field.

### 3.2 The Krypton Lamp (FUV Flat Fields)

Figure 6 is the same as Figure 5, but for the Krypton lamp used for FUV flat fields. As with the Deuterium lamp, the FUV flat fields have shifted to using wider apertures and cenwaves with higher lamp irradiance in order to keep the counts high enough for a robust flat field. There are fewer options available, however, with higher lamp

irradiance (see Figure 10-12 of the STIS Systems Handbook and User's Manual); thus, the FUV flat field will likely have to be shifted to a larger aperture before 2019.



**Figure 6:** Fading of the Krypton lamp used for FUV flats. Left: Total flux. Right: Flux scaled for changes in aperture size and lamp irradiance.

## Acknowledgements

This work made use of use of Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration, 2013) and benefited from discussions with Charles Proffitt, Sean Lockwood, and Daniel Welty.

## Change History for STIS ISR 2017-04

Version 1: 29 September 2017 – Original Document

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