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On-orbit comparison of the emission line intensities of the COS Pt-Ne Calibration Lamps

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ABSTRACT

There are two platinum-neon (Pt-Ne) hollow cathode lamps on the COS calibration platform that are used for wavelength calibration and target acquisition purposes. Due to differences in optical paths and operating currents the fluxes provided by these lamps (P1 and P2) are not the same. We analyze images and spectra taken with both Pt-Ne lamps to determine the ratio of the lamp fluxes as a function of wavelength. The results are used to compute recommended lamp flash durations should P1 be used for a task normally done with P2, and vice versa. In the event that either Pt-Ne lamp should fail, this analysis provides the starting point for continuing operations with a single working lamp.

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1. Introduction

The Cosmic Origins Spectrograph (COS) has an internal calibration platform that houses two Platinum-Neon (Pt-Ne) hollow cathode lamps, designated LINE1 (P1) and LINE2 (P2)[1]. These Pt-Ne lamps are used for two primary purposes: wavelength calibration of external target observations, and aperture location and centering during target acquisition (TA). At present, wavelength calibration is performed exclusively using P1, while both spectroscopic TA and imaging TA are performed exclusively using P2. Each lamp is expected to provide about 9-10 Amp-hours (A·h) of total usage (Nave et al. 2008, 2012; Penton et al. 2008), and upon failure of either lamp, the remaining lamp will be used for both of these tasks. As of 2018 July 26, estimated total (ground and on-orbit) lamp usages are 3.5 A·h for P1 and 1.1 A·h for P2 (T. Wheeler, private communication)[2].

Due to differences in the optical paths, operating currents, and lamps themselves, P1 and P2 provide different fluxes across the wavelength range observable by COS. Both lamps can be operated at three different current levels, designated Low, Medium, and High—6 mA, 10 mA, and 18 mA for P1, respectively, and 3 mA, 10 mA, and 14 mA[3] for P2, respectively—with each setting providing different flux levels. This means that the integration times required to reach a given number of counts—and thus signal-to-noise ratio (S/N)—are different for P1 and P2 at each current level. To ensure that S/N requirements for wavelength calibration and target acquisition are met when the non-default Pt-Ne lamp is used for these purposes, we designed and executed a calibration program (13523) to measure the flux ratio between P1 and P2 as a function of wavelength. Pt-Ne lamp observations from other programs have also been used in our analysis as necessary.

1.1 Errors in Previous COS Pt-Ne Lamp Documentation

During this investigation we discovered that some COS documents have used incorrect information in their analyses. This stems from the fact that the *recommended* locations of P1 and P2 within the COS calibration platform (see Figure 1 in Ebbets 2000) are not the actual locations of P1 and P2 (see Figure 2-5 in Osborne et al. 2004). Light from both Pt-Ne lamps interacts with 2 vacuum-ultraviolet (VUV) beam splitters prior to exiting the calibration platform. The predictions made in Table 2 of Ebbets (2000)

[1]The P1 and P2 naming convention is used in the `FITS` headers of COS data files, and is how we will refer to the lamps herein.

[2]These estimates are based on the *scheduled* ON and OFF times for each lamp, and so may overestimate the actual usage by a few percent.

[3]Note that there is a typo in Osborne et al. (2004), which lists the P2 High setting as 17 mA.

Table 1. Summary of Exposures Used in this Analysis

Program ID	Detector	Optical Element	Cenwave	Lamp	Current	Exposure Time (s)	Rootname
13523	FUV	G140L	1105	P1	Medium	60	lcgp01a1q
13523	FUV	G140L	1105	P2	Medium	60	lcgp01a3q
13523	NUV	G230L	2635	P1	Medium	90	lcgp01a8q
13523	NUV	G230L	2635	P2	Medium	90	lcgp01aeq
13523	NUV	G230L	3000	P1	Medium	60	lcgp01apq
13523	NUV	G230L	3000	P2	Medium	60	lcgp01auq
13523	NUV	G230L	3360	P1	Medium	60	lcgp01blq
13523	NUV	G230L	3360	P2	Medium	60	lcgp01bnq
13523	NUV	MirrorB	...	P2	Low	40	lcgp01bpq
13523	NUV	MirrorB	...	P1	Low	40	lcgp01bsq
13523	NUV	MirrorA	...	P2	Low	20	lcgp01byq
13523	NUV	MirrorA	...	P1	Low	20	lcgp01c3q
13526	NUV	MirrorB	...	P2	Medium	20	lcgq03dnq

for lamps operating at different current levels assume that light from P1 reflects off of both beam splitters, while light from P2 transmits through the first beam splitter and reflects off of the second beam splitter. This does not represent the true layout of the COS calibration platform where light from P1 reflects off of the first beam splitter and transmits through the second beam splitter and light from P2 transmits through both beam splitters. As such, the scaling relations given in Table 2 of Ebbets (2000) are not applicable to COS, and should not be used. Predicted exposure time relations in Table 8 of Sembach (2006) are based directly on Table 2 of Ebbets (2000), and likewise should not be used.

2. Observations

HST program 13523 was designed for the purpose of measuring the fluxes of both P1 and P2 in NUV imaging mode, and as functions of wavelength from about 1100 Å to about 3590 Å in spectroscopic mode. The program consists of a single internal visit with 12 exposures taken using the settings listed in Table 1. The G140L/1105 observation provides wavelength coverage from about 1100 to 2000 Å, while the various G230L observations combined provide continuous wavelength coverage from about 1740 to 3590 Å. In addition, an exposure from HST program 13526 was used to investigate lamp settings not included in program 13523.

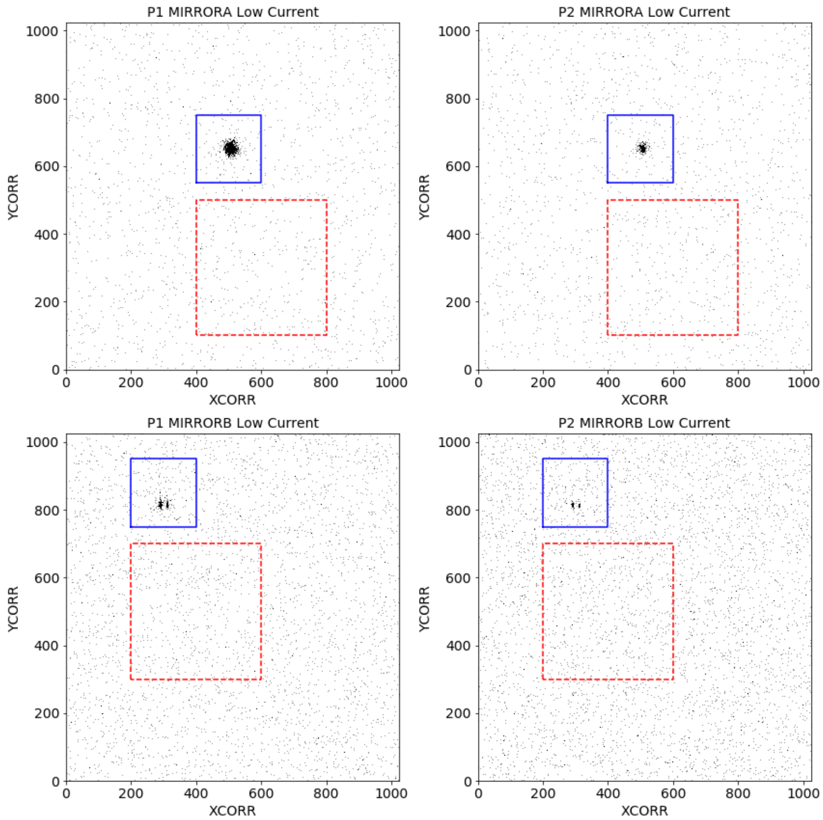

Figure 1. COS NUV images of P1 (left column) and P2 (right column) at Low current using MirrorA (top row) and MirrorB (bottom row). Images are in User coordinates. Solid blue lines mark the regions used to extract net counts (Pt-Ne lamp + background), and are defined by the boundaries $[xcorr_{lo}, xcorr_{hi}, ycorr_{lo}, ycorr_{hi}]$=[400, 600, 550, 750] for MirrorA and [200, 400, 750, 950] for MirrorB. Dashed red lines mark regions used to estimate the background level, and are defined by the boundaries [400, 800, 100, 500] for MirrorA and [200, 600, 300, 700] for MirrorB.

3. Analysis

3.1 Imaging

The last 5 exposures listed in Table 1 provide the data necessary for the imaging portion of our analysis. Images created from `corrtag` data products are shown in Figure 1 for the 4 exposures where the Pt-Ne lamps were operated at Low current, and in Figure 2 for the 1 exposure where the Pt-Ne lamp was operated at Medium current. Rectangular regions were defined to extract counts from the Pt-Ne lamp images and are shown as solid blue boxes in Figures 1 and 2 . The total number of counts extracted from the Pt-Ne Lamp region is the sum of counts from the lamp and background, so an estimate of the background contribution is required to determine the Pt-Ne lamp flux. Regions

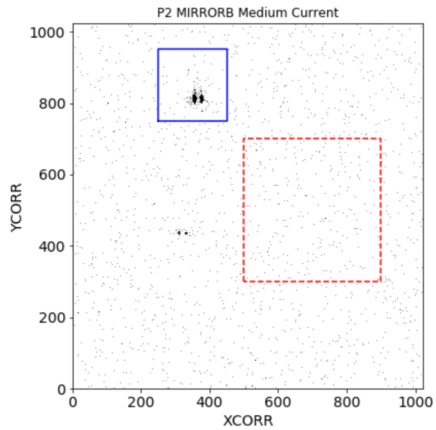

Figure 2. COS NUV image of P2 at Medium current using MirrorB. The image is in User coordinates. Solid blue lines mark the region used to extract net counts (Pt-Ne lamp + background), and is defined by the boundaries $[xcorr_{lo}, xcorr_{hi}, ycorr_{lo}, ycorr_{hi}]$=[250, 450, 750, 950]. Dashed red lines mark the region used to estimate the background level, and is defined by the boundaries [500, 900, 300, 700]. Note that the counts near (*xcorr,ycorr*)=(350,450) are from an external target.

Table 2. Imaging Results

Lamp	Current Level	Optical Element	Net Counts	Background Counts	Pt-Ne Lamp Counts	Pt-Ne Lamp Count Rate (counts/s)
P1	Low	MirrorA	53396	566	52830	2641.5
P2	Low	MirrorA	8939	557	8382	419.1
P1	Low	MirrorB	4596	1180	3416	85.4
P2	Low	MirrorB	2112	1464	648	16.2
P2	Medium	MirrorB	7465	568	6897	344.8

used for estimating the background level are shown as dashed red boxes in Figures 1 and 2. The extent of these rectangular regions are specified in the Figure 1 and 2 captions. For each exposure, the total number of counts in the Pt-Ne lamp region (net), estimated number of background counts in the Pt-Ne lamp region (0.25 times the total number of counts in the background region), inferred number of counts from the Pt-Ne lamp, and inferred Pt-Ne lamp count rates are presented in Table 2. From these measurements, ratios between the fluxes provided by P1 and P2 at different current settings and with different optical elements can be determined.

3.2 Spectroscopy

The first 8 exposures in Table 1 provide the data necessary for the spectroscopic portion of our analysis. They are used to generate FUV (1100–2000 Å) and NUV (1740–3590 Å) spectra of P1 and P2 as follows.

3.2.1 Spectral Extraction

First, `corrtag` event lists are used to construct 2D spectral images of each exposure in *xcorr, ycorr* space. Based on these images, rectangular regions are defined from which to (1) extract Pt-Ne lamp spectra, and (2) estimate the background contribution to the spectra. All of these regions span the entire length of the detector in *xcorr*, and so are defined by $[ycorr_{lo}, ycorr_{hi}]$. G140L/1105 observations are performed with only FUV segment A, and the Pt-Ne spectrum is extracted from [610, 660]. The FUV detector background is low enough that it does not affect these observations, so no correction is made. The NUV observation contains 3 cross-dispersed spectra referred to as stripes A [500, 600], B [600, 700], and C [740, 840]. We define two background regions, BKGD1 [400, 500] and BKGD2 [850, 950], that flank stripes A and C, and create a single background spectrum from the average of the spectra extracted from both regions. This average background spectrum is then smoothed using a 20 point boxcar filter, and the smoothed background spectrum is subtracted from the NUVA, NUVB, and NUVC Pt-Ne spectra. Inspection of the G230L/2635 stripe A, G230L/3000 stripe C, and G230L/3360 stripe C spectra—known to consist only of second-order light (Table 5.4 in Fischer 2018)—shows that they do not provide useful data for our analysis, so we ignore them henceforth. All remaining spectra are then divided by exposure times to set intensity units to counts/s.

Dispersion solutions for the wavelength calibration aperture (WCA) are provided in the `DISPTAB` reference files 05d1514fl_disp.fits (NUV) and 0bn1606sl_disp.fits (FUV at LP2). Because we have extracted spectra from `corrtag` files, they have not been shifted in the along dispersion direction to line up with template Pt-Ne spectra, and so only the dispersion values (i.e., Å/pixel) in the reference files are applicable here. Still, we can simply apply the full dispersion solutions (dispersion and zero point) and then shift each entire spectrum by a constant wavelength to correct this issue. Using a list of measured Pt and Ne emission line wavelengths (in vacuum) and intensities (Sansonetti et al. 2003) we generate a simulated spectrum with line widths and intensities scaled to match each of our background-subtracted spectra. The shift in wavelength between an observed and simulated spectrum is determined via cross-correlation, and the wavelength solution to the observed spectrum is updated accordingly.

At this point, FUV spectra of P1 and P2 cover a wavelength range from about 1100 Å to about 2000 Å, and the FUV processing is complete. The NUV data requires further processing to stitch together the spectra from individual `CENWAVE`s and stripes to produce composite spectra for P1 and P2. The transitions from one spectrum to the next were constrained to occur in line-free regions, and the contribution of individual spectra to the merged spectra are as follows:

1740 Å $\leq \lambda < 2120$ Å: NUVA/G230L/3000

2120 Å $\leq \lambda < 2480$ Å: NUVA/G230L/3360

2480 Å $\leq \lambda < 2850$ Å: NUVB/G230L/2635

2850 Å $\leq \lambda < 3210$ Å: NUVB/G230L/3300

3210 Å $\leq \lambda < 3590$ Å: NUVB/G230L/3360

The merged NUV spectra of P1 and P2 cover a wavelength range from about 1740 Å to about 3590 Å, and are presented in Figure 3, along with the FUV spectra. Note that data quality flags (e.g., grid wire shadows) were not accounted for in the creation of these spectra.

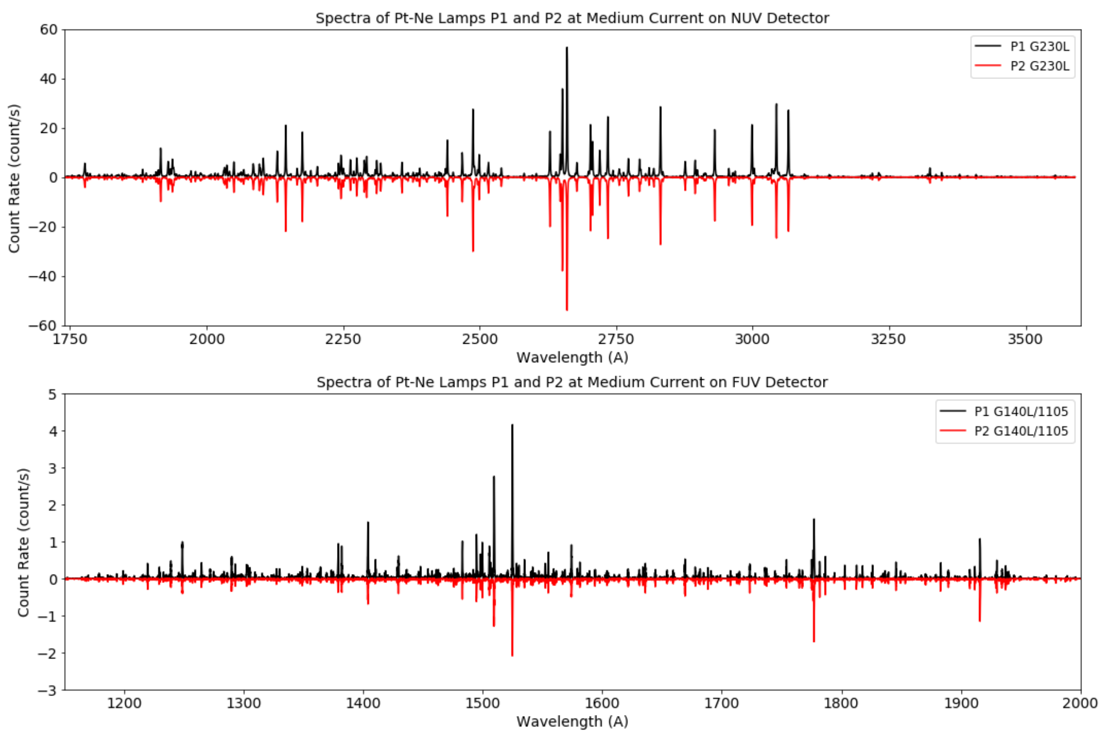

Figure 3. Spectra of P1 (black curves) and P2 (red curves) on the COS NUV (top panel) and FUV (bottom panel) detectors. Note that the P2 spectra have been inverted (i.e., multiplied by -1) to more clearly show all emission lines from both lamps. Emission lines from P2 at $\lambda < 1600$ Å are clearly weaker than their counterparts from P1.

Table 3. Pt-Ne Lamp Results for FUV Spectroscopic Modes

Grating	Cenwave	FUVA			FUVB		
		P1 (counts/s)	P2 (counts/s)	P1/P2	P1 (counts/s)	P2 (counts/s)	P1/P2
G130M	1055	6.33	3.80	1.67	0.00	0.00	...
	1096	20.35	11.63	1.75	0.00	0.00	...
	1222	82.22	35.58	2.31	9.10	5.50	1.65
	1291	97.43	41.45	2.35	46.52	22.40	2.08
	1300	96.43	41.73	2.31	49.62	23.73	2.09
	1309	92.20	39.93	2.31	61.08	29.12	2.10
	1318	94.27	41.03	2.30	67.58	31.88	2.12
	1327	95.70	42.03	2.28	72.78	33.73	2.16
G160M	1577	67.00	43.17	1.55	206.00	100.03	2.06
	1589	64.45	42.23	1.53	209.93	102.65	2.05
	1600	64.95	43.18	1.50	205.40	101.62	2.02
	1611	82.15	56.95	1.44	203.22	101.55	2.00
	1623	82.45	57.40	1.44	199.87	101.42	1.97
G140L	1105	506.17	285.97	1.77	N/A	N/A	N/A
	1280	458.10	263.12	1.74	1.12	0.67	1.67

Note. — Both lamps were operated at the Medium current setting for this analysis.

3.2.2 Integrated Flux Ratios

Using the processed spectra we can compute integrated count rates for P1 and P2 over any arbitrary wavelength range. We did so for the default wavelength ranges for each FUV segment and NUV stripe for all M-grating `CENWAVE` settings at `FP-POS`=3 (Fischer et al. 2018, Tables 5.3 and 5.4). The ratios of the P1 and P2 integrated count rates over these wavelength ranges are plotted in Figure 4, and show a clear dependence upon wavelength. The large-scale wavelength dependence is well-described by the 45° angle-of-incidence transmission and reflectance curves of the two VUV beam splitters[4] in the optical paths of P1 and P2. Integrated count rates for each setting—including the G140L and G230L settings—are presented in Tables 3 and 4. Note that the integrated lamp count rates measured here are *not* expected to match the actual values for each setting, since total throughput is grating dependent, and the data in use were only obtained with G140L and G230L. However, this does not affect the derived flux ratios.

4. Results

The relationship between P1 and P2 presented in Tables 2, 3, and 4 can be used to determine the settings for P1 required for target acquisition purposes, and the settings for P2 required for wavelength calibration purposes, assuming that the goal is to provide the same number of counts when using either Pt-Ne lamp. This is done by scaling the

[4] https://www.actonoptics.com/products/broadband-beamsplitters

Table 4. Pt-Ne Lamp Results for NUV Spectroscopic Modes

Grating	Cenwave	NUVA			NUVB			NUVC		
		P1 (counts/s)	P2 (counts/s)	P1/P2	P1 (counts/s)	P2 (counts/s)	P1/P2	P1 (counts/s)	P2 (counts/s)	P1/P2
G185M	1786	12.13	8.18	1.48	62.46	44.07	1.42	49.66	35.27	1.41
	1817	11.00	7.47	1.47	29.66	22.89	1.30	136.54	113.37	1.20
	1835	12.50	8.48	1.47	39.46	30.14	1.31	165.03	139.83	1.18
	1850	14.58	9.98	1.46	36.58	27.16	1.35	98.64	84.16	1.17
	1864	60.40	41.78	1.45	32.57	24.14	1.35	39.74	33.28	1.19
	1882	61.32	43.61	1.41	50.30	35.93	1.40	54.11	45.62	1.19
	1890	61.67	43.76	1.41	49.96	35.88	1.39	51.01	42.16	1.21
	1900	27.57	20.83	1.32	110.97	89.40	1.24	44.00	35.73	1.23
	1913	27.83	21.50	1.29	118.59	98.18	1.21	34.75	27.65	1.26
	1921	30.83	24.32	1.27	171.27	144.15	1.19	66.77	54.39	1.23
	1941	39.81	29.71	1.34	128.23	107.67	1.19	108.53	91.78	1.18
	1953	37.19	27.23	1.37	83.23	71.04	1.17	115.59	98.88	1.17
	1971	42.35	29.19	1.45	44.10	36.22	1.22	92.64	81.17	1.14
	1986	51.55	37.34	1.38	53.18	44.49	1.20	118.90	106.20	1.12
	2010	108.29	89.74	1.21	34.75	27.65	1.26	107.27	97.30	1.10
G225M	2186	137.01	124.75	1.10	144.61	134.41	1.08	157.61	151.12	1.04
	2217	122.94	115.58	1.06	56.70	50.55	1.12	98.18	93.77	1.05
	2233	171.03	164.47	1.04	123.20	110.12	1.12	64.59	63.50	1.02
	2250	138.19	132.38	1.04	163.21	145.00	1.13	63.13	59.11	1.07
	2268	138.24	130.20	1.06	120.18	109.63	1.10	69.33	64.53	1.07
	2283	132.54	123.26	1.08	158.78	152.52	1.04	69.66	65.37	1.07
	2306	57.41	50.93	1.13	169.88	164.01	1.04	57.42	55.97	1.03
	2325	66.02	56.49	1.17	101.19	96.37	1.05	91.36	89.06	1.03
	2339	139.13	126.38	1.10	36.46	35.89	1.02	130.06	128.86	1.01
	2357	191.60	172.85	1.11	69.68	65.93	1.06	137.19	138.39	0.99
	2373	148.70	134.17	1.11	81.06	75.42	1.07	184.56	187.63	0.98
	2390	152.67	150.44	1.01	69.48	67.65	1.03	232.49	234.16	0.99
	2410	107.76	104.13	1.03	47.78	46.67	1.02	118.23	116.25	1.02
G285M	2617	267.36	270.31	0.99	119.30	120.15	0.99	216.15	210.34	1.03
	2637	94.20	91.64	1.03	331.99	341.69	0.97	189.28	180.74	1.05
	2657	42.85	41.52	1.03	499.44	512.49	0.97	99.24	90.19	1.10
	2676	26.97	26.92	1.00	308.98	314.03	0.98	124.76	111.64	1.12
	2695	20.33	18.11	1.12	227.43	223.44	1.02	118.03	106.48	1.11
	2709	29.65	26.68	1.11	253.76	249.40	1.02	203.69	188.48	1.08
	2719	29.80	27.07	1.10	374.79	371.56	1.01	180.20	168.47	1.07
	2739	128.14	131.00	0.98	232.41	226.31	1.03	47.39	37.23	1.27
	2850	218.61	212.30	1.03	148.86	138.35	1.08	50.17	47.93	1.05
	2952	178.67	167.17	1.07	74.69	70.89	1.05	174.02	145.08	1.20
	2979	48.65	37.91	1.28	89.69	79.34	1.13	21.07	16.51	1.28
	2996	96.71	81.37	1.19	143.81	122.32	1.18	17.47	13.00	1.34
	3018	79.23	72.57	1.09	165.76	137.47	1.21	12.93	10.03	1.29
	3035	140.22	129.09	1.09	217.78	173.29	1.26	13.52	10.47	1.29
	3057	127.59	117.21	1.09	343.10	279.24	1.23	6.80	5.38	1.27
	3074	48.53	47.17	1.03	161.75	135.48	1.19	10.91	8.26	1.32
	3094	61.12	54.89	1.11	21.07	16.51	1.28	24.58	18.07	1.36
G230L	2635	319.27	162.90	1.96	1871.33	1846.72	1.01	396.09	314.31	1.26
	2950	132.24	102.87	1.29	1169.14	1011.08	1.16	549.50	467.34	1.18
	3000	113.80	91.15	1.25	1035.87	891.25	1.16	564.17	503.92	1.12
	3360	1267.25	1190.29	1.06	150.05	105.01	1.43	663.52	618.11	1.07

Note. — Both lamps were operated at the Medium current setting for this analysis.

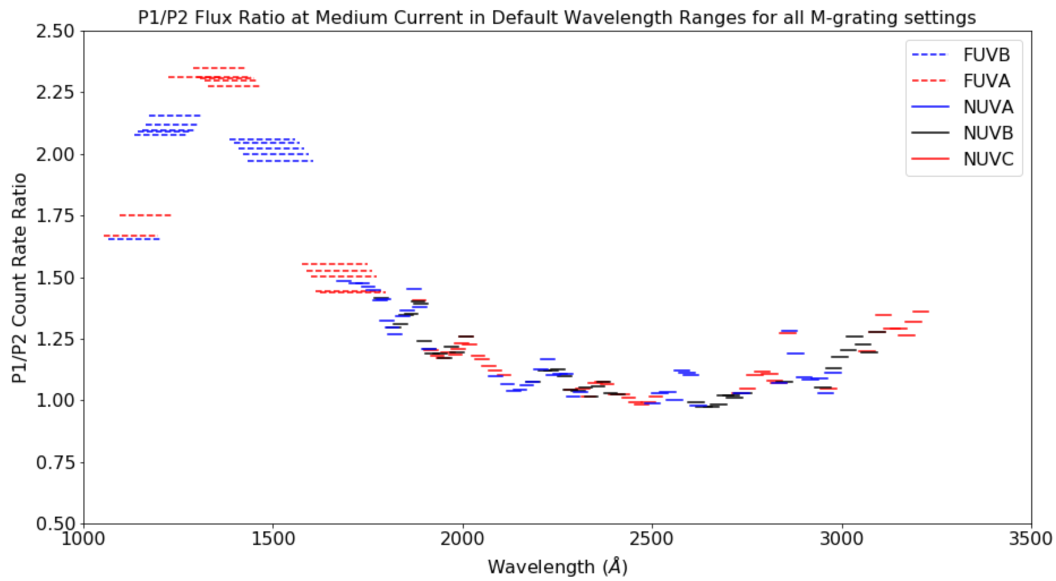

Figure 4. P1/P2 flux ratios determined from the spectra shown in Figure 3. Each horizontal bar corresponds to the wavelength range covered by different M-grating `CENWAVE` settings at `FP-POS`=3 (see Tables 5.3 and 5.4 in Fischer et al. 2018), and shows the ratio of the integrated P1 and P2 fluxes over that range.

in-use parameters by the appropriate lamp count rate ratios.

4.1 Target Acquisition with P1

The Pt-Ne lamps are used in the TA process to ensure that an external target is properly centered in the COS aperture. Because the separation on the detector between the image (or spectrum) of the Pt-Ne lamps and the center of the science apertures is a known quantity, the telescope can be slewed to place the image (or spectrum) of the external target at the desired separation from the lamp image (or spectrum). At present, P2 is used for all target acquisition operations that require a Pt-Ne lamp.

4.1.1 Spectroscopic TA

Default parameters for spectroscopic TA are defined in the HST+COS ground commanding file `LLDEFAULT` in the block of code labeled "*Peakup Parameters*". Here, the Pt-Ne lamp used (`PKLAMP`) is set to LINE2, the lamp current (`PKLAMPCUR`) is set to Medium, and the lamp flash time (`PKLAMPTIME`) is set to 17 s for all spectroscopic target acquisitions, regardless of detector, grating, and `CENWAVE`. As such, using different durations and/or currents for different spectral settings would require substantial commanding changes. Because P1 is as bright as (within 2%) or brighter than P2 for all spectroscopic settings, it will provide at least as much flux as P2 does during spectroscopic target acquisitions. We thus recommend no change (i.e., 17 s lamp durations at Medium current) if P1 is used for spectroscopic target acquisition. We must also note that the 17 s lamp duration in use may not provide the required S/N for target acquisition at several NUV spectroscopic settings as discussed by Indriolo et al. (2017), and only their recommended `CENWAVE`s should be employed (see Section 2.7 in Fischer et al. 2018), even if operation is switched to P1.

4.1.2 Imaging TA

Default parameters for imaging TA are defined in the HST+COS ground commanding file `LLDEFAULT` in the block of code labeled "*Target Acq Parameters*". Here, the Pt-Ne lamp used (`TALAMP`) is set to LINE2, the lamp current (`TALAMPCUR`) is set to Low when MirrorA is in use and Medium when MirrorB is in use, and the lamp flash time (`TALAMPTIME`) is set to 7 s when MirrorA is in use and 12 s when MirrorB is in use. Using the imaging results presented in Table 2, we find a P1/P2 count rate ratio of 6.30 for the case where both lamps are operated at the Low current setting and observed with MirrorA. Because P1 provides ample S/N with the in-use lamp parameters for MirrorA, no changes are necessary for the MirrorA imaging TA parameters.

While we have analyzed an image of P2 operated at Medium current using MirrorB (Figure 2), there are no on-orbit images of P1 operated at Medium current. To estimate P1/P2 in imaging mode when both lamps are operated at Medium current, we utilize the NUV spectra presented herein. By integrating over the full wavelength range covered by the merged NUV spectra we can very roughly approximate the flux that would be observed in a non-dispersed image of both lamps. Note that this does not account for Pt-Ne lines that fall outside the wavelength limits of our NUV spectra, nor does it account for the throughput curves associated with MirrorA and MirrorB imaging (Goudfrooij et al. 2010). In this manner we estimate a P1/P2 flux ratio of 1.1 in NUV imaging mode when both lamps are operated at Medium current. As P1 again provides a higher flux than P2, no changes to the in-use MirrorB imaging TA parameters are required.

In principle, shorter lamp durations could be used to extend the lifetime of P1, but in practice there are limitations on the minimum lamp duration due to potential lag between the commanded and actual lamp turn-on times. Sembach (2006) enforced a minimum lamp duration of 5 s in his recommendations, and the actual minimum duration in use is 7 s. All of our recommended parameters for target acquisition with P1 are given in Table 5, and are identical to those presently in use with P2.

Table 5. Recommended Parameters for Target Acquisition with P1

ACQ Mode	Optical Element	Lamp Current	Lamp Duration (s)
Imaging	MirrorA	Low	7
Imaging	MirrorB	Medium	12
Spectroscopic	All	Medium	17

Note. — All parameters are identical to those currently in use with P2.

4.2 Wavelength Calibration with P2

P1 is currently used for all wavelength calibration purposes. For `TIME-TAG` observations the Pt-Ne lamp is turned on for brief intervals during a science exposure to provide a reference (wavecal) spectrum at multiple points in time in that exposure. The location of these wavecal spectra with respect to a template spectrum (`LAMPTAB`) is used in determining the offset from the zero point of the wavelength solution. P1 is operated at Medium current level for this task, and is turned on for the durations listed in Table 5.2 of the Cycle 26 COS Instrument Handbook (Fischer et al. 2018), which differ for each `CENWAVE` setting. To calculate recommended TAGFLASH times for P2, we multiply the P1 TAGFLASH times by the maximum P1/P2 ratio at each `CENWAVE` in Tables 3 and 4 (i.e., the greatest P1/P2 between FUV segments A and B, and between NUV stripes A, B, and C). This ensures that the new TAGFLASH times are based on the worst-case scenario in terms of P1/P2 at each `CENWAVE`. Our recommended lamp parameters for wavelength calibration with P2 are presented in Tables 6 and 7.

For completeness, we include the recommended lamp current and TAGFLASH time settings for imaging with MirrorA and MirrorB in Table 7. The MirrorA settings are calculated using the default P1 settings of 7 s at Low current and the measured count rates reported in Table 2. Because there are no on-orbit imaging exposures of P1 at Medium current, we again rely on the analysis of NUV spectra described in Section 4.1.2, where we estimate P1/P2 = 1.1. Taking this flux ratio and the default P1 settings of 12 s at Medium current for MirrorB imaging, we calculate the corresponding P2 settings.

We must emphasize that these recommended TAGFLASH times may not provide adequate S/N for wavelength calibration purposes at some spectral settings. This is because the P1 TAGFLASH times have not recently been updated to account for the gradual loss in throughput documented in the time dependent sensitivity monitoring calibration programs for the FUV (De Rosa 2018) and NUV (Taylor 2018) detectors. These monitoring efforts indicate that the fractional throughput for some FUV modes have dropped to about 60% of their original on-orbit values, and for some NUV modes

Table 6. Recommended Parameters for FUV Wavelength Calibration with P2

Optical Element	Cenwave	Lamp Current	Lamp Duration (s)
G130M	1096	Medium	90
	1222	Medium	120
	1291	Medium	28
	1300	Medium	27
	1309	Medium	27
	1318	Medium	27
	1327	Medium	27
G160M	1577	Medium	24
	1589	Medium	24
	1600	Medium	24
	1611	Medium	24
	1623	Medium	23
G140L	1105	Medium	12
	1280	Medium	12

have dropped to about 25% of their original on-orbit values. This does not yet seem to affect the FUV wavelength calibration as the CalCOS pipeline routinely provides accurate wavelength calibration for the FUV modes with the greatest throughput reduction (G160M/FUVA). In the NUV the G285M grating suffers from the greatest throughput reduction. As the G285M grating is infrequently utilized, we cannot determine from existing observations whether all available `CENWAVE`s would be correctly wavelength calibrated using the current P1 TAGFLASH lamp durations. We recommend a study to determine whether or not the current TAGFLASH times with P1 provide adequate S/N for wavelength calibration purposes, particularly for modes with steeply declining sensitivity as a function of time. The result of such a study would be an updated table of P1 TAGFLASH times, which could then be used with the P1/P2 ratios determined herein to provide an updated table of P2 TAGFLASH times that does account for declining sensitivities.

Finally, we note that the use of P2 for wavelength calibration purposes may require the creation of new `LAMPTAB` reference files for some settings, where the reference Pt-Ne spectra are produced using P2. The reasoning here is that the shift between the template and wavecal spectra is found via cross correlation, and the P1/P2 ratio varies as a function of wavelength, particularly in the FUV. For observations with G140L it is possible that the changing relative line strengths between the P1 template and P2 wavecal spectra could cause problems with the CalCOS wavelength calibration routine. Further investigation would be required to determine whether or not this causes a significant problem.

Table 7. Recommended Parameters for NUV Wavelength Calibration with P2

Optical Element	Cenwave	Lamp Current	Lamp Duration (s)
G185M	1786	Medium	17
	1817	Medium	17
	1835	Medium	17
	1850	Medium	32
	1864	Medium	46
	1882	Medium	23
	1890	Medium	16
	1900	Medium	29
	1913	Medium	22
	1921	Medium	15
	1941	Medium	16
	1953	Medium	23
	1971	Medium	24
	1986	Medium	16
	2010	Medium	15
G225M†	2186	Medium	7
	2217	Medium	13
	2233	Medium	7
	2250	Medium	24
	2268	Medium	13
	2283	Medium	12
	2306	Medium	13
	2325	Medium	14
	2339	Medium	13
	2357	Medium	13
	2373	Medium	24
	2390	Medium	7
	2410	Medium	7
G285M†	2617	Medium	12
	2637	Medium	12
	2657	Medium	7
	2676	Medium	24
	2695	Medium	24
	2709	Medium	13
	2719	Medium	7
	2739	Medium	8
	2850	Medium	23
	2952	Medium	8
	2979	Medium	21
	2996	Medium	22
	3018	Medium	28
	3035	Medium	34
	3057	Medium	40
	3074	Medium	42
	3094	Medium	43
G230L	2635	Medium	13
	2950	Medium	8
	3000	Medium	8
	3360	Medium	17
MirrorA	N/A	Low	44
MIrrorB	N/A	Medium	13

Note. — † Warning! Both the G225M and G285M gratings suffer from decreasing throughput over time (Taylor 2018). Recommended lamp durations for these gratings do not account for this effect and should *not* be adopted without first confirming that they provide adequate flux for the CalCOS wavelength calibration procedure.

5. Summary

We have analyzed images and spectra of the two Pt-Ne lamps (P1 and P2) on board the COS calibration platform and determined flux ratios between the lamps for all presently available observing modes. Using the results from this analysis we recommend parameters (lamp current and flash duration) in the case that P1 is used for target acquisition purposes and P2 is used for wavelength calibration purposes. In the event that either lamp should fail, these recommendations should serve as the starting point for a smooth transition to operations with a single working Pt-Ne lamp.

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