Updates on *Hubble* Operations at the Institute

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Abstract

Observations with the *Hubble Space Telescope* continue to be in great demand. The type of observations scheduled with *Hubble* in Cycle 24 had more demanding scheduling constraints than usual. This resulted in a slightly lowered observing efficiency and longer-than-normal tail of programs late into the observing cycle. Two recent activities ensure the ability of the Cosmic Origins Spectrograph (COS) to continue its amazing productivity in both the near term and farther off. A move to a fourth position on the detector will take effect for Cycle 25 observations, and recommendations for operations will extend good COS performance well into the next decade. Several anomalies recently kept *Hubble* operations personnel on their toes, but with no worry about the health of the spacecraft. Recent changes to *Hubble*'s archive ensure that users will always have the best available data available for immediate download.

Cycle 24 observing programs and scheduling efficiency

The past several years have demonstrated strong continued interest by the astronomy community for obtaining *Hubble* data to advance a variety of different astrophysical research areas, with oversubscription factors of 3.6 in proposals and 4.9 in orbits, most recently in Cycle 25. Within this proposal pressure, the nature of the requested observations is changing; a larger portion of the observing cycles now requires specific timing, which has an impact on scheduling efficiency. The most obvious categories are observations of exoplanets requiring specific orbital-phase windows, or mission support proposals for observations of objects in the solar system. Figure 1 demonstrates this increase graphically, and shows the large increase in the number of accepted orbits in the exoplanet and solar system categories over the last several cycles. This increase is apparent even without factoring in the Cycle 24 treasury program "Panchromatic Comparative Exoplanetary Treasury Program" (PI David Sing) with 498 orbits. Other types of observations can also impose tight timing constraints, such as astrometric measurements, target of opportunity observations with short turn-around requirements, and joint observing programs requiring simultaneous observations.

Hubble observations are scheduled in one week increments, and the planning and scheduling team at the Institute tries to maximize the amount of time *Hubble* is "on source," looking at external targets. Due to its low-Earth orbit, which takes about 90 minutes to complete, there is a natural limit to how efficient *Hubble* can be. Initial expectations were a ratio of on source time to total elapsed time of only about 35%, but *Hubble* operations have routinely exceeded this, with long-term averages from Cycle 17 up through Cycle 23 of about 51%, or nearly 84 orbits per week. The number of orbits per week scheduled in Cycle 24 has been slightly less, at 82 orbits/week. This lower scheduling efficiency is due to the tighter scheduling constraints in the cycle. Cycle 24 contains a large amount of solar system observations coordinated with planetary missions (such as *New Horizons*, *Cassini*, and *Juno*). These have specific timing constraints to enable their scientific objectives, such as a large program to study Jupiter's aurorae enabled by combining UV auroral observations with *Hubble* and in situ measurements of Jupiter's auroral acceleration regions by *Juno*. Director's discretionary programs, as well as proposals received at the mid-cycle calls, also require changes to the initial long-range plan created at the beginning of the observing cycle.

Many exoplanet observations also have tight period and phase constraints. The precision of *Hubble*'s satellite orbital ephemeris limits the ability to plan these types of observations far into the future. The time horizon on which observations can be planned with the required precision is about 10 weeks. Observation windows planned beyond 10 weeks are not stable at the level of precision required for these exoplanet programs. This results in an inability to plan exoplanet science accurately throughout the cycle, and requires numerous iterations. The long-range planners mitigate this by "storing" exoplanet visits late in the cycle, and checking on a weekly basis for possible scheduling spots. Director's discretionary programs, as well as proposals received at the mid-cycle calls, are also being accommodated.

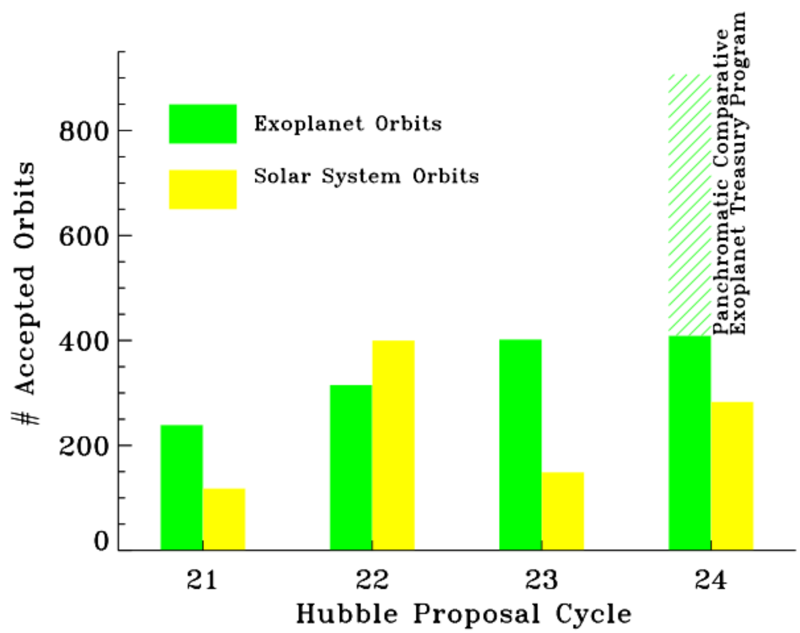

Figure 1: Graph showing the increase in the number of orbits devoted in the last several *Hubble* observing cycles to exoplanetary and solar system observations. Cycle 24 saw a dramatic increase in the number of orbits devoted to both categories. The contribution to this total from one large treasury program is noted with hatched lines.

Another method used to keep the observing efficiency of *Hubble* at its best is to allocate more orbits than can fit in a nominal cycle length. This tail helps ease the transition into a new observing cycle, as it contains a large reservoir of observations that can fill in gaps created late in the cycle. Cycle 24 had a larger than normal tail; typical values are 600–800 orbits, while Cycle 24 initially had about 1100 orbits in its tail. Although a long tail normally increases efficiency, the timing constraints in many of these programs means that the tail has less of a positive impact on the efficiency, compared to other recent cycles.

Keeping COS productive into the next decade

A New Lifetime Position

Real estate agents will tell you about the importance of location in choosing a home. Location is just as important in maximizing the ability to perform sensitive observations at moderate spectral resolution with the COS on *Hubble*. Previous *STScI Newsletter* articles have detailed moves from the initial Far Ultraviolet (FUV) detector location to more pristine locations (Oliveira et al. 2012; Osten et al. 2013; Roman-Duval et al. 2016), and a move to another such position occurred on October 2, 2017. This is the fourth life-time position used for on-orbit operations of the COS FUV detector. The primary purpose for the moves is to alleviate the loss of recorded flux due to charge depletion in the detector. The move to a new lifetime position occurs when a gain sag hole appears at the current location on the detector. Gain sag holes form due to charge depletion from Lyman-alpha airglow emission, typically arising from usage of the G130M grating, falling on the detector. An intermediate solution prior to a lifetime position move is to gradually raise the high voltage at which the detector operates, until the maximum allowable level is reached. As Figure 2 illustrates, these lifetime positions are offset from each other in the direction perpendicular to the dispersion direction. The primary goal of these moves is to continue to offer the highest quality science data possible for FUV spectroscopy.

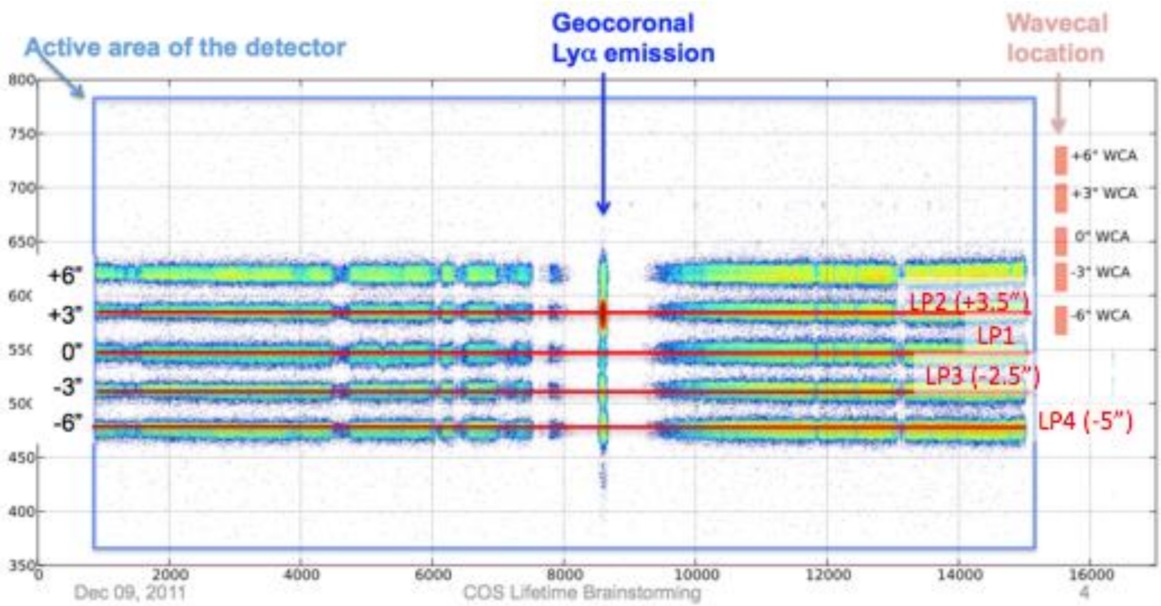

Figure 2: Graphical display of the Cosmic Origins Spectrograph's FUVB detector, with horizontal red lines indicating the previous and future lifetime positions. The red rectangles to the right depict the approximate location in the Y direction where the wavelength calibration aperture (WCA) falls, for each lifetime position. COS commenced operations at the LP4 on October 2, 2017.

The move to a new lifetime position carries with it a number of preparatory programs to explore possible issues with operations, as well as programs to enable and to calibrate science operations at the new location. Such a suite of programs typically encompasses an evaluation of the underlying detector gain at the new location, optimization of the precise location for the new lifetime position, a focus sweep to determine the optimal choice of focus, a check of the spatial and spectral resolution, a determination of target-acquisition parameters appropriate to the new position, a check of the wavelength scales; determination of template profiles for best spectral extraction, and confirmation of operation of the Bright Object Aperture at the new location. These activities have occurred for all lifetime position moves.

There are a few additional programs that are particular to lifetime position 4 (LP4). As Figure 2 indicates, the location of the fourth lifetime position is near the bottom of the active area of the detector. The current correction for geometric distortion at this location was obtained during thermal vacuum testing on the ground. Because the ground-based test data were out of focus at this position, additional study of the ground data and new flight data were needed to ensure optimization of the geometric distortion correction. Additionally, the location of the wavelength calibration aperature, or WCA, for LP4 falls on a region of the detector previously depleted by science exposures at LP2. The emission lines from the lamp are used for determination of the zero point of the wavelength scale by cross-correlation of the lamp spectra with a template. Additional work was required to verify changes to the cross-correlation technique so that the correct wavelength solution could still be obtained in the presence of LP2 depletions. With this groundwork in place, the COS team anticipates a smooth transition to operations at the new lifetime position.

COS 2025 recommendations

The lifetime move described above extends the amount of time COS is able to be used for future science operations, but only for a finite length of time. Operations at each lifetime position can be performed for only about 2.5 years before data quality becomes an issue. Continuing the operations at LP4 in the same manner as done for previous lifetime positions thus would only extend COS's performance into the late 2019/early 2020 timeframe. A fifth lifetime position (marked in Figure 2) is possible but unlikely, as there are drawbacks due to the location of the wavelength calibration lamp spectra.

The 2020 vision for *Hubble*, as expounded upon by now-director Ken Sembach in a 2015 *Newsletter* article, uses a five-year window to set priorities for technical work and observing initiatives. *Hubble* is likely to continue operating beyond 2021, with operations into the middle of the next decade entirely realistic. COS is a fully redundant instrument eight years after installation on *Hubble* in 2009, while the STIS instrument, installed in 1997, operates on its second set of electronics, having switched to the second side in the fall of 2001. There is clear value for UV spectroscopy with *Hubble* in overlapping science operations with the *James Webb Space Telescope*, now expected to occur for several years.

A committee of experts from both the community and the Institute examined the relevant issues, with the mandate of determining the best strategy for UV spectroscopy going forward, to extend good COS performance to 2025. The issue causing the need for successive lifetime position moves—exposure to Lyman alpha airglow and resulting gain sag of the detector—will remain. The ability to relocate to pristine regions of the detector is now limited, as most of the useable area has been used. There are operational limits to the high voltage settings on the detector. The agreed-upon strategy, in place with the start of Cycle 25, is to place all of the geocoronal Lyman alpha on a more limited region of the detector. This approach will deplete the detector more quickly, but the damage will be constrained to less detector area, incurring a 4–10 Å gap in wavelength coverage on the FUVB detector with the G130M grating. The upside is that the remaining detector real estate at LP4 is viable until 2023 or beyond, a gain of three or more years compared to normal operations. The graph in Figure 3 summarizes the availability of different FUV modes for Cycle 25 and going forward, as a function of lifetime position, detector segment, and FP-POS. Users needing all FP-POS to achieve high signal to noise or resolution comparable to 1291 can use the 1222 central wavelength setting. We originally planned a new 1223 setting to optimize the FUVA resolution at LP4, but flight tests demonstrated that this was unnecessary. More information on the COS 2025 strategy is available from www.stsci.edu/hst/cos/cos2025.

	LP2					LP3					LP4				
	FP-POS														
	1	2	3	4	ALL	1	2	3	4	ALL	1	2	3	4	ALL
G130M/1055	✓	✓	✓	✓	✓	X	X	X	X	X	X	X	X	X	X
G130M/1096	✓	✓	✓	✓	✓	X	X	X	X	X	X	X	X	X	X
G130M/1222	X	X	X	X	X	X	X	X	X	X	✓	✓	✓	✓	✓
G130M/1291	X	X	X	X	X	AVAIL	AVAIL	AVAIL	AVAIL	AVAIL	FUVA	FUVA	✓	✓	FUVA
G130M/1300	X	X	X	X	X	AVAIL	AVAIL	AVAIL	AVAIL	AVAIL	FUVA	FUVA	FUVA	FUVA	FUVA
G130M/1309	X	X	X	X	X	AVAIL	AVAIL	AVAIL	AVAIL	AVAIL	FUVA	FUVA	FUVA	FUVA	FUVA
G130M/1318	X	X	X	X	X	AVAIL	AVAIL	AVAIL	AVAIL	AVAIL	FUVA	FUVA	FUVA	FUVA	FUVA
G130M/1327	X	X	X	X	X	AVAIL	AVAIL	AVAIL	AVAIL	AVAIL	FUVA	FUVA	FUVA	FUVA	FUVA
G160M/ALL	X	X	X	X	X	X	X	X	X	X	✓	✓	✓	✓	✓
G140L/ALL	X	X	X	X	X	X	X	X	X	X	✓	✓	✓	✓	✓

AVAIL = Available mode use only (approval needed)
✓ = Supported mode (all GOs can use, no approval needed)
FUVA = Supported mode, but only with Segment=FUVA (all GOs can use)
X = Not supported or available to GOs

Figure 3: Summary of the supported and available science modes versus lifetime position for the COS/FUV observations for Cycle 25 GO programs

Keeping *Hubble* operations on its toes

With 27 years of experience, science operations with *Hubble* are generally smooth, even with the evolution in the types of observations executed each cycle (see above section of this article). A series of recent anomalies has been keeping engineers and scientists awake and alert. These anomalies have occurred primarily within *Hubble*'s Science Instrument Command and Data Handler (SIC&DH). This is the unit on the telescope responsible for sending commands to the science instruments, and directing the flow of data within the telescope. It was installed on *Hubble* during the last servicing mission in 2009. The Control Unit/Science Data Formatter (CU/SDF) within the SIC&DH has experienced a total of ten electronics lock-ups since 2009. Four of these occurred from July 2016 to June 2017, including three in calendar year 2017 (Jan. 13, March 16, and June 19). When a lock-up occurs, the regular flow of information to and from the science instruments stops, and alerts get sent to the ground team. The science instruments respond to the loss by placing themselves in a safe mode to prevent accidental harmful conditions.

These anomalies are well understood, and in each case, once the anomaly is identified, the *Hubble* operations team begins the steps necessary to recover the instrument payload. This includes recovering the science instruments, redelivering the science mission schedule, and re-planning affected science exposures. The time to complete recovery is typically about a day to a day and a half: the speedy recovery after the March 16, 2017 anomaly only took 20 hours. Although the time between the recent events has been short, a review shows that their occurrence is within expected limits and there is no cause for concern. The team is monitoring the frequency of events and will consider possible changes should the frequency of these lock-ups increase further.

Ensuring the freshness of *Hubble* archive data

More than half of the refereed papers published every year based on *Hubble* data do so with only archival data, highlighting the importance of a well-maintained archive that can provide the astronomical community with the highest quality data. Users of *Hubble*'s archive are familiar with On The Fly Reprocessing (OTFR), available for data retrieved from the archive since 2001. OTFR enabled *Hubble* archive users to obtain data processed with the most recent calibration files, software, and data parameters. Because of concerns at the time about disk space, OTFR stored only the raw telemetry files; FITS files were recreated and data processing steps performed on them at the time of the user request. The median processing times were of the order of a few hours.

Since 2015, the *Hubble* archive has been moving towards storing data statically in an online cache. Datasets are reprocessed as needed when new reference files or a new version of the calibration pipeline becomes available. Disk space is no longer a concern, and this modern approach ensures that users will never receive stale data. As of January 3, 2017, all *Hubble* data are stored statically in an online cache. Because the most up-to-date version of the data is already on disk, data retrieval times have significantly improved compared to using OTFR; data are available for immediate download through the MAST Portal, either through the browser or cURL scripts. The delivery of new reference files or updates to calibration software initiates a reprocessing of the affected datasets. Users who request datasets which have been queued for reprocessing are notified of this at the time of request, and the request from the user results in a higher priority for reprocessing the affected datasets. A *Hubble* Pipeline Processing page, provides access to the current status of *Hubble* data reprocessing activities, in particular large reprocessing efforts that may take several days. This is similar to the setup that will be used for access to *Webb* data.

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