Operating COS to 2025

Draft Report for May 2017 STUC Meeting

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Outline

• Problem Statement: lifetime of FUV channel
• Analysis of past COS usage
• Proposed operating plan for extended lifetime at LP4
• Options for further extension

• Appendix A: Usage Analysis
• Appendix B: Options Considered
Recommendation (8): The STUC requests a usage chart of COS GO programs from the past few cycles, for a better understanding of the demands for different instrument setups and requirements. This will help assess the impact and implications of different mitigation options on science return. The STUC also encourages STScI to work with COS Instrument Development Team members at CU-Boulder and UC-Berkeley to quantify the risk-reward trade space for raising the FUV detector voltage to mitigate gain sag effects. Finally, the committee suggests a community workshop (possibly in the form of a virtual workshop) as an effective way to obtain broader user input on what observing modes will best support COS science goals in the future. This may also be used to develop some standard use cases for COS observations.
Problem Statement

• COS FUV micro-channel plate (MCP) gain becomes depleted as a function of photon exposure \(\rightarrow\) results in unusable regions on the detector
• Caused nearly entirely by geo-coronal Ly-alpha
  – Not a consequence of type of science target (just data acquisition time)
• FUV has 3 gratings: G130M, G160M, G140L
  – G130M is the most used (creates Ly-alpha airglow gain-sag ‘holes’ on FUVB)
  – G160M excludes Ly-alpha (but is impacted by holes on FUVB)
  – G140L, used least, puts Ly-alpha on FUVA (not affected by FUVB holes)
• Grating position (OSM) selects for both CENWAVE and FP-POS
  – Moving spectrum on detector provides
    • Averaging fixed pattern in flat field (required for S/N > \(\sim\)20)
    • Relocation of wavelength gap between detector’s two segments (FUVA,B)
    • Increased wavelength coverage at red and blue ends
• Aperture mechanism permits relocation of spectrum on 2-D detector
  – Extends lifetime as MCP is depleted \(\rightarrow\) multiple Lifetime Positions (LPs)
  – Some reduction in spectral resolution when off center (LP1)
  – Move to LP4 (final LP?) in late Cy24

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COS/FUV Lifetime Positions

Active area of the detector

Geocoronal Ly\(\alpha\) emission

Wavecal location

LP2 (+3.5")

LP3 (-2.5")

LP4 (-5")

LP1
Problem Statement (2)

- COS has been operated since SM4 at LP1, LP2, and now LP3
  - Ly-alpha line placed at multiple positions
  - High voltage increased as “holes” reduced gain to untenable levels
  - Each LP provides ~2.5 years of operation
- Continuing to operate LP4 in the same manner greatly reduces COS/FUV science performance after late 2019
- An LP5 is possible but likely has significant drawbacks due to location of cal lamp spectra (unproven configuration due to light leak, uncertain calibration, and considerable increase in aperture mechanism move frequency)
State of FUVB Detector

Modal gain on FUVB at HV = 163 (starting LP4 HV)

1291 @ LP4
99% enclosed energy
1291
80% enclosed energy
Analysis of Past COS Usage

• COS usage patterns make broad use of the FUV channel’s capabilities in resolution and wavelength coverage
  – A broad variety of science topics are supported with QSO spectroscopy being a plurality of the observations since SM4 but Exoplanets are increasing in importance
  – G130M is most popular grating
  – NUV is little used (but primary purpose is backup for STIS)
  – Detailed report below as Appendix

• Mechanism lifetime analysis conducted in 2013 (Proffitt et al. COS TIR 2013-03) is encouraging
  – Aperture Block Mechanism reaches ~50% of ground tested usage in 2019 (motor usage at 50% in 2022).
  – Ground testing is very conservative
  – Aperture Block usage would probably increase significantly at LP5 imposing some risk
  – Rotary OSMs ground tested to 27 million motor steps; with expected lifetime of 600 million motor steps. OSM1/2 are at 33/31 million steps on orbit.
### Scenarios Considered - Summary

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- **Scenario**: All scenarios considered are described in detail in Appendix B, the recommended strategy, A, is described in next slide.

- **Recommendation**: 0. Create incentive to use STIS
  1. Change lamp operations to have another LP at +6” from LP1
  2. Turn off FUVB unless scientifically justified in Phase I
  3. Re-use previous LP and live with gain sag holes
  4. Hybrid model - LP used and having holes or not depends on science goal of program – i.e. different LP for each visit/program
  5. Operate multiple LPs simultaneously in different locations depending on setting, to minimize gain sag hole impact
  6. Create another G130M cenwave to complement 1222 with the resolution optimized for FUVA
  7. Create new cenwaves projecting FUVB wavelength range onto FUVA
  8. a) Move aperture left and right 2-3” to spread gain sag around b) force users to use a restricted number of G130M cenwaves/FP-POS to always burn the same holes c) Re-distribute usage over different cenwaves

- **Strategy recommended**: => combination of 3 + 6 + 8b with some modifications (see next slide)
Proposed Future Strategy

• Rationale/Motivation:
  – Retain full science capability of COS until 2025

• Strategy:
  – Place all geo-coronal Ly-alpha on a limited region of the detector
    • Only support Cenwave 1291 for G130M with 2-4 FPPOS (TBD)
    • Makes holes rapidly unusable (4-10 Angstrom gap in wavelength coverage depending on number of FP-POS allowed)
    • Remainder of LP4 expected to have 3x lifetime (2023+ perhaps 2025)
    • Assuming current COS usage rates
  – Offer new 1223 cenwave with resolution (R) optimized in FUVA to complement existing 1222 where R is optimized in FUVB (Lyα falls in segment gap)
    • Users needing all FP-POS to achieve high S/N at R comparable to 1291 can use 1222 and 1223

• Costs:
  – Observations needing access to certain wavelengths less efficient
  – Calibration of new modes

• Trades:
  – Permit 2 or 4 FP-POS (high S/N versus larger “hole” in wavelengths)

• Move to LP4 and implement new strategy at start of Cycle 25:
  – Will create holes in some Cy24 observations (hold or modify??)
  – Users will need to prepare Phase 2 proposals possibly different that Phase 1 expectations
### FP-POS vs Signal-to-Noise vs Hole/Gap Sizes

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<tr>
<td>1 FP-POS (3)</td>
<td>14.9</td>
<td>20.4</td>
<td>140</td>
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<tr>
<td>2 FP-POS (3,4)</td>
<td>19.3</td>
<td>26.4</td>
<td>390</td>
</tr>
<tr>
<td>3 FP-POS (2,3,4)</td>
<td>22.4</td>
<td>30.6</td>
<td>640</td>
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<tr>
<td>4 FP-POS (1,2,3,4)</td>
<td>24.9</td>
<td>34.1</td>
<td>890</td>
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</table>

1. Signal-to-Noise (S/N) achievable in a single exposure due to detector fixed pattern noise (Massa et al., 2013). Multiple exposures with the same FP-POS, but slightly different OSM positions, or different FP-POS (N_fp) can be combined to average over fixed pattern noise and increase the S/N by $N_{fp}^{0.37}$ (Keeney et al., 2012). Exposures from multiple cenwaves can be combined for higher S/N.

2. Physical FUVB Geocoronal Ly-alpha hole size (in 6 micron wide columns) after G130M usage. G130M and G160M have different dispersions; the hole sizes, in Å, are different for each grating. Assumes that spaces between holes from different FP-POS are unusable.

3. For comparison, the width (in Å) of the 9 millimeter physical gap between the FUVA/B detector segments. With increasing number of FP-POS, the wavelength range not covered by the gap decreases. The use of multiple central wavelengths (cenwaves) is typically used to cover this gap.
Projected life of LP4 extends to >July 2023

Projection for FUVB; Y = 508 to 509; Scale Factor = 1.00

Edge not real, artifact of how gain map aging was performed
G130M LP4 Supported Modes

- G130M Cenwave = 1291 FP-POS 3,4 only option
  - Trade question:
    - Allow FP-POS 1,2,3,4 to increase max S/N at cost of larger hole
    - Do high S/N with 4 FP-POS at 1223 or 1291 (FUVA HV on only)
  - Three limitations:
    - 1291 detector gap → observe with new cenwave1223 on FUVA
    - Red wavelengths → use G160M
    - Ly-alpha → observe at LP2 or LP3 with non-1291 cenwave
  - Note: 1055 and 1096 remain available on LP2 (avoids holes in LP4)
- G160M requires additional Cenwave to avoid gap created by holes

- Create 1223/A with focus to replicate resolution of G130M/1291
  - Provides most of the original coverage of 1291/B in 1223/A with resolution similar to 1291/B
  - There are ~60 Å on the long wavelength side of 1291/A that would not be covered with 1223/A, but could do G130M/1291/A only to get it (or Seg A of any of the other G130M cenwaves)
Current COS FUV Modes + 1223/A

Existing modes, currently offered at LP2 that will continue to be offered at LP2

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Future Work/Questions

Investigate feasibility of moving G160M above LP2 (i.e. above +3.5")

- If possible to move G160M (narrow profiles) to LP5 (+5” below light leak), this would alleviate continuum sagging at the LP4 location, and possibly extend LP4 lifetime, while offering G160M data with resolution similar to that obtained at LP4.
- Also, LP4 airglow holes would not affect G160M data.
High Voltage Adjustment

• One test during SLTV in 2003 increased FUVB HV +4 Steps above nominal max
  – Detector has been run in SI at FUV A/B = 186/179 – uncertain duration
  – Current FUVB limit is 175
  – Increasing FUVB HV to 179 buys 2-3 months using past strategy
    • Could be applied to LP2, 3, and 4 (perhaps LP1)
  – Potential strategy to add ~1-2 years to lifetime in 2023+ timeframe
    • LP2 and LP3 could be used with LP4 single/limited Ly-alpha position strategy to increase usable lifetime
  – Additional HV increases represent un-quantified risks

• HV history based upon discussions with Jason McPhate and IDT
  – General confidence in Detector subassembly’s ability to operate at higher voltages
  – Instrument level (SLTV) qualification provides current constraints
### Existing COS FUV Wavelength Ranges* (Å)

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<tr>
<th></th>
<th>FUVB</th>
<th>FUVA</th>
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<tr>
<td>G130M/1222</td>
<td>1069-1207</td>
<td>1223–1363**</td>
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<tr>
<td>G130M/1291</td>
<td>1137-1274</td>
<td>1292-1432</td>
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<tr>
<td>G130M/1300</td>
<td>1147-1283</td>
<td>1302-1441</td>
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<td>G130M/1309</td>
<td>1154-1293</td>
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<td>G160M/1577</td>
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<td>G160M/1611</td>
<td>1421-1592</td>
<td>1612-1784</td>
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<td>G160M/1623</td>
<td>1434-1604</td>
<td>1625-1796</td>
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* FP-POS=3 ranges. FP-POSs 1 & 2 extend the G130M/G160M ranges by +4.5/+5.8 Å; FP-POS=4 extends the ranges by -2.2/-2.9 Å.

** The G130M/1222 FUVA wavelengths are out of focus and provide low resolution (R<10k)
Proposed Wavelength Ranges* (Å)

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** The G130M/1222 FUVA and 1223 FUVB wavelengths are out of focus and provide \( R < 10k \).
Appendix A
COS Usage Report from Cycles 20-24

Andrew Fox
Location of Lya airglow lines for each cewave/fg-pois setting of the G130M/FUVB grating (xcorr pixel)
OUTLINE OF THIS REPORT:

• Overall COS usage in last 5 cycles
• Breakdown by science category
• Breakdown by channel, grating, science requirements
• Standard science cases
• Conclusions

METHODOLOGY:

• went through Phase I proposals from last 5 cycles with help from Nick Indriolo, Marc Rafelski, Bethan James
• made database of proposal properties
Includes GO, SNAP, DD and joint programs with other observatories
SCIENCE CATEGORY

5-YEAR SUBJECT AVERAGES, BY ORBIT (CY20-24)
SCIENCE CATEGORY

5-YEAR SUBJECT AVERAGES, BY PROGRAM (CY20-24)
SCIENCE CATEGORY

5-YEAR SUBJECT AVERAGES, BY TARGET (CY20-25)
Note that “exoplanet” targets are actually stars (often late type)
FUV (79.5%)
NUV (7.2%)
BOTH (13.3%)

Over Cycles 20-24

CHANNELS USED (BY ORBITS)

CHANNEL USAGE EVOLUTION

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PROPOSAL TYPE (BY ORBITS)

PROPOSAL TYPE EVOLUTION

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GRATINGS USED (BY ORBITS)

Over Cycles 20-24

GRATING USAGE EVOLUTION

G130M
G160M
G140L
NUV
Extended targets are defined (in APT) by FWHM > 0.6” (in practice, mostly galaxies)

Extended target fraction (by orbit) is fairly constant at ~20%

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“broad coverage” means PI is studying a wide wavelength range (either lines or continuum), rather than one specific spectral line.
“high resolution” means science case requires G130M/G160M spectral resolution of ≈20 km s$^{-1}$ FWHM (line profile analysis, narrow lines in the ISM/CGM/IGM, etc.)
STANDARD USE CASES
COMMONLY OBSERVED COS MODES

1) **Quasar spectroscopy (mostly G130M/G160M; ~46% of COS orbits C20-24)**
   1a) metal and H I absorbers in the IGM / CGM / Milky Way halo
   1b) metal and H I absorbers in AGN outflows (intrinsic systems)
       • AGN outflow programs often concurrent with X-ray observations
       • Resolution and wavelength coverage and sensitivity necessary

2) **Galaxy spectroscopy (mostly G140L; ~19% of COS GO orbits C20-24)**
   • green peas, compact dwarfs, emission-line galaxies, etc.
   • Measurement of ISM emission lines e.g. C III] 1909, O III] 1666
   • Measurement of Lyman continuum escape fraction
   • Resolution less important, wavelength coverage needed

3) **White dwarf atmospheres (~10% of COS GO orbits C20-24)**
   • Abundances, temperatures, physical conditions
   • Both M & L gratings used depending on program
   • polluted WDs; disintegrating material falling onto star
   • Broad wavelength coverage needed, resolution often important
STANDARD USE CASES
COMMONLY OBSERVED COS MODES

4) G130M exoplanet transit spectroscopy (~9% of COS orbits in C20-24)
   • late-type host stars (K and M dwarfs; flare potential)
   • time-critical observations of absorption lines during planetary transits
   • growth area (many recent GO & mid-cycle proposals in this area)
   • high resolution necessary in small wavelength regions (often Ly-α)

5) G130M/G160M Spectra of Massive Stars (~2% of COS orbits C20-24)
   • Atmospheres and winds of OB stars in MW and Mag. Clouds
   • Resolution and wavelength coverage necessary
   • Targets could be (and often are) observed with STIS (bright enough)

6) Debris disks around various types of stars (~3% of COS orbits C20-24)
   • Physical & chemical properties of debris disks
   • Black holes, binaries, T Tauris, WDs, protoplanetary
   • Both L & M gratings used for this science

** Note that less used science use cases are not captured in the 6 categories above **
CONCLUSIONS

1) **COS GO Usage** (in targets and orbits) remains high: >800 orbits, >350 targets, >40 programs per year

2) **COS FUV channel** used ~10 times more than NUV channel (by orbit)

3) **QSO spectroscopy** accounts for 46% of all COS GO orbits

4) **Extended targets** (mostly galaxies) account for 20% of COS GO orbits

5) 58% of COS GO orbits are spent on programs that need good resolution (20 km s\(^{-1}\) FWHM)

6) 78% of COS GO orbits are spent on programs that need broad wavelength coverage (not just single line)

7) **Spectroscopy of exoplanet host stars** (often M dwarfs) is growth area 19.1% of Cycle 24 GO orbits are spent in this category
Appendix B: Options Considered
Options for Extending COS/FUV Operations

0. Create incentive to use STIS
1. Change lamp operations to have another LP at +6” from LP1
2. Turn off FUVB unless scientifically justified in Phase I
3. Re-use previous LP and live with gain sag holes
4. Hybrid model where LP used and having holes or not depends on science goal of program – i.e. different LP for each visit
5. Operate multiple LPs simultaneously, and in different locations, depending on setting, to minimize gain sag hole impact
6. Create another G130M cenwave to complement 1222 with the resolution optimized for FUVA
7. Create new cenwaves projecting FUVB wave range onto FUVA
8. Extending Life of each LP, once LP selected
Standard Use Cases – Use for PROS/CONS

1) quasar spectroscopy (mostly G130M/G160M; 46% of COS orbits C20-24)
   1a) metal and H I absorbers in the IGM / CGM / Milky Way halo
   1b) metal and H I absorbers in AGN outflows (intrinsic systems)
      • Resolution and wavelength coverage and sensitivity necessary

2) galaxy spectroscopy (mostly G140L; 19% of COS GO orbits C20-24)
   • green peas, compact dwarfs, emission-line galaxies, etc.
   • Measurement of ISM emission lines e.g. C III] 1909, O III] 1666
   • Measurement of Lyman continuum escape fraction
   • Resolution less important, wavelength coverage needed

3) White dwarf atmospheres (10% of COS GO orbits C20-24)
   • Abundances, temperatures, physical conditions
   • Both M & L gratings used depending on program
   • polluted WDs; disintegrating material falling onto star
   • Broad wavelength coverage needed, resolution often important

4) G130M exoplanet transit spectroscopy (8.7% of COS orbits in C20-24)
   • late-type host stars (K and M dwarfs; flare potential)
   • time-critical observations of absorption lines during planetary transits
   • growth area (many recent GO & mid-cycle proposals in this area)
   • high resolution necessary in small wavelength regions (often Ly-α)

5) G130M/G160M Spectra of Massive Stars (1.5% of COS orbits C20-24)
   • Atmospheres and winds of OB stars in MW and Mag. Clouds
   • Resolution and wavelength coverage necessary
   • Targets could be (and often are) observed with STIS (bright enough)

6) Debris disks around various types of stars (2.6% of COS orbits C20-24)
   • Physical & chemical properties of debris disks
   • Black holes, binaries, T Tauris, WDs, protoplanetary
   • Both L & M gratings used for this science
Create incentive to use STIS by charging orbits differently and saving COS for $\delta \lambda$ that STIS doesn’t have access to

Figure 4.6: Throughputs for COS and STIS in the FUV and NUV.

Comparing E140M and G130M at 1250 for same S/N (neglecting dark)

t_{stis} = t_{cos} * \frac{\text{thruput}_\text{cos}}{\text{thruput}_\text{stis}} \approx \frac{0.06}{0.075} = 8 * t_{cos}

Since E140M has double resolution of COS can bin by 2 and exptime factor between COS and STIS gets reduced to $8/2 = 4 =>$

# orbits(STIS/COS) = 4 for data with overlapping wave range

Neglecting STIS dark rate not a good idea
Exposure Time – COS vs. STIS at same R

COS/G130M/1291 S/N = 10 at 1250 Å
STIS/E140M/0.2x0.2 S/N = 10 at 1250 Å
Flat spectrum normalized to V

Last column gives ratio between $T_{STIS}$ and $T_{COS}$ assuming STIS binned by 2 (to COS resolution)
1. Change lamp operations to have another LP at +6” from LP1

• Description
  – Light leaks through FCA when WCA is turned on beyond +5” (global count rate violation http://www.stsci.edu/hst/cos/documents/isrs/ISR2013_02.pdf)
    1. Can explore if possible to flash lamp at +6” without BOP violation, while still getting data needed for wavecorr
    2. Can consider obtaining wavecal spectrum at a different detector location than spectrum to avoid problem, before and after each exposure

• PROS
  – Get another Lifetime Position similar to LPs up to know at R similar to LP4
  – Calibration would be as always
  – Minimal science impact if
    • Scenario 1) can be carried out
    • Drift issues can be sorted out in scenario 2)

• CONS
  – Need to evaluate impact on calibration of having an FCA spectrum under the science spectrum
  – Need to evaluate if gain sag caused by leaked spectrum is important
  – If 2) would lose ability to drift correct long exposures
    • But could force exposure length to certain value to minimize drift
  – Scenario 2) leads to overhead and poses additional moves on the aperture mechanism
2. Turn off FUVB unless scientifically justified in Phase I

- **Description**
  - Gain sag is worse in FUVB due to Ly\(\alpha\) airglow when observing with G130M. Turning off FUVB for G130M observations would remove this issue

- **PROS**
  - Increases the lifetime of each lifetime position – TBD how much time given that continuum-driven gain sag will go on with each exposure

- **CONS**
  - Additional overhead with turning a segment off (potentially can be hidden in setup and/or occultation depending on orbit layout)
  - Archival value of the data is lost
3. Re-use previous LP and live with gain sag holes

• Description
  – Can go back to use LP1 and LP2, if not care about holes. Or can continue at LP3 beyond appearance of first hole; similarly for LP4

• PROS
  – Resolution is recovered if going back to LP1 (has the highest R)
  – Can re-offer best resolution to programs needing high res on narrow wavelength ranges (exoplanet transit -- problem if Lya)
  – Minimal impact on calibration activities given that LP1 and LP2 ref files already exist
  – Easy to implement.
  – Possible to use LP4 further while minimizing the number of gain sag holes.

• CONS
  – Almost too late to continue at LP3 beyond appearance of first hole due to some Cy 24 programs having to experience it. Would need warning in CP/Primer for Cy 25 soon
  – Certain $\delta \lambda$ would be lost to science both for G130M, G140L, and G160M observations – $\delta \lambda$ ranges would have to be redefined – TBD which depends on LP
  – Impact on archival value of the data
  – Would have to determine how much lifetime we get before LP2-LP3 are going to be comparable to LP1 (where continuum on short wavelength side of A is also sagged). Even with individual holes, LP2-LP3 FUVB problematic for most science cases (even exoplanet transits if Lya is involved), especially difficult to evaluate impact on IGM/CGM due to different z (need tool). Could try to calibrate holes, although calibration in regions close to holes most probably will change quickly with time (re-evaluate them often).
4. Hybrid model where LP used and having holes or not depends on science goal of program

- **Description**
  - User selects LP and SI configuration to optimize their science

- **PROS**
  - Most likely to optimize science for individual programs
  - Minimizes usage of current best LP

- **CONS**
  - Requires extensive support (tools, calibration)
  - Imposes workload on users
  - Someone has to determine which programs get assigned to which LP;
  - Negative effect on archival quality of data
  - It may be difficult to identify uniform/fair/simple criteria to decide which programs get assigned where
  - PIs might preferentially chose locations with the highest resolution
5. Operate multiple LPs simultaneously, and in different locations, depending on setting, to minimize gain sag hole impact

• Description
  – Operate different settings on different regions of the detector depending on the spectral height. e.g. G160M between LP1 and LP2 etc., G130M at +5” etc.

• PROS
  – Extends usable lifetime of remaining photocathode area. How much depends upon mixture of science and how restrictive we make the rules.
  – May preserve resolution
  – LP can be optimized for science case (resolution, DQ, spectral coverage)
  – Maximizes use of detector real estate (e.g., fit the G160M between LP1 and LP2)
  – Re-using old LPs makes calibration easier (no need to recalibrate)
  – Could allow us to use the +5” position for narrow cenwaves

• CONS
  – Increase in the # of aperture block moves
  – Increased overhead in visits due to aperture move
  – Complicated calibration (multiple LPs to calibrate and monitor)
  – Substantial changes to monitoring and calibration algorithms
  – FSW changes (increase LP number)
  – Possibly changes to extraction method for LPs that barely fit between old LPs (e.g., G160M between LP1 and LP2)
  – Gain-sag probably still an issue (non-pristine regions of detector re-used).
6. Create another G130M cenwave to complement 1222 with the resolution optimized for FUVA

- **Description**
  - G130M/1222 setting places Lyα airglow in segment gap. 1222 resolution optimized for FUVB, FUVA resolution much lower than 1291. By creating a new setting that optimizes resolution of 1222/A people could cover the 1291 δλ using 2 cenwaves and not placing Lyα airglow in the detector

- **PROS**
  - Improved performance at 1291 without airglow damage

- **CONS**
  - Increase overhead

![Resolving Power Graph](image)
7. Create new cenwaves projecting FUVB wave range onto FUVA

- **Description**
  - Create new settings that place all G130M FUVB cenwaves on FUVA. There are several different ways to do this. One such way would be to offer this only at LPs where the FUVB has been sagged – such as LP1 and LP2 and LP3. So for instance FUVB could be observed at LP1(2,3) and FUVA would then be observed at the same position in a different exposure.

- **PROS**
  - When FUVB is dead, ability to keep operating COS
  - Only 4 gain-sag holes on left side of FUVA, good DQ
  - Monitoring and calibration are easier than operating different segments at different LPs.
  - Resolution of both segments will not be affected by move in x-dispersion, even if constraints on the focus mechanism motion range might have an impact on FUVB resolution

- **CONS**
  - Increased overhead in observing (due to spectral coverage cut in half)
  - Initial evaluation suggests achievable resolution is relatively low ($R \approx 12,000$), and optimum focus is out of allowed mechanism limits (Focus < -2200)
    - Additional feasibility studies ongoing
  - Keeping calibration straight may be tricky
  - Unclear how much time will be left on FUVA

03/15/17

Operating COS to 2025
8. Extending Life of Each LP Once LP Selected

a. Moving aperture left and right 2-3” to spread gain sag around

b. Force users to use a restricted number of G130M cenwaves/FP-POS to always burn the same holes

c. Re-distribute usage over different cenwaves to minimize hole creation over a single cenwave