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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

Hubble Space Telescope Status

Cycle 27 TAC Presentation

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9 June 2019

Welcome!

Thank you for serving on the Cycle 27 HST TAC

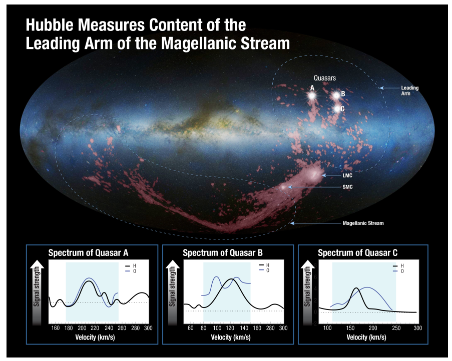
- The Hubble Space Telescope has now completed 29 years in operation
  - We are now 10 years past Servicing Mission 4
    - At that time, planning was for 5 years of science operations
  - In most respects, Hubble is working now at its very best
    - There is some slight instrument performance degradation
    - But we (GOs and STScI+GSFC) have become smarter in how we use the observatory
- Over the next several days, the team in this room has the privilege and responsibility of defining what Hubble does next

Hubble is as Powerful as Ever

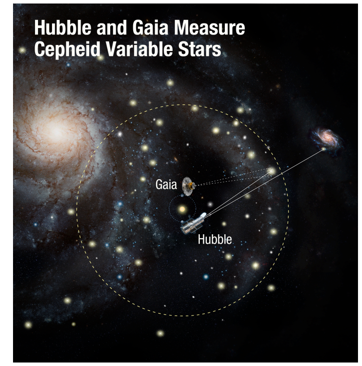
Deep, precise, stable pan-chromatic imaging

Slitted and slitless spectroscopy, coronagraphy, astrometry

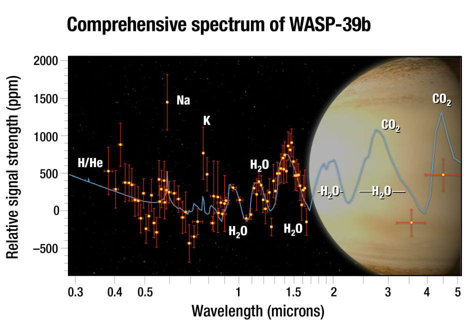
star formation and its galactic impact



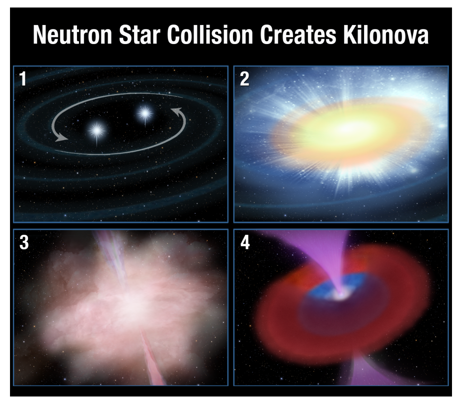
life stories of galaxies



cosmology and fundamental physics

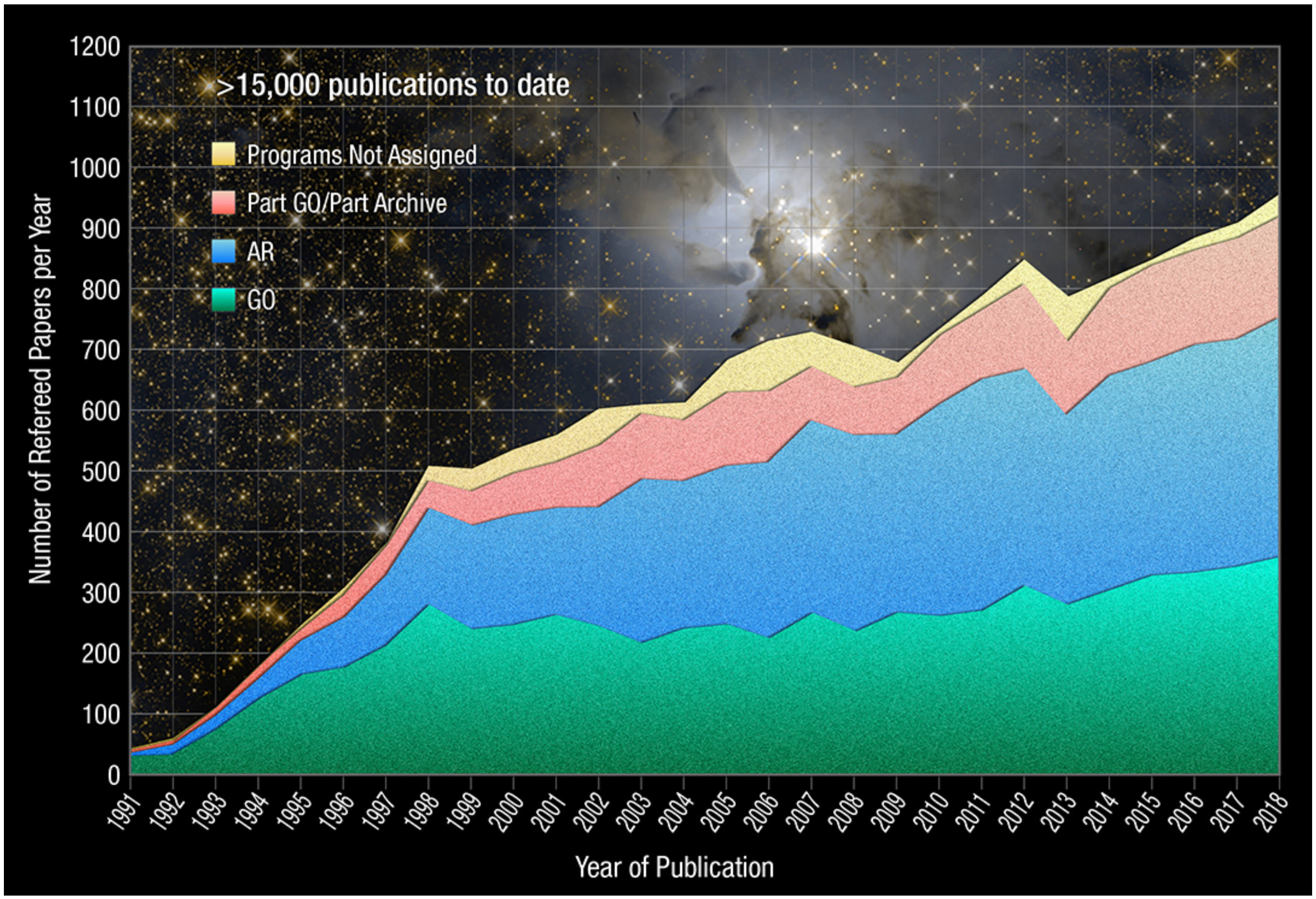


planetary atmosphere characterization



Transient GW Counterpart

Science Productivity at All Time High



- 950+ refereed science papers a year
- Now 16,000+ refereed science papers to date
- 800,000+ citations
- 600+ PhD theses
  - currently ~1 per week
- 2+ published papers per day
- 1 in 6 astronomy papers influenced by Hubble
- Hubble h-index continues to climb:

year	2016	2017	2018
h-index	257	274	288

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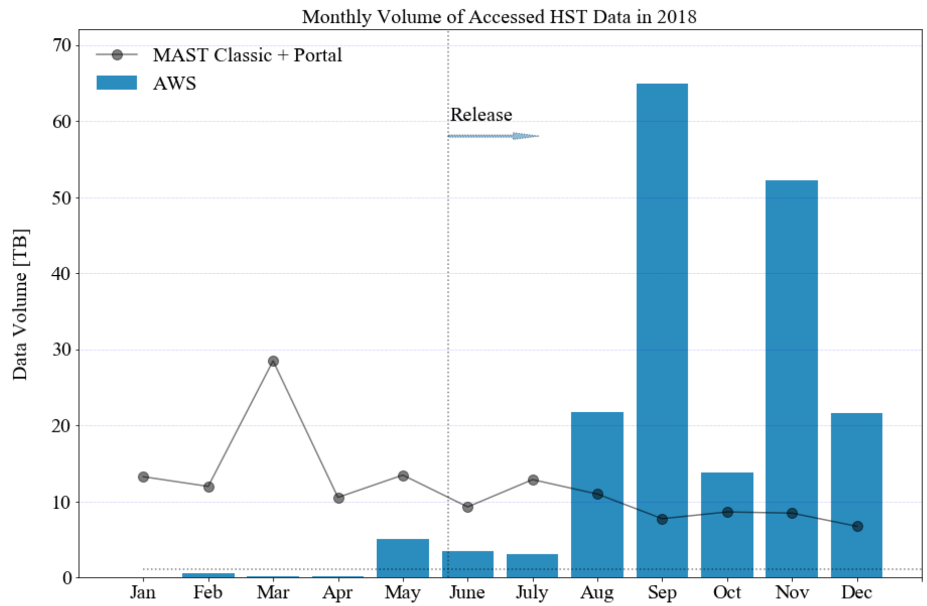
Data from the Programs You Select Will Produce Science for Years to Come

- HST archive size is ~160 TB
- 6-15 TB per month retrieved
- >12,000 registered archive users (85 countries, 50 states)
- HST archive online cache delivers data within minutes to users
- Amazon Web Services is now available for archival research
  - All HST data with very fast local processing on their servers



2020 → 2025 Vision

Operate Hubble out to 2025 and beyond. Expect overlapping science observations with the James Webb Space Telescope, performed in a manner that maximizes the science return of both observatories by taking full advantage of Hubble's unique capabilities and the astronomical community's scientific curiosity.

Expect several years of overlap between HST and JWST

How long will Hubble continue to operate?

→ As long as it remains scientifically productive

What is needed to keep Hubble scientifically productive? →

- An operating observatory
- Capable science instruments
- Scientific drivers (demand)
- Adequate staffing and user support
- Appropriate funding
- Common purpose & teamwork

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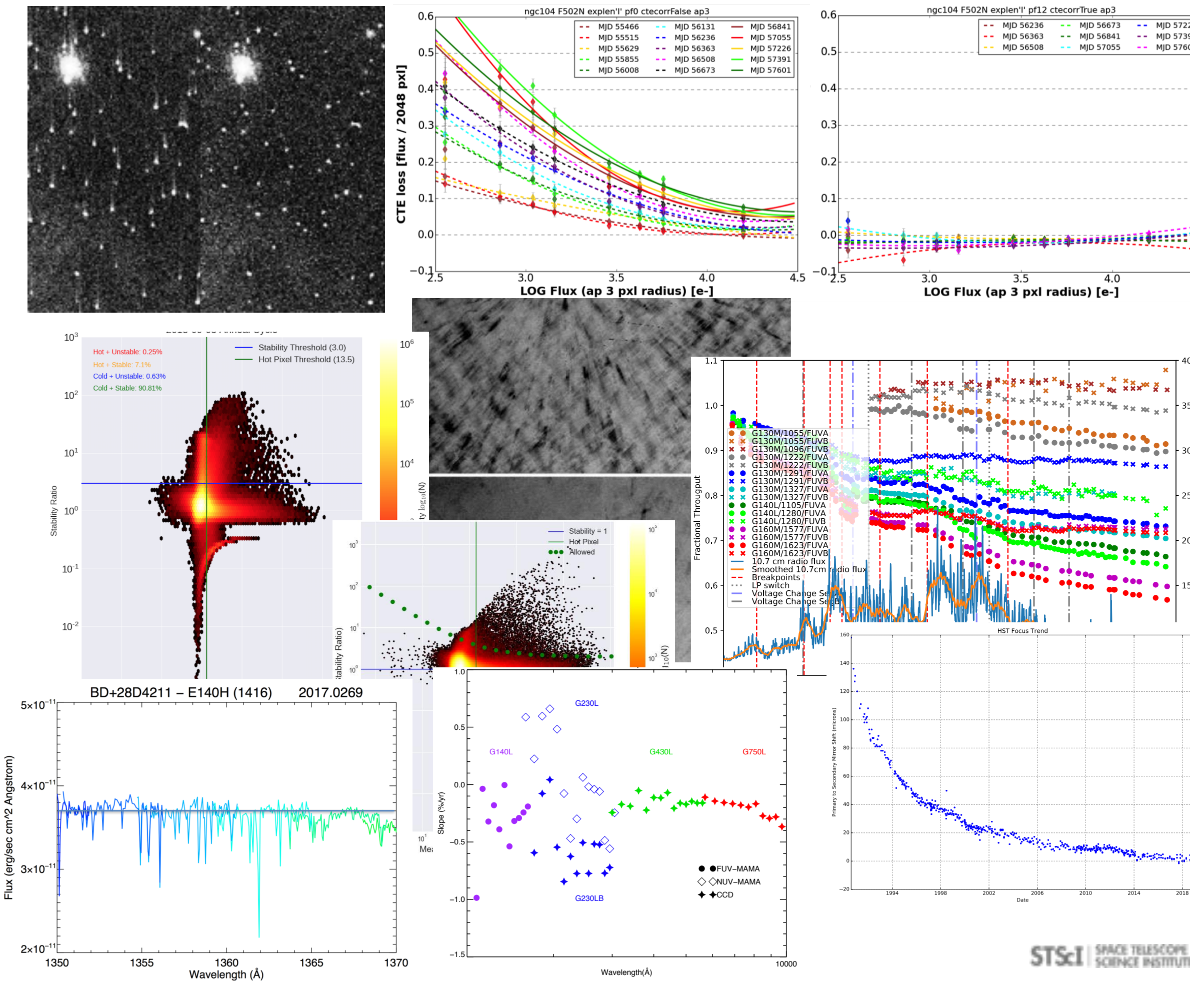
Graceful Aging of Observatory Largely Mitigated

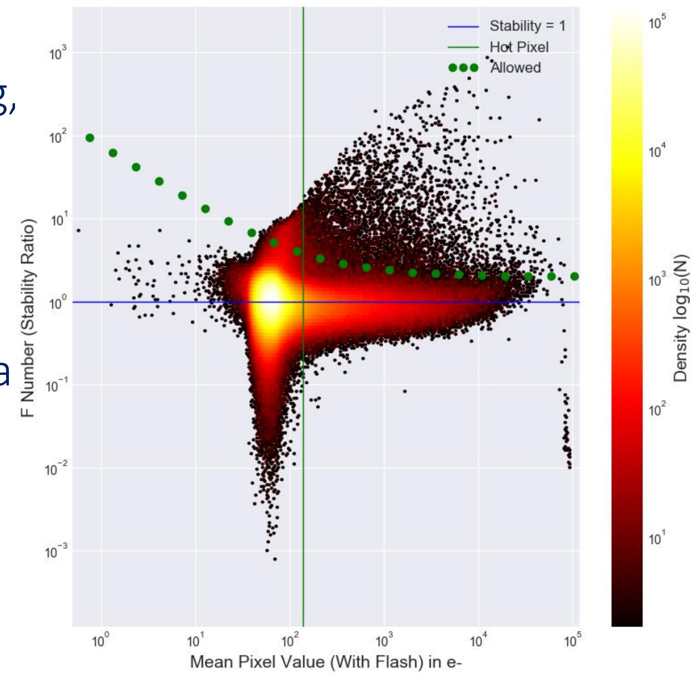
- Charge transfer efficiency degradation mitigated by flashing and corrected at the pixel level
- Vast majority of defective pixels (warm, hot, dead) mitigated through extensive monitoring, reference files, and appropriate algorithms
- Changes in flat fields and sensitivities monitored and addressed in pipeline
- Drifts in focus and alignment corrected by both mechanism motions and calibration updates



Advanced Camera for Surveys

Continued Good Performance

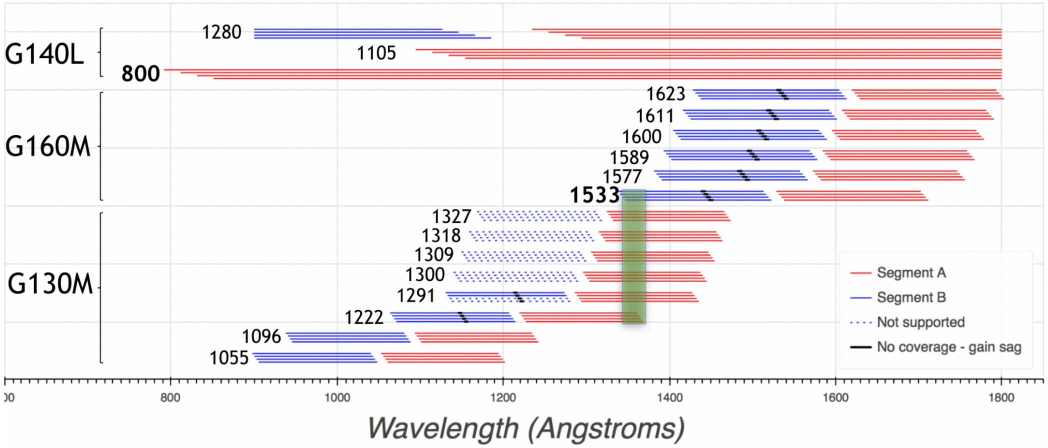
- Updates to CALACS include sink pixel detection, DQ-array flagging, retention of long-term stable warm/hot pixels in DQ array, high dynamic range WFC super darks, Gaia DR2 refinements to WFC Geometric Distortion solution, updates to WFC bias shift correction
- SBC dark current vs temperature characterized with 16 years data
- Updated web tools for WFC Zero-Points and Pixel-Area Maps
- Revised L-flats for WFC, based on 16 yrs of 47 Tuc monitoring
- Analysis of entire pixel history; Vast majority of hot pixels are stable and no longer flagged

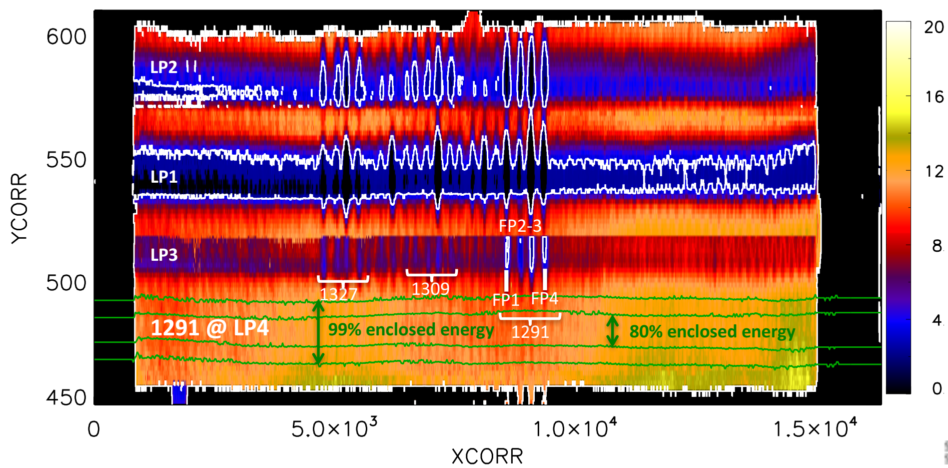


Cosmic Origins Spectrograph

COS is operating nominally

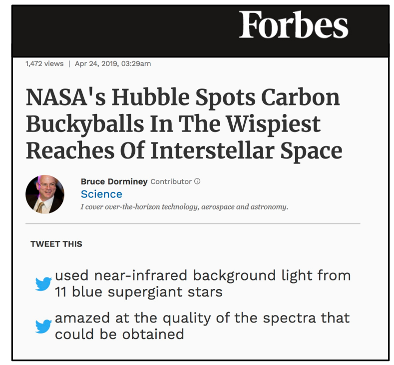
- New FUV observing modes
  - G160M/1533 enables high SNR, medium resolution spectra over a broad range of wavelengths with just 2 settings: G130M/1222 and G160M/1533.
  - G140L/800 provides broad wavelength coverage (800-1950 Å) on FUV segment A with no gaps and lower astigmatic height
- FUV detector at LP4 since Oct. 2017
  - Changes in strategy extend useful LP4 until ~2023
  - Future options for extending COS FUV

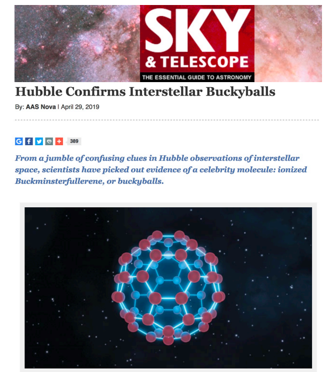


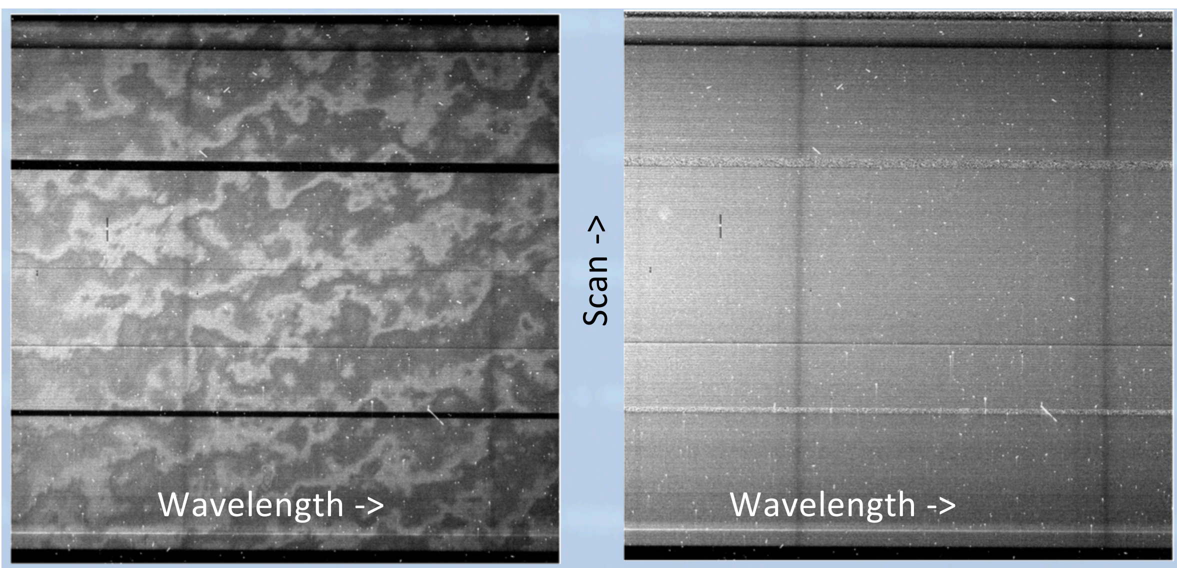


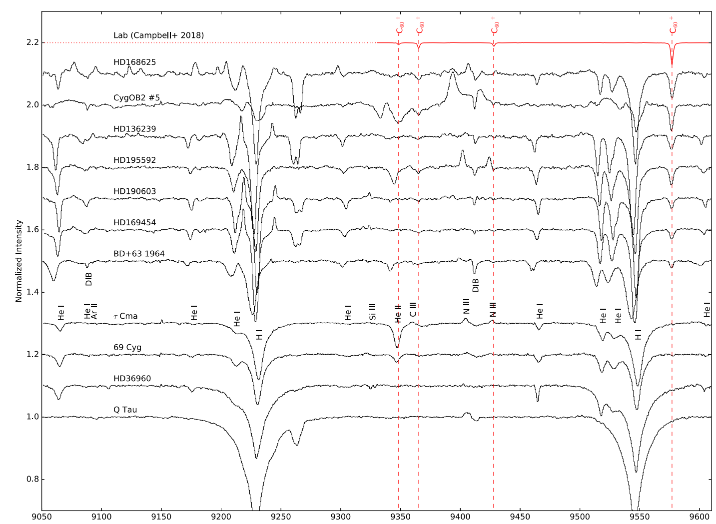
Space Telescope Imaging Spectrograph

- STIS status is unchanged; celebrating 22+ years in space
- Spatial scanning mode for moderate resolution, high S/N spectra to observe weak spectral features
    - More photons collected before full well
    - Better averaging over flat field imperfections
    - Better agreement with contemporaneous Tu lamp fringe flat





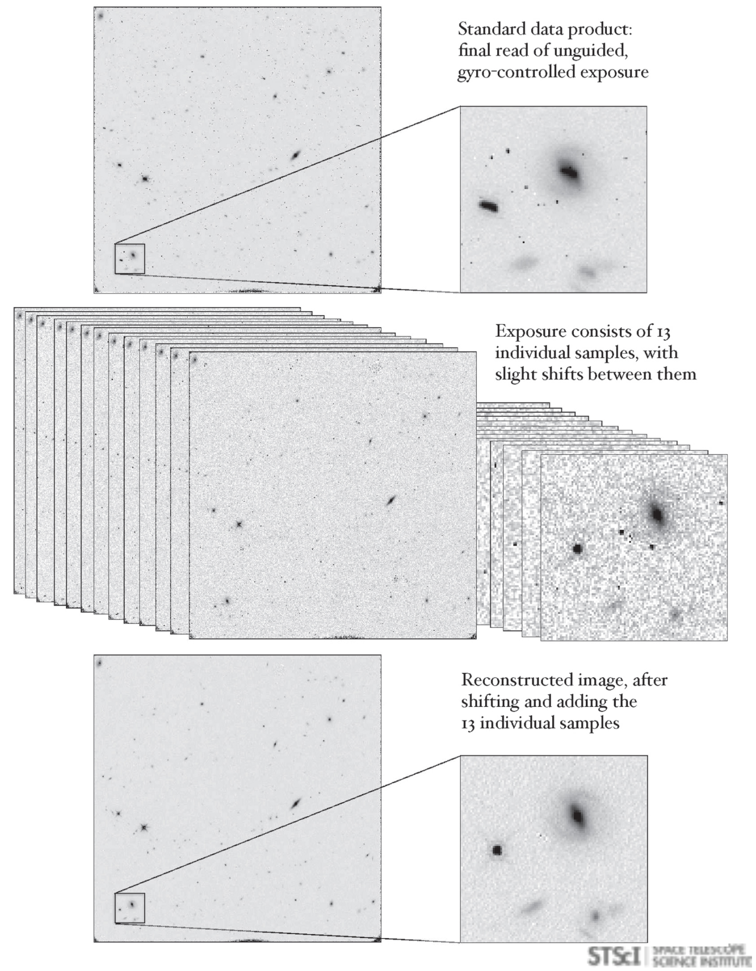




Diffuse interstellar bands C^{+}_{60} Cordiner et al. (2019)

Wide Field Camera 3

- Nominal Performance (January 2018 suspend due to SEU – benign event
- New planning tools for spatial scanning
- Filter-based geometric distortion solution for full-frame broad, medium, narrow band UVIS filters
- PSF library with >20M stars covering all UVIS filters
- Drift and Shift (DASH) observing mode
    - Normally, shifts > 130" require guide star re-acquisition
    - DASH allows imaging under gyro control only
    - Up-the-ramp imaging with WFC3/IR allows image reconstruction that corrects for the drift
    - Allows for tiling up to eight fields (37 sq arcmin) in one orbit instead of two fields (9 sq arcmin)



Healthy Science Instruments

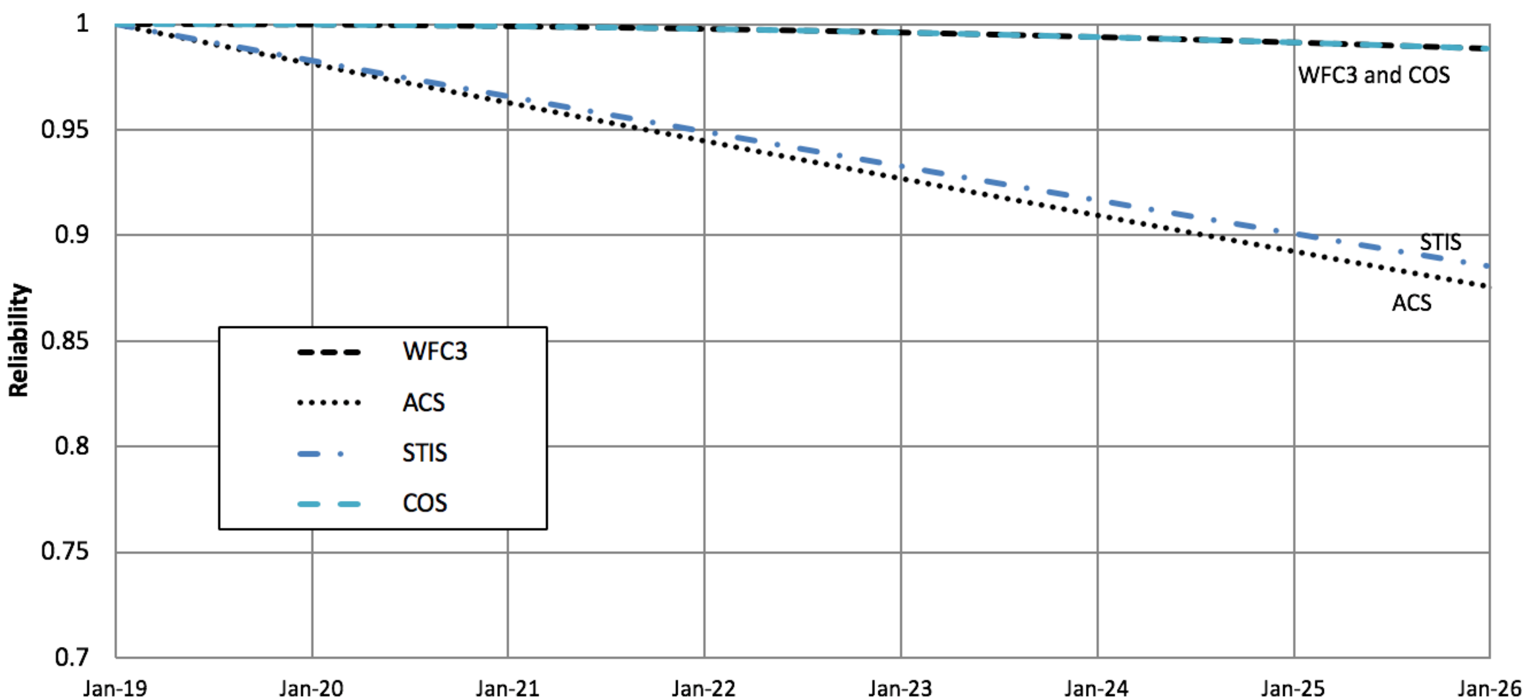
Subsystem		Summary
Science Instruments (SI)	G	• ACS suspend on 2/28/2019 due to failed checksum during return to science mode following anneal cycle; returned to normal operations status on 3/6; repeated 4/3. Tiger Team investigation identified EEPROM chip exhibiting a temperature dependence – successful mitigation implemented for May 3 anneal • WFC3 January 2019 suspend attributed to Single Event Upset within onboard telemetry collection circuitry – nominal operation resumed. WFC3 performance excellent. • COS moved to 4th position 10/2017 began COS 2025 initiative; investigating potential 5th lifetime position • STIS repaired instruments (SM4) performing nominally
Data Management System	G	• SI Control and Data Handling (C&DH) has had 12 lockup recoveries since 6/15/09; most recent was 1/19/18 • Developed requirements and operations concept for a rapid recovery from the periodic Science Instrument Control and Data Handling lock up events to reduce return to science from ~24 hours to less than 10 hours; anticipate operational summer 2019.

Instrument Reliability

Science Instrument reliability remains high

NASA Engineering and Safety Center provided methodology

- Greater than 95% probability for each of WFC3 and COS operating through 2025
- Greater than 85% probability for each of ACS and STIS operating through 2025



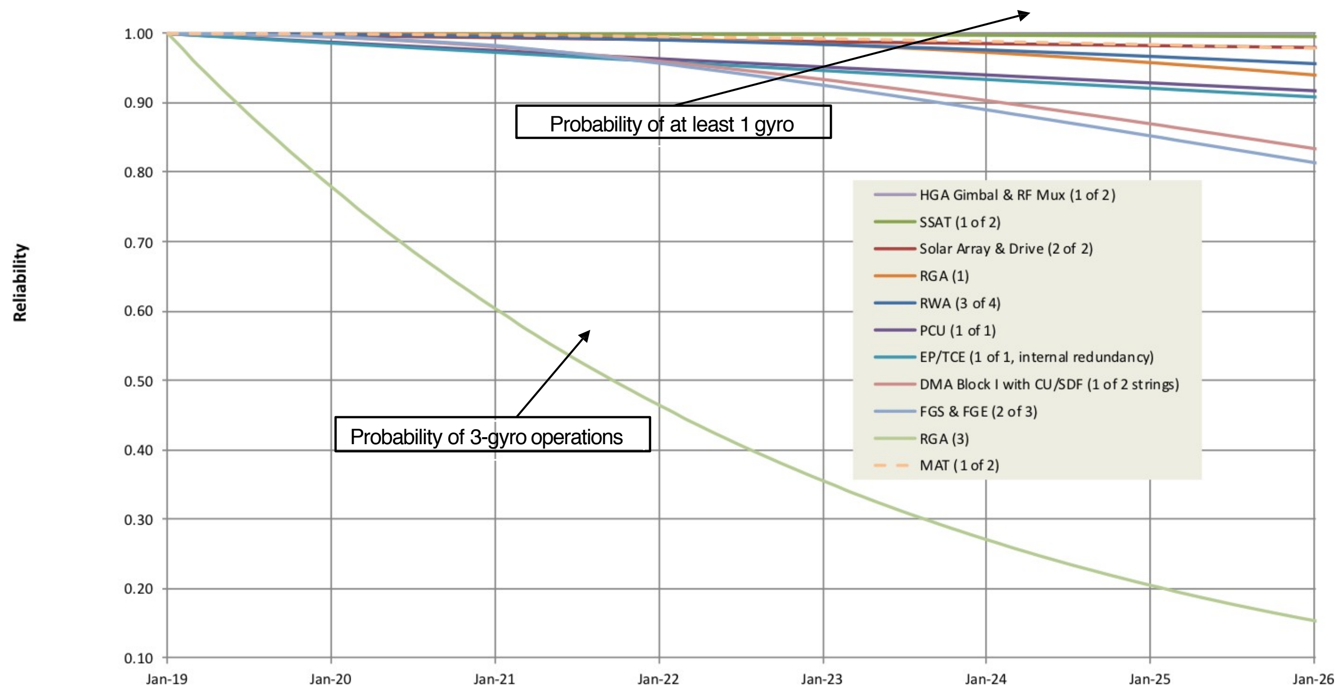
Healthy Spacecraft (main limitation is duration of 3 Gyro operations)

Subsystem		Summary
Electrical Power	G	• Excellent battery performance; Solar Array 3 performance remains excellent • Solar Array Drive Electronics (SADE) investigation following 2/15/13 SWSP; no further actions
Pointing Control System	G	• Gyro 6 motor current increased from ~120 mA to ~180mA on 3/21/2019; Gyro 4 similar event 9/2011 • Gyro 3 powered on 10/6/2018 – initial high output rates reduced to normal 10/19/2018; (3-4-6 complement) • Gyro 2 failed on 10/5/2018 • Gyro 1 failed on 4/21/2018; Gyro 6 powered on 4/21/2018 • Gyro 5 failed on 3/7/14; Gyro 6 powered off 3/13/14 • Gyro 3 removed from control loop/powered off 2011; Gyro 6 powered on • FGS-3 bearings degraded (~10% duty cycle to preserve life); FGS-2R2 Clear Filter operations 1/2015
Data Management System	G	• Solid State Recorders (SSRs) 1&3 each experienced lock up in 2011 in the South Atlantic Anomaly (SAA); SSR3 experienced another lockup in SAA on 1/9/18; Alert monitors detect condition to minimize data loss
Communications	G	• Multiple Access Transponder 2 (MAT2) coherent mode failed (12/24/2011); Two-way tracking unavailable
Thermal Protection System	G	• New Outer Blanket Layers (NOBLs) installed on Bays 5,7, and 8 during SM4 • Thermal performance is nominal

Spacecraft Reliability

Critical subsystem reliability remains high

- Greater than 80% probability of critical systems operating through 2025
- Nearly 95% probability of one gyro being available through 2025; 50% probability of 3-gyro operations through late 2021



Long Range Plan: Current Status (May 2019)

Cycle 26 averaging 75.4 orbits/week over first 33 weeks

- Without 3-week downtime in fall 2018, 83.0 orbits/week
- Cycle 17-23: 84 orbits/week
- Cycle 24: 82 orbits/week
- Cycle 25: 85 orbits/week

Previous Cycle Completeness

- Cycle 24: 22 orbits left in plan through fall 2019
- Cycle 25: ~630 orbits remain (due to 1200+ more orbits accepted in Cycle 25)

Nominal Cycle 26 boundary Oct 1, 2018; delta-TAC led to actual start in January 2019

- ~2200 orbits of Cycle 26 material remain

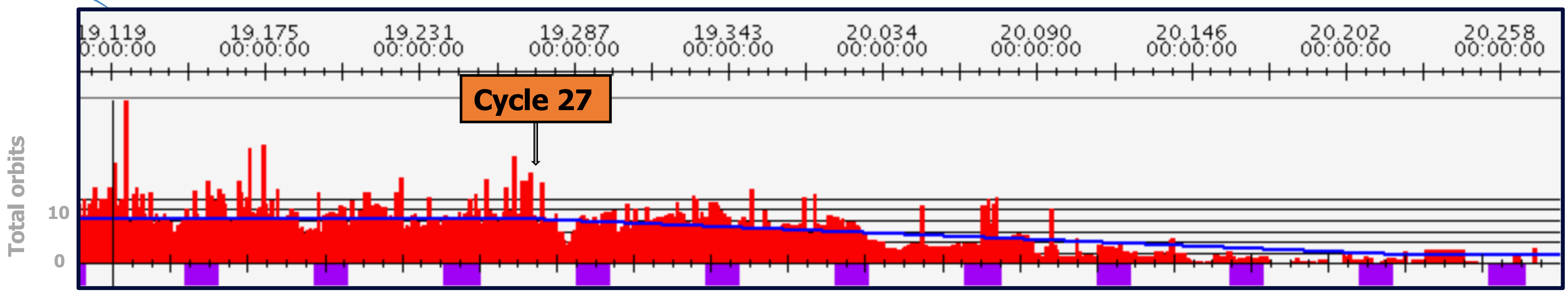
Cycle	Orbits
24	22
25	632
26	2193
Total	2847

C25 snaps	1367
C26 snaps	0
Total snaps	1367

Instrument	Orbits
WFC3	1379
COS	615
ACS	409
STIS	446
FGS	0
Total	2849(1)

(1) Some programs have more than one prime SI.

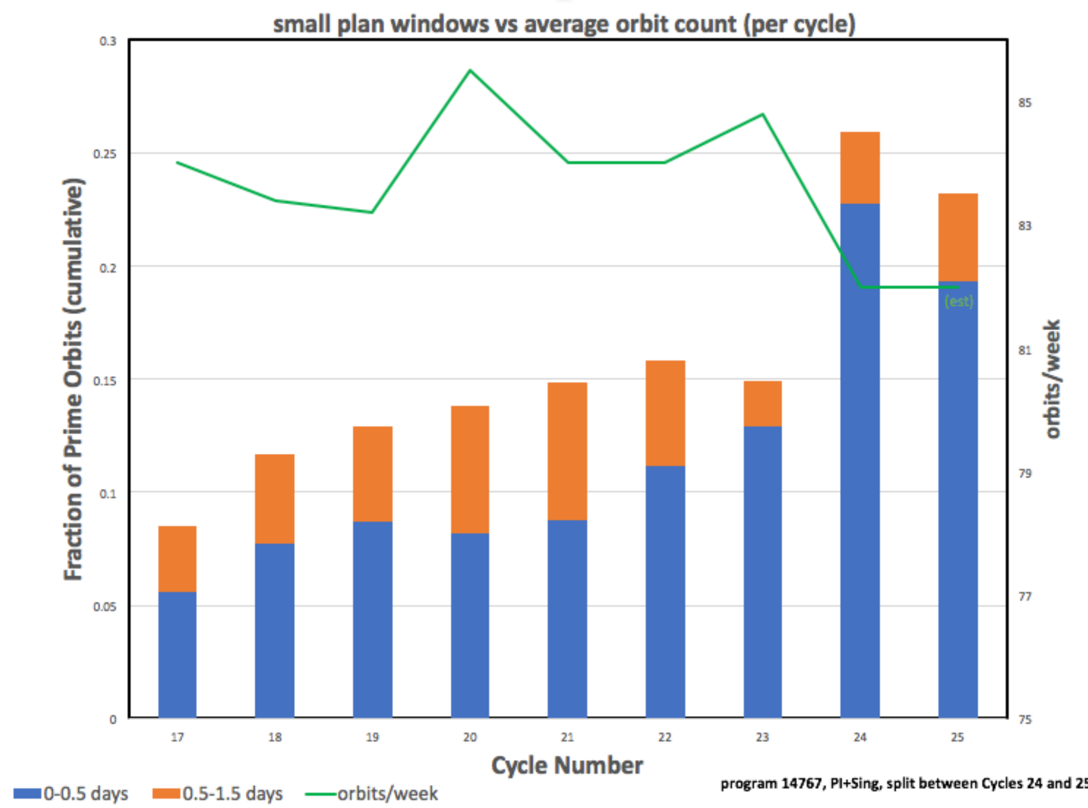
Long Range Plan: Current Status



- **While Cycle 26 nominal start was October 2018**
  - Cycle 25 still dominates the current plan
  - Currently, the Cycle 26 tail (Oct 2019 and later) contains ~1500 orbits (2x typical size)

Challenges to Efficiency – Time Constrained Science Programs

- Approximately 20% of science visits in Cycles 24 and 25 had timing constraints of a few orbits or less
- Creates conflicts between science programs
- Results in fewer flexible visits later in the plan that can be moved forward to fill schedule gaps
- We now build templates of constrained visits in advance to identify conflicts early in the process
- We are now requiring proposers to justify their constraints at the Phase I stage (as of Cycle 26)
- May begin rationing constraints at the TAC in future cycles



HST GYROs since SM4

- SM4 installed 6 new Gyros
    - 3 with enhanced flex leads(*)
- Historical HST Gyro lifetimes were ~5 years
- Gyro #2 had high level of jitter in its final year
- Gyro #3 has stability issues
    - Bias drift impacts (re-)acquisitions
- On-going work to accommodate Gyro #3
    - Some efficiency implications including small increases in overheads and scheduling constraints

Gyro	Status	Lifetime (Years)
1	Failed 4/18	5
2	Failed 10/18	5.4
3*	Operating^	>3.1
4*	Operating	>10
5	Failed 3/14	5.9
6*	Operating	>5.1

- Impacts pm Science Operations:
    - Higher rate of acquisition failures → higher HOPR rate impacting LRP stability and efficiency
    - Some failures were assumed when LRP is built but higher rate will be assumed for C27

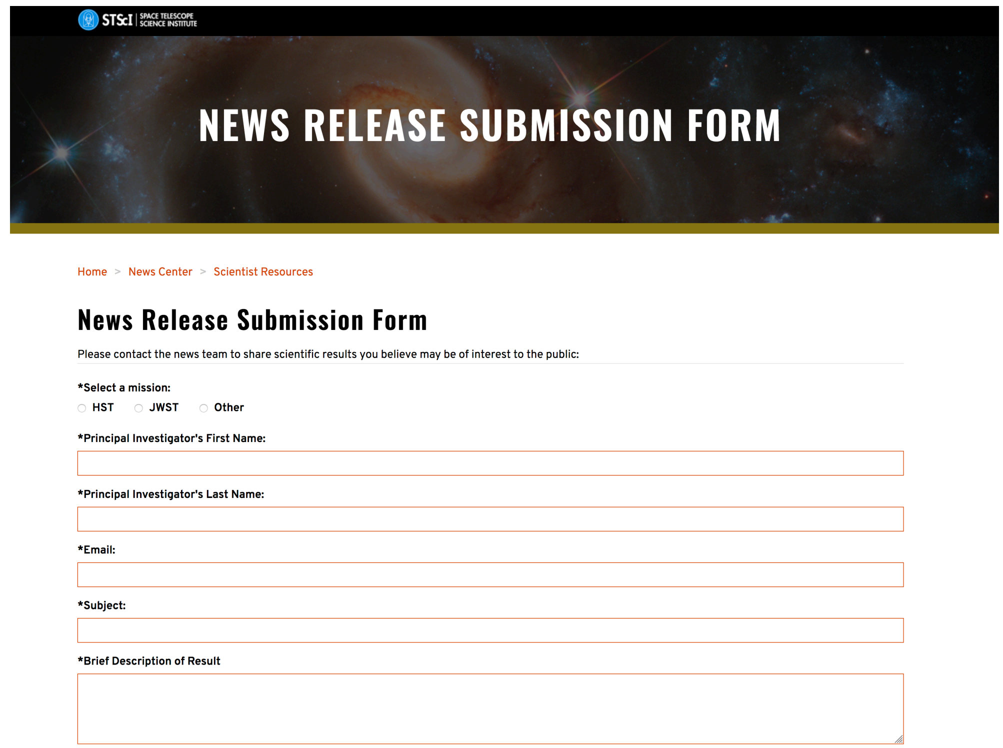
One Gyro Science Mode

- Hubble is now one gyro failure away from needing to use One Gyro Science mode
- Preparation steps have been completed to minimize the time required to make the transition into OGS and minimize our science down time
- OGM Mode limitations:
  - Reduced Field of Regard (~40% of sky visible at any given time)
  - No GYRO only observations (i.e. no DASH mode)
  - ~73 versus ~84 orbits schedulable per week
  - Limitations on ORIENTS
- Current expectation is the HST will transition to OGM in ~2021
- <u>TAC should assume Three Gyro Mode for Cycle 27</u>

Please Share Your Science with the Public

- Scientist PR submission form
    - Alerts news chief
    - Automatically logs entry for news team
    - Initiates follow-up from STScI to PI
    - http://www.stsci.edu/news/scientist-resources/scientist
- Archive auto-notice
    - Reminds PI of pending “end of program”
    - Encourages communication to STScI about publications and newsworthy results

Congratulations! Your program, GO-12345, “Amazing HST Observations”, is nearing completion. As your program draws to a close, we would like to ask you to coordinate with Space Telescope Science Institute to improve the dissemination of your results and help us better follow HST usage…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Please contact the news team to share scientific results you believe may be of interest to the public:

*Select a mission:

HST JWST Other

*Principal Investigator's First Name:

*Principal Investigator's Last Name:

*Email:

*Subject:

*Brief Description of Result

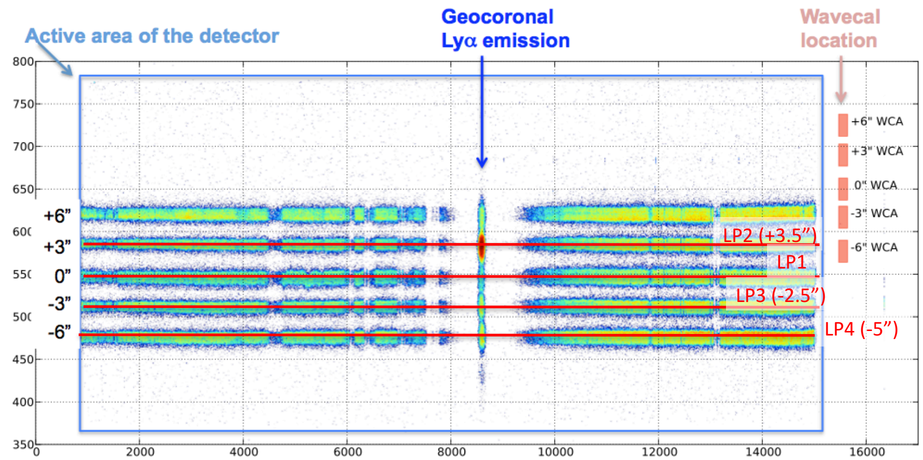
Leave the Scheduling and Technical Issues to Us

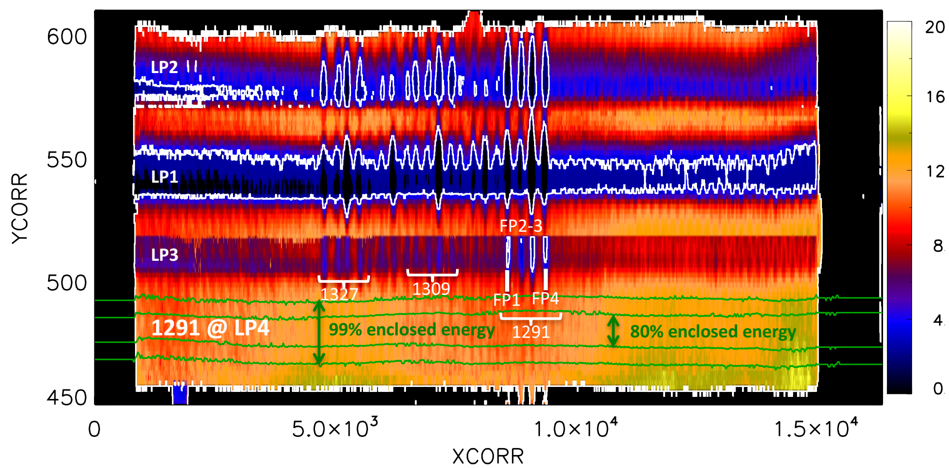
- In reviewing Cycle 27 proposals, Panels and TAC should focus on the best science

  - Constraints/Special Requirements must be scientifically justified
  - However, leave scheduling constraints to us to consider in the context of the entire Cycle 27 pool of recommended proposals
  - Also, let us consider the suitability of observing programs if we do not remain to the nominal 3-gyro configuration

Extending COS Operational Lifetime

- COS has two channels: FUV & NUV
- FUV channel depleted with illumination (mainly Geo-Ly-alpha)
- Prior operational strategy employed a series of ~2.5 year lifetime positions (LPs)
- Active detector area allows for 4 normal LPs (possibly 5 –being studied)
- New approach for LP4 essentially limits number of positions for spectrum
- Ly A burns holes much more quickly but holes limited to much less area
- LP4 lifetime 2x – 3x longer (scientific utility declines in 2023+)





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