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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

Hubble Space Telescope Status

Cycle 31 TAC Presentation

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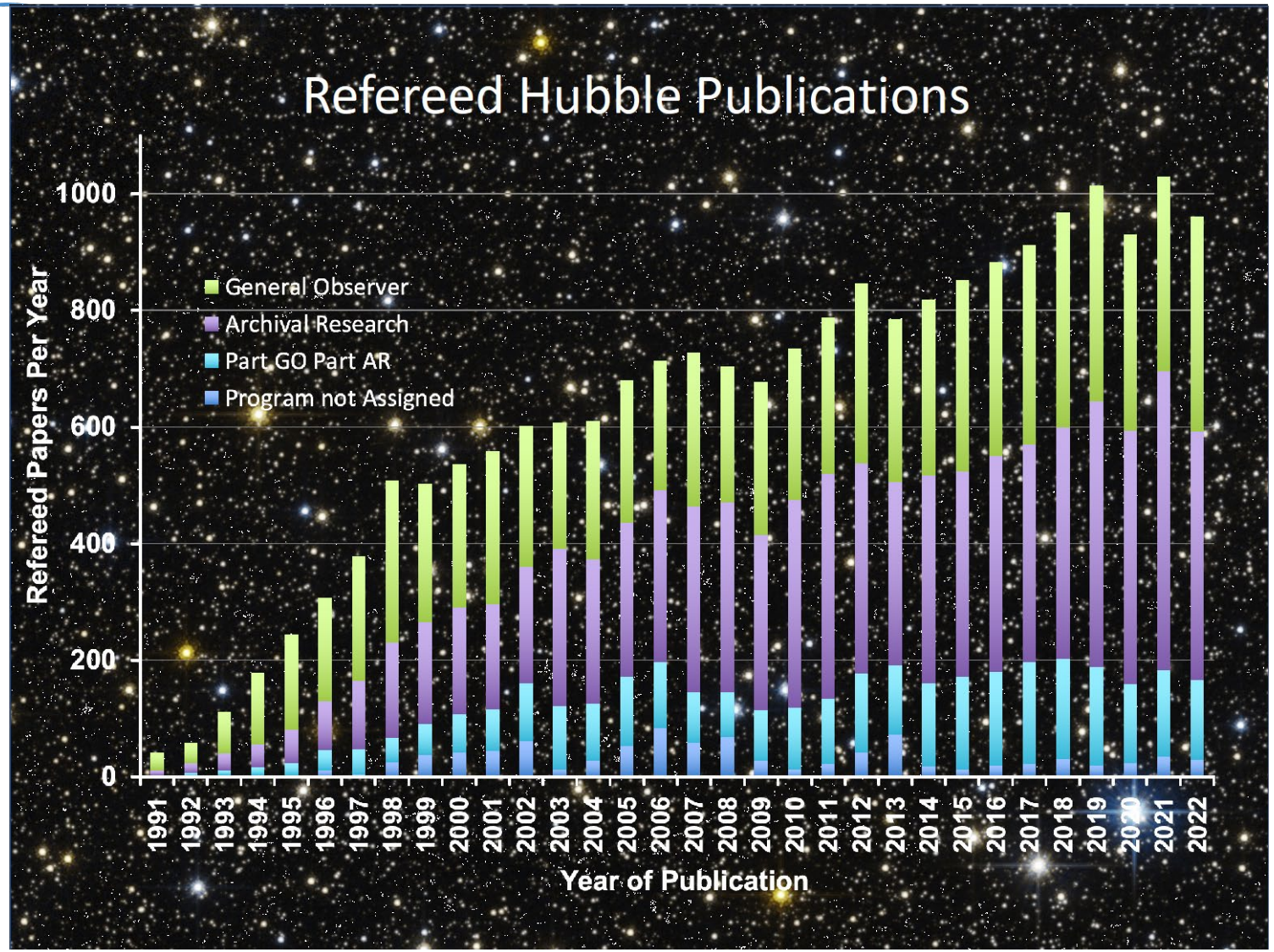
12 & 14 June 2023

Welcome!

Thank you for serving on the Cycle 31 HST TAC

- The Hubble Space Telescope has been operating for over 33 years!!!
  - We are more than 14 years past Servicing Mission 4
    - At that time, planning was for 5 years of science operations
  - In most respects, Hubble continues to work as it has since SM4 in 2009
    - There is some slight instrument performance degradation (mainly in CCD charge transfer efficiency)
      - This results in very minimal change over the past 5+ years and very slow future impacts are expected
    - Some degradation in the pointing control system results in more failed acquisitions than the long term average (2% has increased to about 5% and sometimes more for short periods – more later)
    - Lost ~10% of 2021 due to computer problems but S/W fixes in place for one issue and effort underway to recover lost redundancy on the other issue – HST continues to have multiple layers of redundancy!
    - We all (GOs and STScI+GSFC) have become smarter in how we use the observatory and to get the best science from its observations
- You, by serving the HST TAC process, have the privilege and responsibility of defining what Hubble does next!

Science Productivity at All Time High



- Hubble GO and AR programs produced 961 refereed science papers in 2022
- 20296 refereed science papers at end of 2022
- >1.16 million citations so far
- 600+ PhD theses
  - currently ~1 per week
- ~1 in 6 astronomy papers influenced by Hubble

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

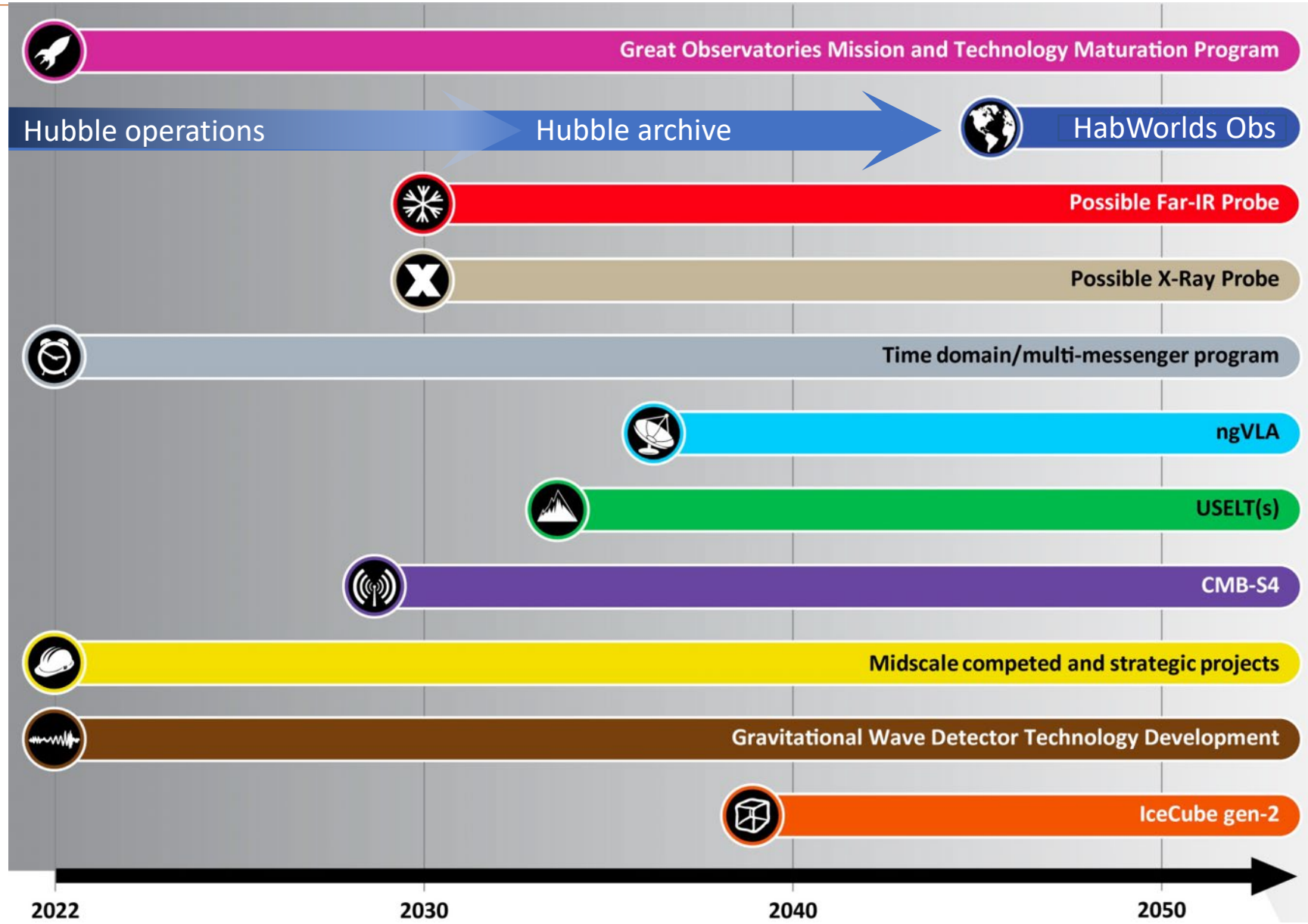
- HST archive size is >160 TB
- 6-15 TB per month retrieved
- >12,000 registered archive users (85 countries, 50 states)
- HST archive online cache delivers data within minutes to users
- Amazon Web Services became available in 2018 for archival research
  - All HST public data with very fast local processing on their servers
- Hubble Advanced Products (HAP) now available via MAST
  - Combines multiple images from multiple visits
- HST processing has moved to Cloud (AWS) for increased speed and reliability

Hubble remains unique for many years

(Astro 2020 timeline places HST in context)

Hubble will continue to be a crucial asset in the context of 2020 facilities

- Hubble observations quite possible past 2030
- Unique physical insights from UV/O with high spatial & spectral resolution
- Every operating facility will drive demand for Hubble data that confirm, complement, & extend their discoveries
- Hubble is a bridge to HWO, the next flagship mission for NASA



Supporting Time Domain Science

Hubble increasingly operates in an era of all-sky + multi-messenger surveys

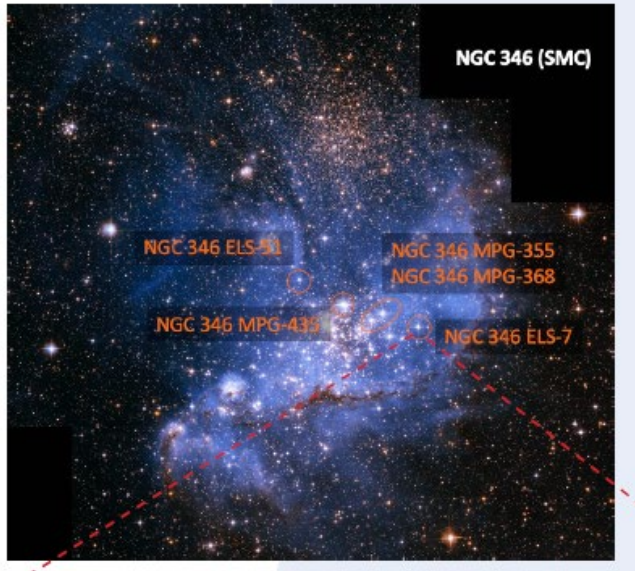
- Increasing excitement & pressure from discoveries of transient phenomena
  - All-sky O/IR surveys (e.g., Rubin, Roman, Zwicky Transit Facility)
  - Gravitational wave experiments (e.g., LIGO, Kamioka, Virgo, LISA)
  - Neutrino observatories (e.g., IceCube Gen2, Super Kamiokande, Hyper Kamiokande)
- Scheduling tension between exciting science programs
  - Exoplanet & Solar System programs require tight timing constraints, as do observations coordinated with other facilities
  - Transient phenomena often require rapid response
- We are exploring ways to maximize scientific return while accommodating competing pressures
  - Hubble can provide crucial context on various timescales (days to years)
  - UV evolution distinct & provides physical insights unavailable at longer wavelengths
  - New “Flexible Thursdays” allow rapid Target of Opportunity response with minimal disruption of other science

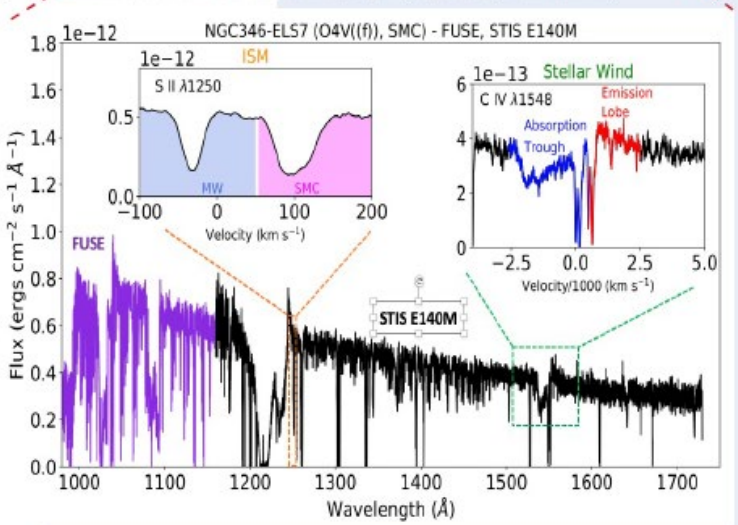
2017 NS-NS GW kilonova

ULLYSES: Ultraviolet Legacy Library of Young Stars as Essential Standards

- Nearly complete ~1000 orbit Director's Discretionary program
- Ultraviolet spectroscopic library of young high- and low-mass stars (500 orbits each)
- Uniformly samples the astrophysical parameter space for each mass regime
  - Spectral type, luminosity class, and metallicity for massive stars
  - Mass, age, and disk accretion rate in low-mass stars
- Frequent public releases of enhanced data products; Latest DR6 includes:
  - COS+STIS new and archival spectral of nearly 300 massive stars in the LMC, SMC and other lower metallicity nearby galaxies (NGC 3109, IC 1613, WLM, Sextans A, Leo P)
  - COS + STIS new and archival spectral of 108 single-epoch T Tauri stars in the Milky Way
  - Spectral time series of 4 T Tauri stars monitored with HST

Region	Instrumental modes
LMC and SMC	COS/G130M/1096 (brightest O stars) COS/G130M/1291 + COS/G160M/1611 or STIS E140M STIS/E230M/1978 (O9 I – B9 I only) STIS/E230M/2707 or COS/G185M/1953 + 1986 (B5-9 I)
Sextans-A and NGC 3109	COS/G140L/800
Survey T Tauri stars	COS/G130M/1291 + COS/G160M/1589+1623 STIS/G230L + STIS/G430L + STIS/G750L
Monitoring T Tauri stars	COS/G160M/1589 + 1623 + COS/G230L/2635 + 2950





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; this has declined only slightly in Cycles 26 – 30 with the completion of two large programs that had very strong timing constraints
- Creates conflicts between science programs and may cause programs to have delayed execution dates
- Results in fewer flexible visits later in the plan that can be moved forward to fill schedule gaps and thus a less efficient program overall
- We ask proposers to avoid constraints and special requirements that are not scientifically required
- Starting in Cycle 26 proposers are required to justify their constraints at the Phase I stage

New Scheduling Opportunity for Cycle 31 – Flexible Thursdays

- In addition to the long-standing Target of Opportunity (ToO) categories, a new ToO category is available starting in Cycle 31 → **FLEXIBLE THURSDAYS**
- One Thursday per month, the Hubble schedule will include a Flexible Thursday (beginning at approximately 12:00 UT) with targets that can be rescheduled relatively easily (*i.e.* Thursday's original schedule can be disrupted with only minor impacts)
- Triggers for a ToO must be received with fully detailed activation and Phase II submission by 10:00 UT on Tuesday (nearly as fast as a rare "ultra-disruptive" ToO)
- This significantly increases the potential number of fast turn-around observations with HST for Cycle 31 from 8 disruptive ToO's (2-5 days) by adding 20 possible ToO (2-3 days) over 10 Thursdays during the Cycle
- There are a number of hard constraints on the use of the ToO necessary to limit both its impact of the scheduling of HST and the workload of the scheduling teams

Please Share Your Science with the Public

- STScI provides support for sharing your findings with the public. Please visit
    - http://www.stsci.edu/news/scientist-resources

- Simplified email based system will initiate a process with the news team

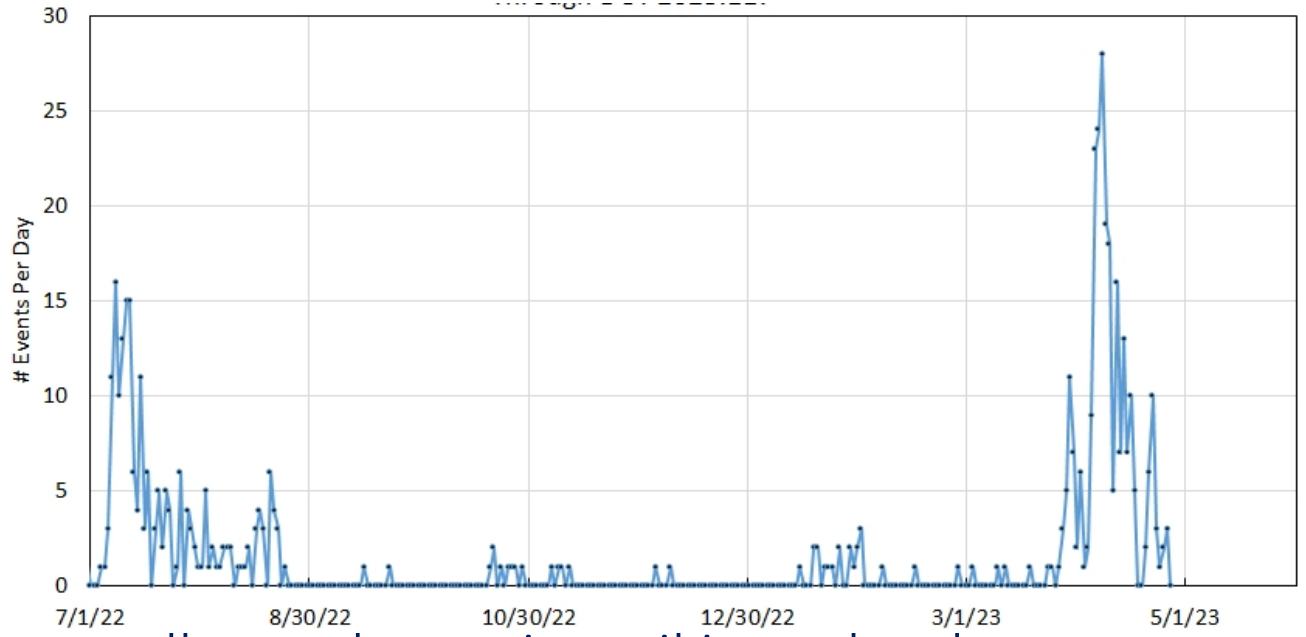
Observatory and Instrument Update

Spacecraft Status

- High confidence in operations for at least several more years
- Current engineering efforts are extending time in 3-gyro mode
    - 3 (of 6) Gyros remain functional although one (G3) has higher noise and drift rate
        - Has resulted in more frequent acquisition failure rates; operational and software mitigation efforts have improved this with some additional improvements expected
    - The 3 working gyros are enhanced devices with lifetimes expected to be >20 years
    - 1-Gyro mode is available and tested; models predict operations into mid-2030s
    - TAC should assume 3-gyro mode for Cycle 31
- HST orbit stable well beyond 2030
- Power, thermal, communications, etc. retain significant redundancy→ 2030+ *possible!*

FGS2 Issues

- FGS2 experiences periods of servo saturation events, causing lost observations
- Might be due to debris in servo and uneven distribution of lubricant



- Some benefit from mitigating operations – usually need to wait until it settles down
- Some of these cause total or partial loss of visit; some of these result in no loss of science
- Latest erratic behavior covered most of April
- Worse case caused ACQ/REACQ problems in 30% of SMS
- Actively re-balancing observations to FGS1-3 pair (sometimes results in shifting schedule)
- Now have resumed normal FGS2 usage (w/exception of spatial scans & moving targets)
- Exploring various options to reduce future impacts if (when?) this reoccurs

B-Side Operations

NASA Servicing Mission 4 animation
14 May 2009

- 13 June 2021 – NASA Standard Spacecraft Computer (NSSC) halted on Science Instrument Control and Data Handling (SIC&DH) System while operating on SIC&DH Side B
- Likely due to Power Control Unit (PCU) power clear circuit
- 15 July 2021 – Transition to SIC&DH Side A
- GSFC and STScI immediately began investigating the possibility of operations on Side B, by sending commands from 486 to instruments, bypassing NSSC
- Would also be applicable if similar failure occurred on Side A
- 4 Nov 2022 – Preliminary Ops Concept Review, looked promising
- 4 Apr 2023 – Ops Concept Review went extremely well; development on-going

HST Instruments

- HST supports four science instruments (plus the FGS may be used for astrometry)
  - ACS = Advanced Camera for Surveys (installed 2002; SM3b)
  - COS = Cosmic Origins Spectrograph (installed 2009; SM4)
  - STIS = Space Telescope Imaging Spectrograph (installed 1997; SM2)
  - WFC3 = Wide Field Camera 3 (installed 2009; SM4)

- For TAC purposes, the performance of these instruments has been basically stable since 2009
- More information:
  - https://www.stsci.edu/files/live/sites/www/files/home/hst/_documents/HST-Booklet.pdf
  - https://hst-docs.stsci.edu/hsp/hubble-space-telescope-science-policies-group-and-peer-review-information/general-info-getting-started/hubble-and-its-instruments
  - https://www.stsci.edu/hst/instrumentation

Advanced Camera for Surveys (ACS)

- ACS/WFC has the largest field of view and highest throughput in visible light of any HST instrument
- The ACS/WFC grism provides well-calibrated, wide-field slitless spectroscopy of visible to near-IR light
- ACS is the only active space-based, high spatial resolution polarimeter, providing synergy with JWST dust studies
- The ACS/SBC is especially optimized for FUV imaging, but also supports slitless spectroscopy

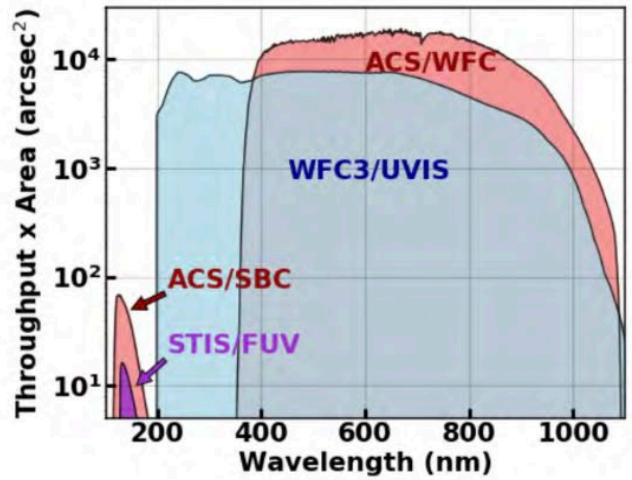
Wide Field Channel (WFC)

- Optical imaging and slitless spectroscopy (3,500–11,000 Å)
- Highest throughput on HST in visible light
- 202'' x 202'' field of view, largest on HST
- 13 wide, medium, and narrowband filters
- 15 tunable wavelength filters
- Grism (5,500–10,500 Å); R ~ 100 at 8,000 Å
- Near-UV / visible linear polarization filters

Please see the ACS Instrument Handbook for more detailed information on ACS capabilities.
https://hst-docs.stsci.edu/display/ACSIHB/

Solar Blind Channel (SBC)

- FUV imaging and slitless spectroscopy (1,150–1,700 Å)
- High throughput, best for FUV imaging
- 35'' x 31'' field of view
- 5 longpass filters, 1 Lyman α filter
- Two prisms; R ~ 79 and 96 at 1,500 Å

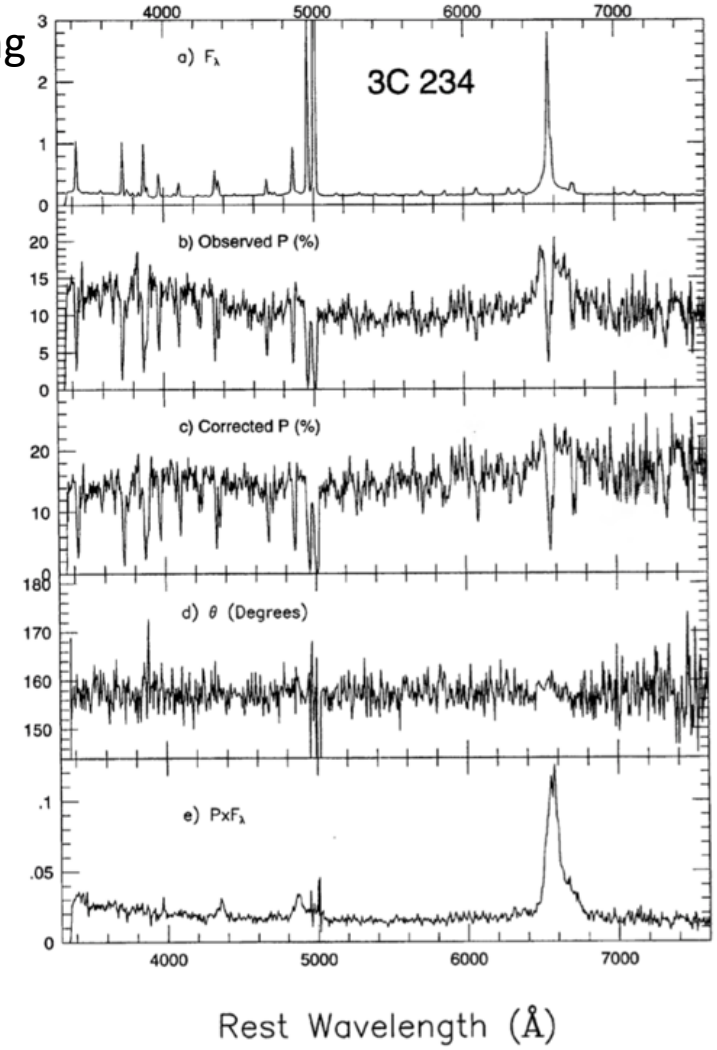


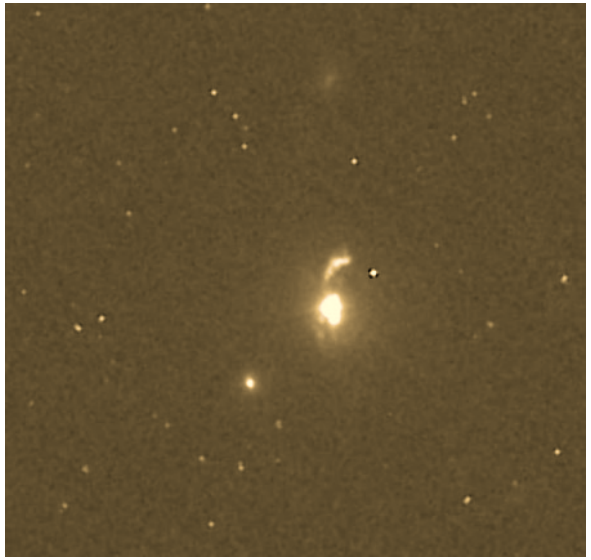
An Innovation for Cycle 31: New Spectropolarimetry Mode on ACS

- ACS polarimetry was previously supported for imaging
- New mode for C31 provides spectropolarimetry
  - 0°/60°/120° polarizers × G800L grism
- Optical spectropolarimetry difficult from the ground (limitations of adaptive optics)

- Physical insights include:
  - Luminous vs. scattered emission
  - Nature of scattering particles
  - Geometry, orientation, structure
  - Magnetic field

- Science applications include
  - Active galactic nuclei
  - Interstellar medium
  - Protoplanetary & debris disks
  - Supernova remnants
  - Transiting exoplanets
  - Solar system targets
  - Star-forming regions

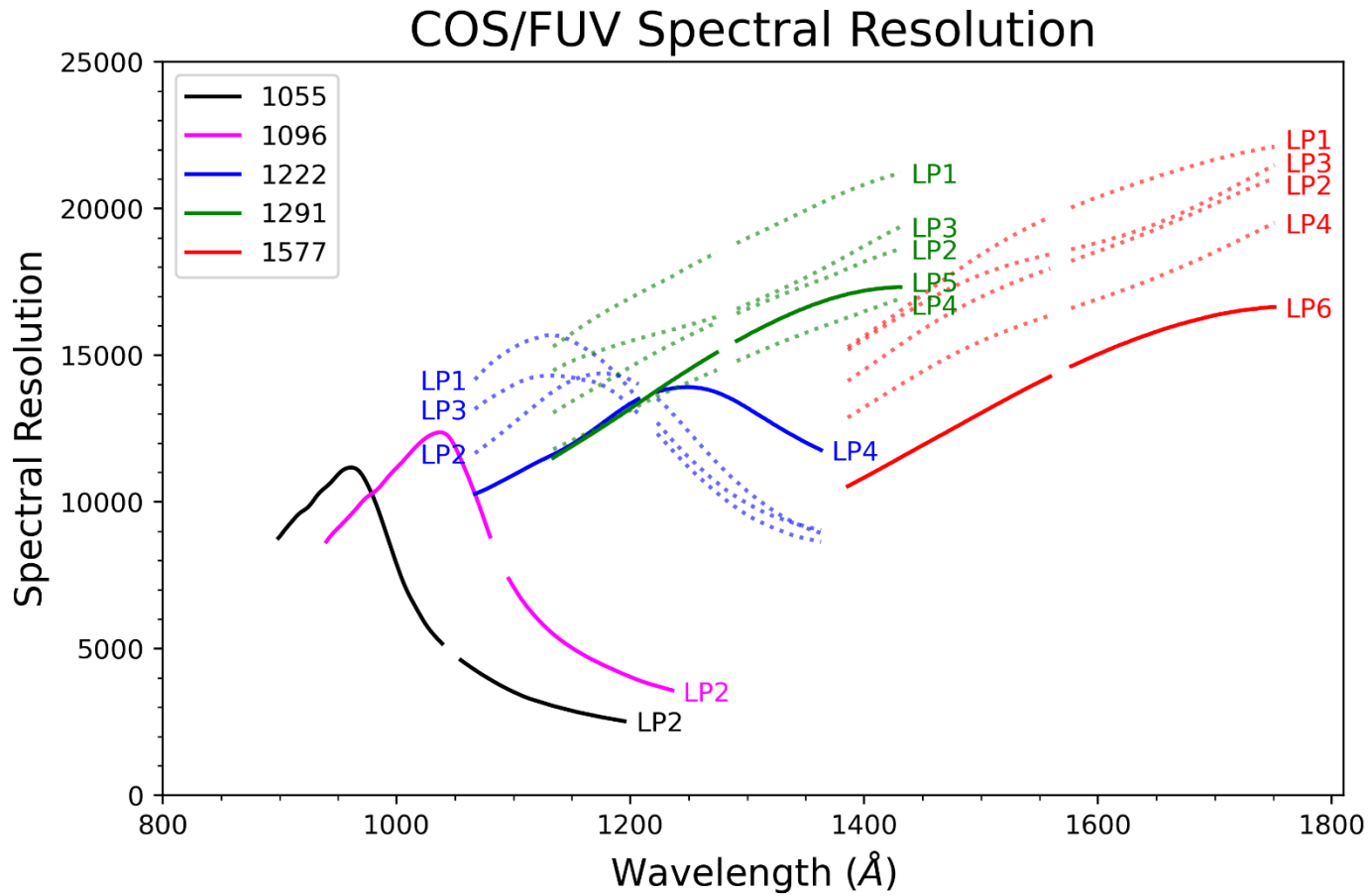




Keck spectropolarimetry

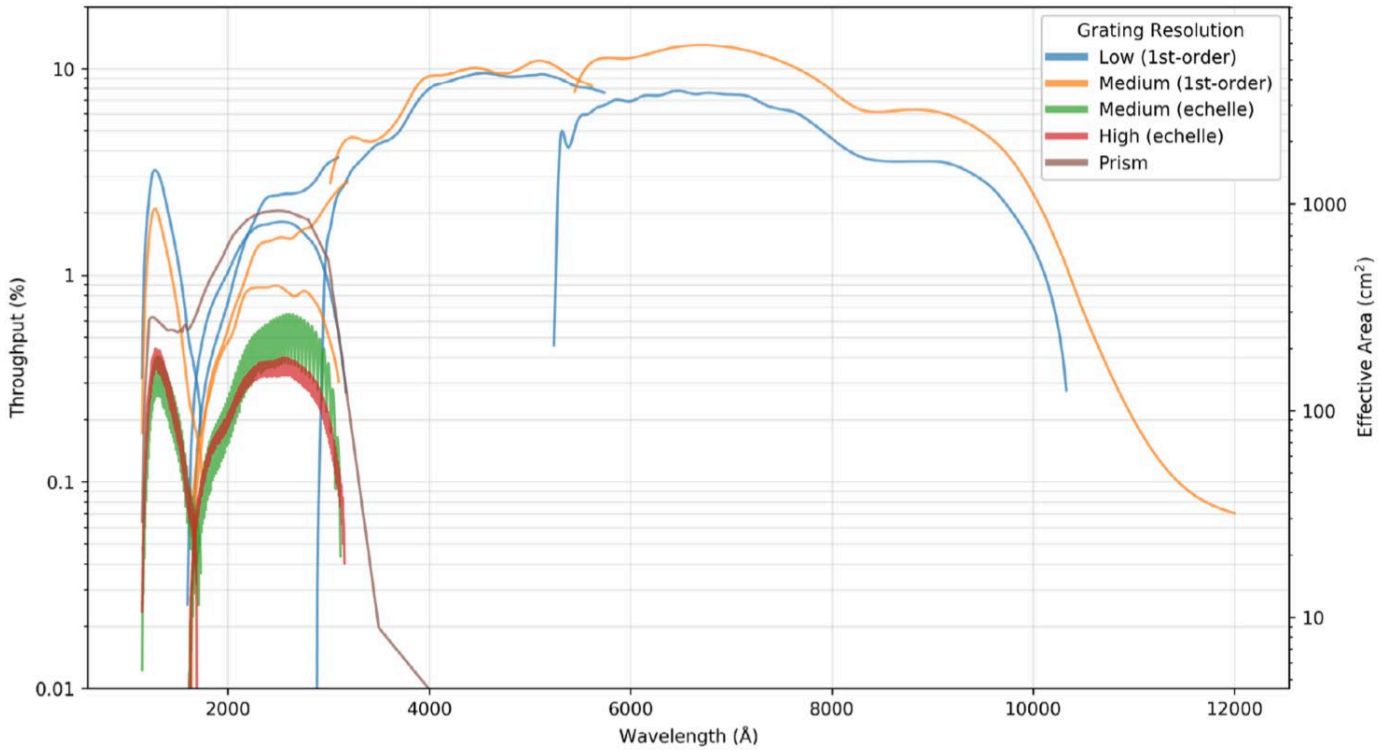
Cosmic Origins Spectrograph (COS)

- COS provides low to medium resolution spectroscopy from 800 to 3200 A.
- Has a fixed 2.5 arc second diameter aperture
- High sensitivity for observing faint sources
- Spectroscopy down to 800 A with the blue modes



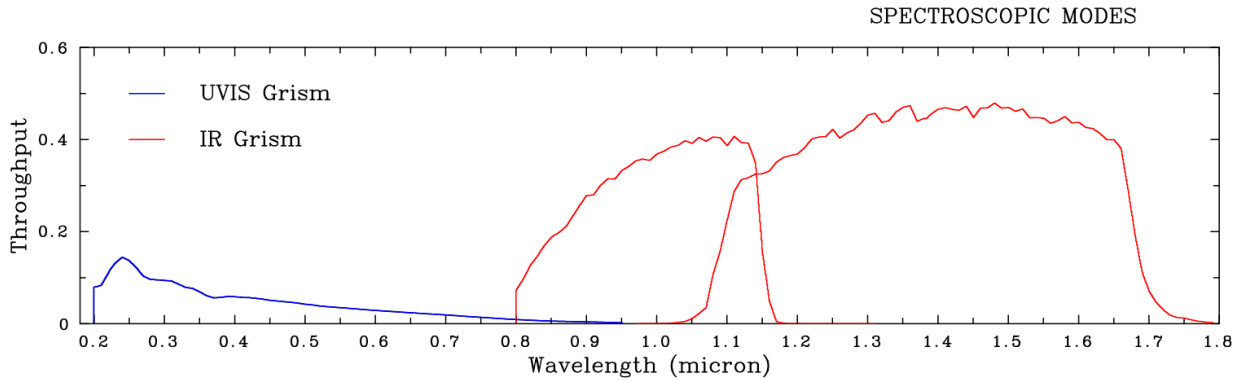
Space Telescope Imaging Spectrograph (STIS)

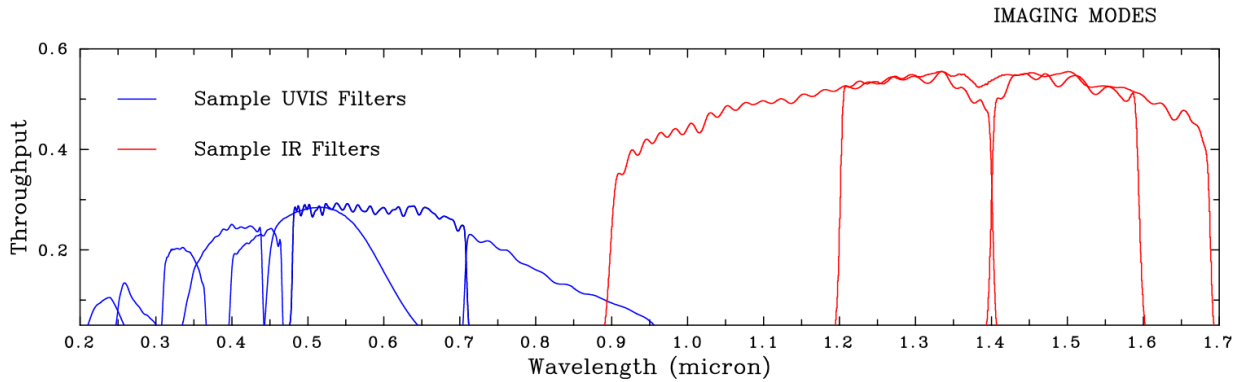
- STIS UV and visible imaging and low to high resolution spectroscopy with a variety of apertures.
- Has a coronagraphic mask and occulting bars
- Time-tag mode in the UV allows time-resolved observations
- Spatial scanning with the CCD allows high SNRs to be obtained while avoiding saturation
- High spatial resolution in the UV and visible



Wide Field Camera 3 (WFC3)

- Two channels: UVIS operating between 2000 to 10000 A, and IR operating between 0.9 to 1.7 microns.
- High resolution imaging from 2000 A to 1.7 micron with a wide complement of filters
- Grism spectroscopy providing low resolution spectra at high spatial resolution in the UV/visible and IR
- Spatial scanning by slewing during an exposure to achieve high SNR photometry while avoiding saturation with direct imaging
- Grism scanning by slewing during an exposure to provide extremely high SNR spectra





Science Instruments Status

- Engineering estimates give high confidence for long term operation well beyond 2025
  - >95% COS and WFC3, >85% for ACS and STIS
- Re-designed management of COS FUV detector extends useful life to ~2030 or longer
- Graceful aging of CCD detectors
  - Charge transfer efficiency degradation mitigated by flashing and corrected at the pixel level with algorithms of increasing sophistication
  - Vast majority of defective pixels (warm, hot, dead) mitigated through extensive monitoring, reference files, and appropriate algorithms
- Recent increase in ACS/SBC MAMA detector dark rate
  - Appears to have corrected itself; being monitored and some mitigation possible if needed in future
  - Assume nominal performance at this time
- Changes in flat fields and sensitivities monitored and addressed in calibration pipelines
- Drifts in focus and alignment corrected by both mechanism motions and calibration updates

Please Leave the Scheduling and Technical Issues to Us

- In reviewing Cycle 31 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 31 pool of recommended proposals
  - Also, do not concern yourselves with the suitability of observing programs if we do not remain in the nominal 3-gyro configuration
    - That is, *assume current state of Hubble performance*!

- Thank you again for participating in this important process.