2023 marks the 33rd anniversary for the Hubble Space Telescope producing exemplary science. HST, a powerful observatory, probes the astrophysics of the cosmos from Solar System studies to the high-redshift universe. Many compelling investigations have benefitted from a long baseline of consistent observations over time, and now, new possibilities with Webb and Hubble combined studies.
Key Science Threads

- Properties of the huge variety of exo-planetary systems: compositions and inventories, compositions and characteristics of their planets

- Probing the stellar and galactic evolution across the universe: pushing closer to the beginning of galaxy formation and conducting coordinated observations with JWST

- Exploring traces of the nature of dark energy

- Probing the effect of dark matter on the evolution of galaxies

- Quantifying the types and astrophysics of black holes of over 7 orders of magnitude in size

- Tracing the distribution of chemicals of life in the universe

- Investigating phenomena and possible sites for robotic and human exploration within our Solar System

- Time domain observations probing a wide range of astrophysics

Besides the general observing opportunities provided by the annual call, mid-cycle call, and continuous Director’s Discretionary time, HST has several dedicated topical initiatives and also joint proposals with other facilities.

ACS Celebrating 21 years of operations, ACS offers wide field imaging from FUV to near-IR. Starting forward from HST Cycle 31, imaging (slitless) spectropolarimetry will be offered as a new mode of operation for the Wide Field Channel. Calibration updates continue to be made to the Solar Blind Channel, offering unique FUV imaging capabilities not offered elsewhere.

WFC3 offers high resolution imaging in many bands ranging from 2000 to 17000 Angstroms, as well as spectroscopic capability in the near ultraviolet and infrared. Many different modes are available for high precision photometry, astrometry, spectroscopy, mapping and more.

COS Entering its fifteenth year of operation, COS continues to provide critical spectroscopic observations of the ultraviolet universe. Plans are in place to retain the full science capability of the far ultraviolet (FUV) detector out to 2030 and beyond, with Lifetime Position 6 having been introduced for Cycle 30.

STIS Spatial Scanning is an available-but-unsupported mode for obtaining extremely high S/N spectra of bright objects by trailing them on the detector, which has applications for measuring weak absorption features or high precision stellar fluxes for, e.g., exoplanet transit characterization. More about the performance at https://www.stsci.edu/contents/news/stis-stans/march-2021-stan.html#spatial-scans

Cover: Hickson Compact Group Of Galaxies
The Hubble Space Telescope’s Ultraviolet Legacy Library of Young Stars as Essential Standards (ULLYSES) is a Director’s Discretionary program of approximately 1,000 orbits that is producing an ultraviolet spectroscopic library of young high- and low-mass stars in the local universe. The ULLYSES program uniformly samples the fundamental astrophysical parameter space for each mass regime, including spectral type, luminosity class, and metallicity for massive stars, and the mass, age, and disk accretion rate in low-mass stars. The program was executed over a three-year period, from Cycle 27 to Cycle 29.

### PROJECT MILESTONES

<table>
<thead>
<tr>
<th>Period</th>
<th>Milestone Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer/fall 2020</td>
<td>First observations and data release (DR1)</td>
</tr>
<tr>
<td>Spring/summer 2021</td>
<td>DR2 and DR3 First epoch of monitoring for TW Hya, RU Lup</td>
</tr>
<tr>
<td>Fall/winter 2021</td>
<td>DR4 First epoch of monitoring BP Tau, GM Aur NGC 3109 spectroscopy</td>
</tr>
<tr>
<td>Spring/summer 2022</td>
<td>DR5 Second epoch of monitoring TW Hya, RU Lup</td>
</tr>
<tr>
<td>Fall/winter 2022</td>
<td>DR5b, release of ULLYSES catalog/search form</td>
</tr>
<tr>
<td></td>
<td>Second epoch of monitoring BP Tau, GM Aur Spectroscopy of Sextans A</td>
</tr>
<tr>
<td>Spring/summer 2023</td>
<td>DR6, close-out</td>
</tr>
</tbody>
</table>

### Observing Strategy and Technical Specifications

The ULLYSES program is divided into two primary observational campaigns of high- and low-mass stars. The focus on high-mass stars includes observations of 65 stars in the SMC, 98 stars in the LMC, as well as 6 additional stars which are accessible in the even lower metallicity Local Group galaxies NGC 3109 and Sextans A. For low-mass stars, observations will focus on about 65 K- and M-type T Tauri stars and brown dwarfs within 8 star-forming regions in the Milky Way, including time-domain monitoring of 4 prototypical T Tauri stars with well-known rotation periods and magnetic configurations.

All targets are being observed with COS and/or STIS medium-resolution modes, as detailed in Table 2.

<table>
<thead>
<tr>
<th>Region</th>
<th>Instrumental modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMC and SMC</td>
<td>COS/G130M/1096 (brightest O stars) + COS/G130M/1291 + COS/G160M/1611 + STIS E140M + STIS/E230M/1978 (09 I – B9 I only) + STIS/E230M/2707 or COS/G185M/1953 + 1986 (B5-9 I)</td>
</tr>
<tr>
<td>Sextans-A and NGC 3109</td>
<td>COS/G140L/800</td>
</tr>
<tr>
<td>Survey T Tauri stars</td>
<td>COS/G130M/1291 + COS/G160M/1589+1623 + STIS/G230L + STIS/G430L + STIS/G750L</td>
</tr>
<tr>
<td>Monitoring T Tauri stars</td>
<td>COS/G160M/1589 + 1623 + COS/G230L/2635 + 2950</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th># ULLYSES targets</th>
<th># AR targets</th>
<th># ULLYSES orbits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMC</td>
<td>98</td>
<td>55</td>
<td>225</td>
</tr>
<tr>
<td>SMC</td>
<td>65</td>
<td>65</td>
<td>220</td>
</tr>
<tr>
<td>Sextans-A</td>
<td>3</td>
<td>6</td>
<td>~37</td>
</tr>
<tr>
<td>NGC 3109</td>
<td>3</td>
<td>0</td>
<td>~15</td>
</tr>
<tr>
<td>Lupus</td>
<td>27</td>
<td>4</td>
<td>142</td>
</tr>
<tr>
<td>Cha I</td>
<td>12</td>
<td>3</td>
<td>98</td>
</tr>
<tr>
<td>η Cha</td>
<td>1</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>ø Cha</td>
<td>4</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>η Ori</td>
<td>3</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Σ Ori</td>
<td>3</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>CrA</td>
<td>2</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Monitoring CTTS</td>
<td>4</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>TOTAL</td>
<td>233</td>
<td>137</td>
<td>981</td>
</tr>
</tbody>
</table>

For more information, visit https://ullyses.stsci.edu

Download data at https://mast.stsci.edu/search/ui/#/ullyses
Massive Stars

The massive star component of ULLYSES leverages on existing FUSE and HST archival data, to provide full UV coverage at medium-resolution for ~240 targets uniformly sampling spectral type and luminosity class.

The ULLYSES dataset for massive stars will enable transformative science in the field of stellar astrophysics, and enable a legacy of studies of the interstellar and circum-galactic media.

T Tauri Stars

The 58 T Tauri stars to be surveyed in 8 Milky Way star-forming regions uniformly sample mass and disk accretion rate. The library of UV-optical-NIR spectra from ULLYSES will enable studies of the accretion and resulting UV radiation in those objects, which affects the evolution of proto-planetary disks and the chemical composition and atmospheric escape of young planets.
Wide Field Camera 3 (WFC3) offers high resolution imaging in bands ranging from 2000 to 17000 Angstroms, as well as spectroscopic capability in the near ultraviolet and infrared. A variety of modes are available for high precision photometry, astrometry, spectroscopy, mapping and more: https://www.stsci.edu/sites/www/home/hst/instrumentation/wfc3.html

**Select filters shown. UVIS/IR channels feature 62/15 filters, respectively, with varying bandwidths for many spectral features**
**Direct Imaging**
High resolution, wide field imaging. Large complement of filters for various photometric bands/spectral features.

**Grim Spectroscopy**
Using grisms instead of imaging filters allows low resolution spectroscopy, while maintaining high spatial resolution.

**Spatial Scanning**
Slewing during exposure (spatial scanning) places source flux on hundreds of pixels/avoids saturation, achieving extremely high SNR photometry.

**Grim Scanning**
Combining scanning and grism spectroscopy allows for extremely high SNR spectra. Useful for transit observations.

Handbook: [https://hst-docs.stsci.edu/display/WFC3IHB](https://hst-docs.stsci.edu/display/WFC3IHB)
**SPACE TELESCOPE IMAGING SPECTROGRAPH (STIS)**

**FUV MAMA (Multi Anode Microchannel Array)**
- 1024 x 1024 CsI detector, TIME-TAG available
- Imaging: 25'' x 25'' FOV, 0.025'' pixels, 9 filters
- Spectroscopy: 2 first order and 2 echelle gratings
  - \( \lambda = 1150 - 1740 \, \text{Å} \), \( R \sim 1000 - 200,000 \) — ~30 cen. wave. configurations

**NUV MAMA**
- 1024 x 1024 CS2Te detector, TIME-TAG available
- Imaging: 25'' x 25'' FOV, 0.025'' pixels, 12 filters
- Spectroscopy: 2 first order and 2 echelle gratings
  - \( \lambda = 1650 - 3100 \, \text{Å} \), \( R \sim 500 - 200,000 \)
  - ~55 cen. wave. Configurations
- Prism Spectroscopy:
  - \( \lambda = 1150 - 3620 \, \text{Å} \), \( R \sim 10 - 2500 \)

**CCD**
- 1024 x 1024 SITE CCD detector
- Imaging: 52'' x 52'' FOV, 0.051'' pixels, 9 filters
- Spectroscopy: 6 first order gratings
  - \( \lambda = 1650 - 11,000 \, \text{Å} \), \( R \sim 500 - 10,000 \)
  - ~40 cen. wave. Configurations
- Usable with coronagraphic mask and occulting bars
  - Broadband imaging (2000 - 10,300 Å)
  - Bar-occulted spectroscopy (2000 - 10,300 Å)

STIS is one of the oldest active instruments on the Hubble Space Telescope (HST).
- Large fraction of total HST observing time (10-15% GO observations in recent Cycles)
- Incredibly versatile and highly configurable instrument
- Numerous filters, gratings, and apertures
- Large variety of unique photometric and spectroscopic modes
- High spatial resolution in the UV and optical

**ACCESS TO UV**

**HIGH RESOLUTION SPECTRA**

Magnesium lines trace Betelgeuse’s winds
UNIQUE USES OF STIS

Spatial Scanning with the STIS CCD

Spatial scanning is now an available-but-unsupported mode on STIS.

- Allows for more photons to be collected before reaching the CCD full-well saturation.
- Better averaging over variations in the flat field,
- Can lead to much better IR fringe removal than non-scanned images.
- For example, Signal-to-Noise ratios of 600-800 have been achieved in 1D extracted G750M/9336 spectra

TIME-TAG Mode

The STIS MAMA allows time-resolved observations through TIME-TAG mode.

- Tracks the collection time of each individual photon event at a time resolution of 125 microseconds.

Coronagraphy

- The STIS CCD allows optical coronagraphy with a range of occulter sizes
- 2 perpendicular WEDGE occulters can be used at widths ranging from 0.6” to 2.8”
- 2 BAR occulters of dimensions 10x3” and 5x0.3”

STIS Jupyter Notebook Tutorials Repository: https://github.com/spacetelescope/STIS-Notebooks
For more information about STIS: www.stsci.edu/hst/instrumentation/stis
If you have questions about STIS/HST/STScI: https://stsci.service-now.com/hst
ADVANCED CAMERA FOR SURVEYS (ACS)

Dust Pillars in Carina observed with the ACS/WFC. Uses filters F502N ([O III], blue) and F658N (Hα + [N II], red).

Gravitational lensing in Abell 370 observed with ACS/WFC. Uses filters F475W (blue), F625W (green), and F814W (red).

Wide Field Channel (WFC)
- Optical imaging, slitless spectroscopy and spectropolarimetry (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

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

Please see the ACS Instrument Handbook for more detailed information on ACS capabilities. https://hst-docs.stsci.edu/display/ACSIHB/
Detection limits for WFC and SBC (flat spectrum in frequency)

<table>
<thead>
<tr>
<th>Camera</th>
<th>Filter</th>
<th>V-band AB limit (S/N=5 in 1 hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFC</td>
<td>F606W</td>
<td>28.2 mag</td>
</tr>
<tr>
<td>WFC</td>
<td>F814W</td>
<td>27.7 mag</td>
</tr>
<tr>
<td>SBC</td>
<td>F125LP</td>
<td>26.0 mag</td>
</tr>
</tbody>
</table>

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

MOST RECENT ISRS

- Corrections to Commanding Overheads for ACS/WFC Exposures
- Improved Identification of Satellite Trails in ACS/WFC Imaging Using a Modified Radon Transform
- ACS/WFC CTE Photometric Correction Improved for Bright Point Sources
- Systematic Effects in ACS/WFC Absolute Gain Measurements

For a complete list of ACS instrument science reports, please visit:
https://www.stsci.edu/hst/instrumentation/acs/documentation/instrument-science-reports-isrs
COSMIC ORIGINS SPECTROGRAPH (COS)

COS Overview

**Far Ultraviolet (FUV)**
- Medium Resolution mode:
  \[ R \approx 15,000-21,000 \]
  \[ \lambda \approx 900-1800 \text{ Å} \]
- Low Resolution mode:
  \[ R \approx 1,500-4,000 \]
  \[ \lambda \approx 800-2050 \text{ Å} \]
- Effective area \( \approx 1800-3000 \text{ cm}^{-2} \)
- Three gratings:
  - G130M
  - G160M
  - G140L
- Pixel format: 16384 x 1024

**Near Ultraviolet (NUV)**
- Medium Resolution mode:
  \[ R \approx 15,000-24,000 \]
  \[ \lambda \approx 1700-3200 \text{ Å} \]
- Low Resolution mode:
  \[ R \approx 2,100-2,900 \]
  \[ \lambda \approx 1650-3200 \text{ Å} \]
- Effective area \( \approx 600-750 \text{ cm}^{-2} \)
- Four gratings:
  - G185M
  - G225M
  - G230L
  - G285M (available but unsupported)
- Pixel format: 1024 x 1024

SEE OUR HANDBOOK AT
https://hst-docs.stsci.edu/display/COSIH/BB/

COS spectra through April 2017
the Hubble Spectroscopic Legacy
Archive (HSLA):
https://archive.stsci.edu/hst/spectral_legacy/
STScI's COS 2025 policy places restrictions on G130M cenwaves allowed at Lifetime Position 4 and 5 to reduce gain sag from geocoronal Ly-alpha with the goal of retaining full science capability of COS/FUV to 2030 and beyond. Lifetime Positions 5 (G130M) and 6 (G160M) were introduced in Cycles 29 and 30 to facilitate this goal.

More information is available at: https://www.stsci.edu/hst/instrumentation/cos/proposing/cos2025-policies

**WHAT'S NEW AND UPCOMING?**

**FUV Lifetime Positions** — FUV spectra continue to be obtained at LP2, LP3, LP4, LP5, or LP6, depending on cenwave. LP6, the default location for G160M spectroscopy, has increased wavelength calibration overheads. Please see the COS Instrument Handbook for more details.

**ULLYSES** — COS observations play an extensive role in ULLYSES (see information and references in this booklet). The latest Data Release (DR6) arrived in March, including high-level science products (HLSPs) for 59 additional targets observed since June 2022, for a total of 398 ULLYSES targets to date.

**Hubble Advanced Spectral Products** — The co-add production developed through the ULLYSES program will be applied to all archival COS and STIS observations in the upcoming HASP program. Expected Fall 2023, HASP will provide an automated co-add process within the MAST archive, producing 1-D HLSPs for all COS and STIS observations at the visit and program level.
EXOPLANETS

Discovery, confirmation, cloud structures

Transit, direct imaging, spectroscopy, IR and near IR WFC3, detection of water & chemistry, clouds

**K2-18b**

Super-Earth exoplanet temperate, water

K18 is red dwarf with active atmosphere hostile for life?

**K13BC**

Very hot Jupiter, 5000 F, tidally locked

Titanium cools with altitude on dayside, High wind transport TiO to cold side, precipitation.

Parent star is triple, with third member orange dwarf star Kepler-13C

**Wasp-121b**

“Atmosphere characterization, flows” = Mg, Fe

“Heavy metals” = Mg, Fe

Escaping hot Jupiter 4,600 F atmosphere

Upper atmosphere heating, tidally foot ball shaped

Earthshine as a proxy for atmosphere signature

**Exoplanet Radius vs. Distance from Star**

Two warm Neptunes found near “Hot Neptune desert”.

Loosing atmospheres, one faster than the other.

Ages 2 and 4 Byr. Older GJ3470b atmosphere loss 100x faster than GJ436b 347b
LENSED SUPERNOVA IN ABELL 370