The HST Exposure Time Calculators: Estimating accurate observing times for HST Observations

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Figure 1a

What is the ETC and how it works

The ETC is a web-base application (http://etc.stsci.edu) developed to assist Hubble Space Telescope observers in preparing their observations with any of the supported modes available at HST. The main purpose of the ETC is to calculate the Exposure time needed for observations requiring a given Signal-To-Noise ratio (SNR) and to also calculate the SNR for a simulated observation for a specified amount of time. These quantities are key for the preparation of proposals and observations during Phase I and Phase II of the proposing Cycle.

Currently the ETC provides support for all the active HST instruments:

- **Advanced Camera for Surveys (ACS)**
- **Cosmic Origins Spectrograph (COS)**
- **Near Infrared Camera and Multi Object Spectrometer (NICMOS)**
- Space Telescope Imaging Spectrograph (STIS)
- Wide Field Camera 3 (WFC3)

Figure 1a and 1b show specific observing modes for two different instruments. These ETC forms are intentionally separated into 6 well defined sections to allow HST observers and STScl instrument scientist to easily identify the relevant information that is needed in the calculations. As seen in Figure 1a-b, the same structure is maintained for all the ETC modes and instruments, making easier for HST users to plan observations for different HST instruments. In terms of the management of the software, it helps to track changes that are instrument dependent to those that affect all the instruments. For example, options available under 2., 3., 4., and 5. are shared by all the ETC modes, while sections 1. and 6. depend on the instrument in use and type of observation.

xposure Time Calculato Home page and news ETC Version STIS Spectroscopic ETC ETC: 18.0Pysynphot: 2009-09-02 ETC Help • User's Guide ACS ETCs ubmit Simulation Reset All Paramet COS ETCs G750M i 8561 🖲 G430M c 4451 🛟 OG230LB COS Team ETC Help an G230MB c 1713 52 x 0.2 NICMOS ETCs t Order FUV MAMA (see special MAMA <u>Imaging</u> <u>Spectroscopy</u> c 1222 🛟 ○ G140M STIS ETCs 52x0.2 t Order NUV MAMA (see s <u>Imaging</u> <u>Spectroscopy</u> <u>Target Acquisition</u> Cen. Wave WFC3 ETCs OG230M c 1687 Grating Cen. Wave. Cen. Wave. rating || Previous results 0.2x0.2 c 1234 🛟 0.2x0.09 MAMA Objective Prism



Operated for NASA by AURA

Average 😫

30.0 1.0

Figure 1b

ETC V

Pvsv

ETC H

ACS E

NICM

STIS E

	ingino opeenograph
e Time Calo	culator
<u>d news</u> sion	COS Spectroscopy ETC
0 ot: 2009-09-02	This form will calculate the count rates and S/N ratio for a simulated spectrum of ONE source in a COS spectroscopic observation.
р	For general help on how to use this Exposure Time Calculator or for help on various topics, click on the appropriate highlighted words. You may also want to check the main FTC page for relevant new items.
ude (INS link m)	Please insure that you have read the current <u>release notes</u> before submitting any ETC calculations
Cs	Submit Simulation Reset All Parameters
copy ter	1. Select one Detector+Grating and an aperture:
aphic Imaging aphic Ramp	Grating: Cen. Wave. Grating: Cen. Wave.
Cs	● G130M 1309 ↓ ○ G185M 1850 ↓
copy copy Target	O G160M 1600 • O G225M 2250 • O G140L 1250 • O G285M 2850 •
on Target	O G230L 3000
on m ETC Help	Aperture Primary Science Aperture
ase Notes	2. Specify the exposure parameters:
S ETCs	• Exposure time needed to obtain a S/N ratio of 10.0
	S/N ratio reached in an exposure time of 900 seconds.
<u>copy</u> Cs	S/N or exposure time specified for a <u>wavelength</u> of 1310 Å.
CB	Select the source type:
copy equisition	The photometric extraction region is the same for both point and extended sources. 47 pixels high and a 6 pixel wide resolution element for the FUV. 8 pixels high and a 3 pixel wide resolution element for the NUV.
TCs	Point Source
105	O Extended Source
ng aging	Diameter is 8 arcsec
roscopy estroscopy	3. Choose one of the following spectral distributions for the source:
	Please note: for User supplied and uploaded spectrum, please use only FITS or text (DAT) formet files
results	Upload Spectrum File:
	O Browse
	Other HST Spectrum:

Although the exposure parameters (selection 2.) seem to be identical for all the instruments, the underlying calculations might vary slightly depending on the instrument, observing mode and sometime detector. The ETC handles these differences by subdividing the calculations in stages, making it easier to integrate these into the basic equations.

The ETC relies heavily on the Synthetic Photometry software package, pysynphot. Pysynphot is part of the Space Telescope Science Data Analysis System (STSDAS) and is developed and maintained by the Science Software Branch (SSB) at STScl. This package performs simulated photometry by computing the detected photons as a function of wavelength (and for spectrographs, detector bin) using a specified input spectrum and known throughput and detector quantum efficiency curves. The results are used by the ETC to compute exposure times and signal-to-noise ratios. Its predictions made by the pysynphot software rely on the throughput information for all the optical components of the instruments that are part of the Calibration Database System (CDBS) at STScl. This database contains not only the information regarding the sensitivity of the instrument components, but also about the thermal response of the infrared detector and a large number of available source spectra (HST Calibration tables, Catalogs, and Models). Figure 2 shows the flow of data between the Web interface, ETC and pysynphot. First the user inputs the observational parameters into the ETC web server. The parameters are then formatted by the ETC in a pysynphot request and submitted to the pysynphot package. The quantities calculated by pysynphot are the imaging and spectroscopic countrate, the thermal countrate for the IR detectors and the effective wavelength of an observation. The pysynphot response is retrieved by the ETC application and the count rate used for the calculation of the S/N and exposure time.

Figure 2. Data flow between we	b client, ETC, pysyphot, and CDBS data
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	Instrument/Exposure	-	pysynphot request	1
web client		ETC	pysynphot	

	\bigcirc S/N ratio reached in an exposure time of 900 seconds.	and the second second second second	
			Castelli and Kurucz Models: O3V 45000 4.0 (Sp Teff log(g)
	S/N or exposure time specified for a <u>wavelength</u> of 4451 Å.	A DESCRIPTION OF TAXABLE PARTY.	log(z)=0]
	Select the source type. The indicated extraction region (centered on the target) that will be used for the S/N ratio	And in case of the local division of the loc	O Pickles Models: O5V 39810.7K (Sp Teff)
	calculation:	and the second se	O Kurucz Models: O5V 44500 5.0
	Point Source	And in case of the local division of the loc	O Bruzual Synthetic Stellar Spectra: O5 V
	• Use the default region (height of 7 pixels).	The second s	HST Standard Star spectra:
	O Use a region of height: 7 = pixels.		O GD50 (DA2, 14.06)
	The length gives a structure are in a second with (and him doing lifes the CCD)		O Non-Stellar Objects: Elliptical Galaxy [240,34000Å]
	The lambda-pixel extraction region is one pixel wide (one binned pixel for the CCD).		a Black body with temperature T = 10000
- 62	Width of a resolution element is normally two lambda pixels.		
	When using the CCD with dispersion binning a resolution element is one binned pixel.		• a Power-law: $F\lambda = \lambda ** -1$
	O Extended Source		• a Flat continuum in $F \lambda$
	Diameter is 8 arcsec		No continuum. If selected, at least one emission line must be specified below and the reference wavelength from part 2 above must correspond to one of t
		the second s	lines.
	The lambda-pixel extraction region for extended sources is a 1 x 2 box.	A DESCRIPTION OF TAXABLE PARTY.	Specify the optimation E(P to Average Coloctic
	Width of a resolution element is normally two lambda pixels.	the second s	Specify the extinction $\frac{B(D-V)}{D}$ (Average Galactic $= 0.0$
	When using the CCD with dispersion binning a resolution element is one binned pixel.		Extinction applied before () normalization.
	3. Choose one of the following spectral distributions for the source:		
	Please note: for User supplied and uploaded spectrum, please use only FITS or text (DAT) format files.	the second s	Specify the redshift $z = 0.0$
	O Upload Spectrum File: Browse		Add emission lines to the input spectrum (optional):
	Other HST Spectrum:		Line Center FWHM Integrated Flux
	0 CDBS Synphot spectrum file		(\AA) \AA $(\text{erg/cm}^2/\text{s})$
			(vacuum)
	Castelli and Kurucz Models: U3V 45000 4.0 F [Sp Teff log(g) log(z)=0]		0
	O <u>Pickles Models</u> : O5V 39810.7K (Sp Teff)	and the second	0.
	O <u>Kurucz Models</u> : O5V 44500 5.0	the second s	0. 0.
100 C	O Bruzual Synthetic Stellar Spectra: O5 V	and the second	0. 0.
	O HST Standard Star spectra: GD50 (DA2, 14.06)	the second s	
	O Non-Stellar Objects: Elliptical Galaxy [240,34000Å]	the second second second second	Note: integrated flux units are per arcsec ² for extended sources. All three of the
1000	a Black-body with temperature T = 10000		parameters (line center, fwhm and integrated flux) must be specified for an emission line to be included.
	• a Power-law: $F\lambda = \lambda * * -1$	And in case of the local division of the loc	
-			4. Normalize the target's hux:
	No continuum. If selected, at least one emission line must be specified below, and the reference	and the second division of the second divisio	$\bigcirc \qquad \qquad$
	• wavelength from part 2 above must correspond to one of the lines.		Calex FIIV $=$ 15 (AB magnitudes) (arcsec ⁻² for
	Specify the autientics E/B IA Average Calentic		extended sources) or
	Specify the extinction $E(B-V)$ Average Galactic $= 0.0$	and the second	1.5e-13 ergs $cm^{-2}s^{-1}\dot{A}^{-1}$ (arcsec ⁻² for extended sources) at
	Extinction applied before 🛟 normalization.		0 1310 Å or
			Do not Renormalize Point Source Spectrum Use only for User Input
	Specify the redshift $z = 0.0$ Add emission lines to the input spectrum (optional):		• Spectrum or Calibration Spectra.
	And emission must to the input opeca and (optional).		5. Specify the expected <u>background levels</u> :
	Line Center FWHM Integrated Flux		a) Specify normalization for zodiacal background
	(\AA) \AA $(\text{erg/cm}^2/\text{s})$	and the second se	• Standard zodiacal light normalizations:
3 mail 1	(vacuum)		Compute zodiacal light on sky position:
	0. 0.		R.A.: 00:00:00 (hh:mm:ss or decimal)
			Dec.: +00:00:00 (dd:mm:ss or decimal)
	0.		either $(0, \lambda_{1})$ (90) degrees
	0. 0.	and the second se	
	2		- or - 🔮 Date: 2009 🟹 January 🟹 1 👽
	Note: integrated flux units are per arcsec for extended sources. All three of the parameters (line center, fwhm and integrated flux) must be specified for an emission line to be included.	and the second second second	O Normalize zodiacal light to magnitude:
	4 Normalize the target's flux.		• Scale zodiacal light by factor $(1.56 = average)$:
	$\frac{1}{2} \frac{1}{2} \frac{1}$	and the second se	b) Specify normalization for earth shine background
	i johnson/v i = 15 (vega magnitudes) (arcsec for extended sources) or		• Standard earth shine light normalizations: Average
	O Galex FUV \Rightarrow = 15 (AB magnitudes) (arcsec ⁻² for extended sources) or	the state of the s	Normalize carts shine light to magnitude
	$\bigcirc 1.5e-13 \qquad ergs \ cm^{-2} \ s^{-1} \ Å^{-1} \ (arcsec^{-2} \ for \ extended \ sources) \ at \ 5500.0 \qquad Å. \ or$	The second s	50.0
	O Do not Renormalize Point Source Spectrum. Use only for User Input Spectrum or Calibration Spectra.	and the second se	$\bigcirc \qquad \text{Scale earth shine light by factor } (0.5 = \text{average}): \qquad 1.0$
	5. Specify the expected <u>background levels</u> :	Contraction of the local division of the loc	c) Air Glow
	Specify normalization for zodiacal background	Conception of the second second	Average 🛟
	Compute zodiacal light on sky position:	State of the local division of the local div	
	P A (00:00:00 (thummus or docimel)	Contraction of the local division of the loc	Submit Simulation Reset All Parameters
	Dec.: +00:00:00 (dd:mm:ss or decimal)		If you have any questions regarding this calculator, please contact the STScI Help De
	either $\bigcirc \lambda - \lambda_{\alpha}$: 90 degrees		to include your <u>ETC ID</u>
			Copyright Notice
	- or - 🔮 Date: 2009 🟹 January 🟹 1 🟹	Contraction of the local division of the loc	
	Normalize zodiacal light to magnitude: 30.0		🕱 The Institute
1000	Scale zodiacal light by factor (1.56 = average):		
	b) Specify normalization for earth shine background		
	• Standard earth shine light normalizations:		111



ETC Pysynphot response (countrate)

CDBS

• Imaging

<u>Imaging</u>
<u>Spectros</u>

The results of the calculation are displayed to a web page and saved in a file for future reference. For example, to recall previous calculation results or to plot or show a table of the input spectrum, instrument throughput, or detected counts or signal-to-noise as a function of wavelength. An example of the output of a run for an ACS observing configuration as well as that for a COS spectroscopic observation is given in Figure 3a and 3b, respectively.

The ETC output gives detailed information on the counts rates that are due to the source and background, the selection of parameters for the source and instrument, as well as other relevant information to the instrument and mode used. The output information is separated in sections which are common to all the instruments and modes. However, detailed information and instrument configuration information will change from instrument to instrument and also with detectors.

Other capabilities of the ETCs are:

- option for user-supplied input spectra

- calculation of optimal S/N as would be obtained by PSF fitting
- inclusion of instrument-specific effects. For example, NICMOS spectroscopy simulations include the degradation in the spectral purity due to the line spread function.
- verification that user-supplied wavelengths fall within instrumental range - bright-limit checks

Support for new instruments.

The last HST Servicing Mission added two new instruments: Wide Field Camera 3 (WFC3) and Cosmic Origins Spectrogaph (COS). Adding support for WFC3 was relatively strightforward since the similarities between the two channels covered by WFC3 detectors with ACS (for the UV) and NICMOS (for the IR) made it possible to implement support for the WFC3 modes with few changes. The main differences between these ETC are the instrument specific parameters. Other differences have to do with the extraction box size and shape, and the way in with the size of the extraction box and size are indicated.

		lugintude.	50.0
1.1	Scale earth shine light by factor	(0.5 = average):	1.0
	c) Air Glow		
	Average	\$	
	6. Additional <u>CCD parameters</u> :		
	Binning	Gain	CR-SPL I
	Dispersion Axis Spatial Axis	Gam	CK-SI LI
80	1 pixel	1 e-/ADU 🛟	2
	Submit Simulation Reset All Pa	rameters	

🕅 The Institute

Figure 3a. Output for WFC3 Imaging ETC Hubble Space Telescope Field Camera 3 🍪 Co COS Spec WFC3 Imaging ETC **ETC Version ETC Vers** posure ID: WFC3.A173530 • ETC: 18.0 • ETC: 18. Requested Signal/Noise Ratio = 10.00 • Pysynphot: 2009-08-17 • Pysynpho gives: Time = 0.0306ETC Help gives: optimum SNR = 17.73ETC Help gives: Time to Saturation (for a single exposure) = 21.59 seconds <u>User's Guide</u> <u>Source Model</u> <u>Release Notes</u> **Detailed Information** Source M Release N **ACS ETCs** Counts in circle with radius 0.2 arcsec ACS ETC 20.81 14,144.708 433.08 Source 0.28 Background 2.493 0.08Imagi Ramp 0.27 2.453 0.080.04 Dark Current 0.040 1.23E-3 37.98 Read out • <u>Co</u> 43.31 • Co Fotal in selected region 14,147.201 433.16 3,241.487 49.62 Brightest pixel **COS ETCs** COS ETC Count rate • <u>Spectroscopy</u> • <u>Spectr</u> 16,435.67 Source (infinitely large region) <u>Spectroscopy Targe</u> Sky Background (arcsec[^]-2) 19.52 Extraction region • <u>Im</u> • <u>COS Te</u> <u>Release</u> • COS Team ETC Help and circle with radius 0.2 arcsec Release Notes Fraction of flux 80.14 Area (pixels) **NICMOS ETCs** NICMOS Fraction of flux in brightest pixel 0.20 5389.60 Å Effective Wavelength • Imagin • Spectroscop Target [point source] • Specti **STIS ETCs** Model ID = 1**STIS ETC** + Flat 1.00 in Fλ Renormalized to Johnson V = 15 in magnitudes relative to Vega Imaging Spectros Instrument name: WFC3 WFC3 ETCs Detector: UVIS1 WFC3 ET Bandpass: [F555W] WFPC2 V # Frames: 2 <u>IR Imaging</u> <u>UVIS Imaging</u> • <u>IR I</u> Selected background • <u>UVIS I</u> IR Spectroscopy UVIS Spectroscop • <u>IR S</u> Sky Background: • UVIS Earth Shine: Average **Previous results** Zodiacal Light: Average **Previous r** Air Glow: Average

Figure 3b. Output for COS Spectroscopic modes

e Space Teles	cope			
nic Origi	ns Spectrograph			
coscopy ETC				
n	Exposure ID: COS.A173529			
009-08-17	Exposure time (seconds) = $10,000.0000$ at wavelength 1310.00 Å gives: SNR = $2,164.81$ (per resolution element)			
	Exposure time calculation HAD WARNINGS.			
	WARNING MESSAGE: XDL Bright limits: total count rate per pixel exceeds bright limit, value = 20.3, limit = 0.7			
2	WARNING MESSAGE: Buffer time must be greater	r than or equal to	80.0 seconds	
	WARNING MESSAGE: Observation exceeds FUV segment B global count rate limit of 15000.0 counts per second for non-variable sources.			
c Imaging	WARNING MESSAGE: Observation exceeds FUV segment A global count rate limit of 15000.0 counts per second for non-variable sources.			
<u>c Ramp Filter</u>	WARNING MESSAGE: You have requested S/N > 40. Additional calibration steps might be required to achieve S/N > 40 in the FUV", value = 2164.8 , limit = 40.0			
Target	Detailed Information	Count rate	Total counts	Associated noise
		(counts/s)	(counts)	(counts)
t Acquisition C Help and	Counts (box 47 pixels high) Source Background Sky	(1 pixel) 78.107 1.058E-4 6 806E-12	(6 pix resel) 4,686,422.07 6.35 4 08E-7	2,164.81 2.52 6 39E-4
ГCs	Dark Current	1.058E-4	6.34	2.52
	Total in selected region Brightest Pixel (1225.01 Å)	78.107 20.290	4,686,428.42	2,164.82
	Count rate entire detector	2,276,168.741		
	Count rate segment A Count rate segment B	774,565.407 1,501,603.333		
	Buffer time (cec)		1	
tion	For APT purposes, the recommended buffer time should be 2/3 of the buffer time calculated		1	
S	above, or the exposure time, whichever is shorter. Please refer to the COS Instrument Handbook for more details			
<u>py</u> scopy	Target [point source]			
nlte	Model ID = 5504 + Castelli-Kurucz (O3V): Temp = 45000 , LogZ = 0.0). $Logg = 4.5$		
uits	. Renormalized to Johnson $V = 10$ in magnitudes re	elative to Vega		

The design of the COS detectors, on the ther hand, possed significan challenges for the ETC developers. The FUV channel is a photon counter with 2 segments that can operate independently and that have a 9 mm gap in between. The NUV channel creates a three spectrum stripes for the science data with a gap of 3.70 mm between them. Because of this the ETC needed also to provide with:

- the count rate and global count rate that accounts for the sensitivity of the segments or stripes and the gap between them
- validate the input wavelength for the grating-central wavelength combination
- specify the global and maximum local count rates on each channel

Since the FUV channel is regularly used in time tag mode the ETC also estimates the buffer time. Furthermore, due to the vulnerability of photo multiplier detectors to damage, the ETC needs to calculate various total count rates for segments and stripes and the corresponding maximum observed count rates within the segments or stripes, and appropriate buffer time values. When these exceed or are close to exceed global or local limits for the detectors, these are clearly flagged by the software as shown in Figure 3b.



Recently STScI has started an effort to rewrite the ETCs in Python. The reasons for this re-implementation include the following goals:

Grating: [G130M] Grating (R ~ 20,000-24,000) Primary Science Aperture Total Counts Signal-to-noise Source spectrum Throughput

Streamlining the code and data that has been built up organically over many years and instrments.

- Permitting better integration with many of the new STScl science software tools that are being written in Python, for example, pysynphot, a Python re-implementation of SYNPHOT.

- Making some of the underlying components for the ETC available for other science purposesthat would be distributed as part of STScI science calibration and analysis software, for example, background models and signal-to-noise calculations. The ETC computational engine will eventually be distributed with the rest of the science software.
- Anticipating JWST ETC development needs.

The re-implementation will also make possible some other capabilities not yet possible, such as scripting ETCs from Python for batch use and perhaps drive the web version of the ETC from a Python script running on a user's computer.

The new ETCs will retain much of the same web user interface as the existing ETCs so users should not find much difference in how they use the ETCs. The ability to recall past calculations, plot them, and have access to the tabular results will remain.