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Instrument Science Report ACS 2003-008

Baseline Tests for the Advanced Camera for Surveys Astronomer's Proposal Tool Exposure Time Calculator

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July 10, 2003

ABSTRACT

The verification tests for the Astronomer's Proposal Tool (APT) Exposure Time Calculator (ETC) for the Advanced Camera for Surveys (ACS) are presented. Our baseline suite of test cases includes one calculation for a variety of filter modes with the same target, plus one subset for all kinds of targets through the same filter, plus a variety of additional tests, (e.g. square vs. circular apertures, the intensity of the various sky components, extinction, etc...). Also, we describe the enhancements and new features of the APT ETC and compare them with the CGI ETC capabilities. A new tool installed in the IRAF/STSDAS Synphot package to estimate counts in a given aperture is introduced and described. The APT ETC performs satisfactorily and is now available for use by the astronomical community.

1. Introduction

A set of five ACS Exposure Time Calculators (ETCs) were developed within the Astronomer's Proposal Tool and are being released to the public, one for imaging, one for spectroscopy, one for ramp filters and two for coronagraphy, i.e. with standard filters and with ramps. The public version Web URLs are at http://www.stsci.edu/hst/acs/software/etcs/ETC_page.html, where all calculators can be found. These ETCs represent a step forward with respect to the old CGI ETCs GOs have used for the past years. They allow for new modes of calculation (e.g. the coronagraphic mode) and introduce improvements in various areas of the exposure calculations. A detailed discussion of such enhancements and improvements is presented in Section 2. Both the APT ETCs and the CGI ETCs will be available to users for the time being, with the recommendation that users give preference to the former and know that the latter are “close to retirement”. In Section 3, the testing baseline is presented; we describe in some detail the various exposures. Four tables, including the whole set of test exposures, are provided. Section 4 includes an example of hand checking calculations; and the last Section addresses the issue of red targets to be observed at wavelengths longer than ~8000 Å.

2. The new and improved Exposure Time Calculator

New modes

A coronagraphic mode is now available and comes in two flavors: one to be used with standard imaging filters and one to be used with ramp imaging filters. The newly implemented tool estimates exposure times for coronagraphic exposures, accounting for the additional background contribution from the central occulted source PSF, as described in the ACS Instrument Handbook for Cycle 13 (see Chapters 5 and 6) by Pavlovsky et al. (2003).

Enhancements of already existing modes

1) For the Signal-to-Noise and exposure time calculations, the user can select square regions or circular apertures for point source photometry. Several options are provided in the form of pull-down menus.

2) The sky contributions are from the Earth shine, the zodiacal light and the geocoronal lines. There are a few improvements with respect to the old CGI ETCs:
2.a) both Earth shine and zodiacal light can be independently selected as low, average, or high (or very high in the case of the Earth shine), following the prescriptions of Giavalisco et al. (2002). In addition, each contribution can be scaled to a user’s selected factor or normalized to a user’s selected magnitude;
2.b) the geocoronal lines have a gaussian profile with a narrow thermal width (only relevant for STIS echelle observations);
2.c) the geocoronal line intensity can be high, average, low or zero.

3) Emission lines can be included in all types of source spectra or can be used by themselves.

4) The source counts are calculated more accurately, because the fraction of encircled energy is taken at the effective wavelength instead of the pivot wavelength of the observ-

ing mode. The effective wavelength is the weighted average of the system throughput AND source flux integrated over wavelength, while the pivot wavelength does NOT depend on the source spectrum. For red targets in F850LP, the use of the Synphot package in IRAF is recommended (see last Section).

5) The calculation of the brightest pixel is now more precise.

6) Any continuum can be red-shifted, not only QSOs.

7) For the spectroscopic modes, the source counts are calculated with the appropriate fraction of energy in the specified extraction height as a function of wavelength, while the old CGI ETCs used a constant value calculated at the observing wavelength.

8) For extended sources, the source diameter is selectable, which enables the proper global limit calculation for SBC exposures.

3. Our baseline of exposures for the APT ETC

A baseline of exposures starting with the prescriptions of our previous ISRs (Boffi et al. 2000a, van Orsow et al. 2000, Boffi et al. 2000b) was created. We tested the ETCs by keeping the spectral distribution fixed (flat spectrum) for a variety of filters, and also by keeping the filter fixed and varying the source spectral distributions. We have also tested a variety of apertures, different sky background combinations, the emission lines individually or in addition to a continuum spectrum, and redshifts and reddening. This baseline serves as reference and allows quick checks when changes or improvements are made to the exposure time calculators available. To verify the correctness of the APT ETC results, we compared the output values with the CGI ETC, and with results either derived from the IRAF/STSDAS Synphot package or calculated by hand. For most quantities the agreement between all these values is good to less than a few %, and in some cases, when comparing a hand calculation (which is based on certain assumptions) with a more accurate result from the ETCs (which are calculating an integral), the agreement is roughly within 25% (see the hand check which is presented in Section 4). In Tables 1 and 2, all imaging and ramp mode exposures are listed for point and extended sources. In Table 3, the spectroscopy exposures are given, and Table 4 contains the coronagraphy. In all tables, the first seven columns give the input parameters: detector, filter, spectral distribution, normalization (in erg $sec^{-1}cm^{-2}$ $Å^{-1}$ or magnitude), exposure time (or signal to noise ratio), and aperture, respectively. In the spectrum column, “flat” indicates a constant flux distribution in erg sec^{-1} cm^{-2} $Å^{-1}$, “p. law” indicates a power law spectrum of the form $F(\lambda) = \lambda^n$ (where the default n=-1 is used), “BB” indicates a black body spectrum of Temperature = 10000 K, “G5V” is a Kurucz model atmosphere (for coronagraphy, other Kurucz spectral

types may be used), “GD71” is an HST standard star, “M-L-T star” indicate three different user’s provided spectra for red targets, and “em. line” is for an emission line. When either a redshift or reddening was applied to the spectrum, these quantities are indicated with the spectrum. In the spectrum column, for coronagraphic exposures, two spectral distributions are indicated, one for the target and one for the central (occulted) star. In column 4, the normalization column, either a flux value or a magnitude of normalization is given; when “NO” is indicated, no normalization was performed (e.g. for standard stars). In the aperture column, either a radius in arcsec (e.g. 0.2 for WFC and HRC or 0.5 for SBC) or a box size (in pixels) is provided. When 80% is indicated, we are asking the ETC to run the calculations for whatever circular aperture encloses 80% of the total flux. In imaging, a 1000 second exposure (CRSplit=2) is run in most cases to achieve at least ~100 counts for the source; a one second exposure (CRSplit=1) is run in the brightest cases to avoid saturation of the CCD and a 100 second exposure is run for all SBC cases to achieve a S/N~10. For extended sources the exposure time is between 1000 and 2000 seconds.
For all observations gain =2 was used. For the Wide Field Channel and High Resolution Channel, the detector dark rate is 2.2×10^{-3} and 2.5×10^{-3} e^{-} sec^{-1} pix^{-1}, respectively; the read noise is 5.3 or 4.7 e^{-} rms for gain=2; for the Solar Blind Channel, the dark count is 1.2×10^{-5} counts sec^{-1} pix^{-1}. See also the ACS Instrument Handbook (Pavlovsky et al. 2003). The cases are all with average Earth shine and Zodiacal light and include geocoronal lines except as indicated in Table 1 by footnotes. For spectroscopic exposures, similar criteria were followed to choose exposure times. The last five columns give the main output results of the ETC. They are: signal to noise ratio (SNR), or else, in parenthesis, the estimated exposure time when a SNR was provided in input; opt. SNR from the calculation for an optimal extraction; brightest pixel; source; and total sky. Source and sky are expressed in counts. The brightest pixel in column 9 is in counts sec^{-1} pix^{-1} for the SBC and in counts pix^{-1} for the CCDs. For spectroscopic exposures all output values are per resolution element (as indicated in the ETC User’s guide). The optimal SNR is the signal to noise ratio calculated using the same observing conditions that the WFPC2 ETC adopts for the calculation of the signal to noise ratio (see the FAQ in the APT ETC webpages). This quantity is calculated for all imaging modes and point sources.

Table 1: Imaging and ramp modes: Point Sources

Det.	Filter	Spec.	Norm.	texp (SNR)	aper.	SNR (texp)	opt. SNR	B.Pix.	Sou.	Sky
wfc	f435w	flat	1.e-18	1000.	0.2	31.5	47.6	355.	2674.	1527.
wfc	f435w	flat	1.e-18	1000.	5x5	36.3	47.6	355.	2486.	743.
wfc	f502n	flat	1.e-18	1000.	0.2	2.84	5.90	21.9	162.	99.0
wfc	f502n	flat	1.e-18	1000.	5x5	3.71	5.90	21.9	151.	48.1

Table 1: Imaging and ramp modes: Point Sources

Det.	Filter	Spec.	Norm.	texp (SNR)	aper.	SNR (texp)	opt. SNR	B.Pix.	Sou.	Sky
wfc	f502n	flat	1.e-18	1000.	80%	3.22	5.90	21.9	151.	65.
wfc	f555w	flat	1.e-18	1000.	0.2	43.3	62.	570.	4335.	2697.
wfc	f555w	flat	1.e-18	1000.	5x5	49.2	62.	570.	4074.	1312.
wfc	f555w	flat	1.e-18 redd.0.1	1000.	5x5	49.0	62.	566.	4046.	1312.
wfc	f555w	flat	1.e-18 redd.1.	1000.	5x5	47.9	61.	550.	3914.	1312.
wfc	f850lp	flat	1.e-18	1000.	0.2	48.4	73.	486.	4777.	1975.
wfc	f850lp	flat	1.e-18	1000.	5x5	51.	73.	486.	4153.	961.
wfc	f850lp	Mstar	NO	1.	0.2	321.	383.	20000.	1.04e5	1.98
wfc	f850lp	Mstar	NO	1.	5x5	300.	383.	20000.	9.07e4	0.96
wfc	f850lp	Lstar	NO	1.	0.2	67.	88.	1063.	5582.	1.98
wfc	f850lp	Lstar	NO	1.	5x5	65.	88.	1063.	4863.	0.96
wfc	f850lp	Tstar	NO	1.	0.2	2.10	5.60	14.9	82.1	1.98
wfc	f850lp	Tstar	NO	1.	5x5	2.58	5.60	14.9	72.	0.96
wfc	f555w	e.line	1.e-16	100.	2x2	1.15	1.48	7.52	18.8	21.
wfc	f555w	p.law	V=20	1.	5x5	5.06	7.65	39.4	148.	1.31
wfc	f555w	BB	V=20	1.	5x5	5.19	7.83	40.4	152.	1.31
wfc	f555w	G5V	V=20	1.	5x5	5.04	7.62	39.2	147.	1.31
wfc	f555w	G5V + e.line (5550)	V=20 + 1.e-16	1.	5x5	5.04	7.63	39.2	147.	1.31
wfc	fr388n (3880)[a]	flat	1.e-15	1.	0.2	2.11	4.47	22.8	82.	0.03
wfc	fr388n (3880)[a]	flat	1.e-15	1.	0.4	1.14	4.47	22.8	87.	0.12
wfc	fr388n (3880)[a]	flat	1.e-15	1.	80%	2.3	4.47	22.8	78.	0.02
wfc	fr388n (3880)[a]	flat	1.e-15	1.	5x5	2.77	4.47	22.8	77.	0.01
hrc	f220w	flat	1.e-18	1000.	0.2	1.09	3.88	12.2	99.	32.5
hrc	f220w	flat	1.e-18	1000.	9x9	1.53	3.88	12.2	95.	15.2
hrc	f220w	flat	1.e-18	1000.	5x5	2.25	3.89	12.1	80.	0.56*

Table 1: Imaging and ramp modes: Point Sources

Det.	Filter	Spec.	Norm.	texp (SNR)	aper.	SNR (texp)	opt. SNR	B.Pix.	Sou.	Sky
hrc	f344n	flat	1.e-18	1000.	0.2	0.43	1.5	5.04	38.6	10.9
hrc	f344n	flat	1.e-18	1000.	9x9	0.59	1.5	5.04	36.5	5.10
hrc	f344n	flat	1.e-18	(0.6)	9x9	(1016)	1.52	5.12	37.1	5.18
hrc	f344n	flat	1.e-18	1000.	80%	0.51	1.5	5.04	36.6	6.85
hrc	f850lp	flat	1.e-18	1000.	0.2	27.5	53.	188.	3080.	1333.
hrc	f850lp	flat	1.e-18	1000.	9x9	35.0	53.	188.	3017.	622.
sbc	f115lp	flat	7.e-17	100.	0.5	5.98	18.3	0.57	387.	3796.
sbc	f115lp	flat	7.e-17	100.	15x15	8.73	18.3	0.57	331.	1105.
sbc	f122m	flat	7.e-17	1000.	80%	2.62	9.74	0.031	199.	5600.
sbc	f150lp	p.law	V=20	100.	0.5	15.1	16.6	0.39	230.	6.06e-3
sbc	f150lp	p.law	V=20	100.	15x15	14.2	16.6	0.39	200.	1.76e-3

* For this exposure a high zodiacal light, low Earth shine and low geocoronal lines, are selected.
a The wavelength of observation is indicated in parenthesis.

In Table 2, extended sources are considered. The table columns are the same as Table 1. Currently, the calculations are over a 2x2 resolution element since the source size is assumed to be larger than the ACS resolution; the user can input a size in arcsec of the extended source and the global count rate limit for SBC exposures is based on this value.

Table 2: Imaging and Ramp Modes: Extended Sources

Det.	Filter	Spec.	Norm.	texp (SNR)	aper.	SNR (texp)	B.Pix.	Sou.	Sky
wfc	f555w	flat	V=22	2000.	2x2	15.9	124.	556.	420.
wfc	f555w + pol_v	flat	V=22	2000.	2x2	6.28	32.6	138.	104.
wfc	fr459m (5005)[a]	e.line (5005) nocont	1.e-16	(10.)	2x2	(6e5)	5747.	2150.	3.86e4
hrc	f435w	A5V	R=16	1000.	2x2	101.0	1304.	1.04e4	20.60

a The wavelength of observation is indicated in parenthesis.

In Table 3, the spectroscopic exposures are presented. The output values provided by the ETC are given as count rates per pixel and as total counts per resolution element. The total counts are used in the calculation of SNR and exposure time. A resolution element is given by 2 pixels in the dispersion direction. The spatial direction, when default is selected, is the number of pixels corresponding to encircling ~80% of the PSF light.

Table 3: Spectroscopic Modes

Det.	Filter	Spec.	Norm.	texp (SNR)	aper.	SNR (texp)	B.Pix.	Sou.	Sky
wfc	g800l	flat	1.e-16	100.	1x5	50.	460.	3052.	141.
wfc	g800l	flat red0.1	1.e-16	100.	1x5	52.	507.	3242.	141.
wfc	g800l	e.line (6500) nocont	1.e-15	100.	1x5	11.6	51.	382.	141.
hrc	g800l	flat	1.e-16	100.	1x9	25.4	98.	1127.	43.0
hrc	pr200l	flat	1.e-16	100.	1x9	70.	1307.	5652.	18.7
hrc	pr200l	flat	1.e-16	100.	1x1	46.	1307.	2169.	2.08
hrc	pr200l	flat red0.1	1.e-18	100.	1x9	1.72	12.8	51.	18.7
sbc	pr110l	flat	1.e-16	1000.	1x15	4.93	0.058	153.	807.
sbc	pr110l	flat	1.e-16	1000.	1x1	5.11	0.058	53.	54.
sbc	pr130l	flat	1.e-16	1000.	1x15	6.70	0.034	60.	100.
sbc	pr130l	flat	1.e-16	1000.	1x1	5.59	0.034	41.3	13.3
wfc	g800l	GD71	NO	1.	1x5	57.0	812.	3477.	1.41
wfc	g800l	GD71 red0.1	NO	1.	1x5	50.	641.	2756.	1.41
hrc	pr200l	GD71	NO	1.	1x9	186.	1.16e4	3.5e4	0.19
hrc	pr200l	GD71 red0.1	NO	1.	1x9	151.	8061.	2.3e4	0.19
sbc	pr110l	GD71	NO	1.	1x15	57.	567.	3242.	0.81
sbc	pr110l	GD71	NO	1.	1x1	33.4	567.	1118.	0.05

For both the first and second exposures in Table 3, the S/N ratio, brightest pixel, source and sky are calculated at 6500 Å. In the second line, for a reddening of E(B-V)=0.1, the renormalization at 5500 Å is done after applying the reddening, so that the S/N is higher at 6500 Å. In Table 4, the exposures with the coronagraphic mode are listed. In the detector column, under "hrc", the diameter (in arcsec) of the occulting spot and the objects separation (in arcsec) are given. Two spectral energy distributions are indicated in the third column, as expected, the first for the target source and the second for the central (occulted) source. Two normalizations are correspondingly indicated in the normalization column. In the last column, two sky contributions are provided: the sky component of the target source alone and the contribution to the sky from the PSF wings of the central source as measured at the target location (see Chapters 5 and 6 in the ACS Instrument Handbook for a detailed treatment of the coronagraphic mode and for examples).

Table 4: Coronagraphic Modes

Det.	Filter	Spec.	Norm.	texp (SNR)	aper.	SNR (texp)	opt. SNR	B.Pix.	Sou.	Sky
hrc 3.0 4.25	f435w	M6V + F0V	V=20.5 + V=6.0	1000.	9x9	40.5	109.	538.	6013.	198. + 1.2e4
hrc 3.0 4.25	f435w	M6V + F0V	V=20.5 + V=6.0	1000.	0.2	32.0	109.	538.	6680.	424. + 2.6e4
hrc 3.0 6.00	f435w	A5V + A5V	R=16. + V=3.9	1000.	2x2	58.	n.a.**	878.	4942.	9.78 + 2059.
hrc 1.8 4.0	fr459m	e.line (4590) + A5V	1.e1-6 + V=3.9	2.47	2x2	5.0e-5	n.a.**	0.79	6.7e-4	0.01 + 6.7

**The targets are extended sources.

4. Checking exposures by hand

In the following, we present our hand calculations to check the ETC output for an exposure with the coronagraphic spot. Examples for standard filters and spectroscopic elements are in our previous reports (Boffi et al. 2000a, VanOrsow et al. 2000, Boffi et al. 2000b) and in Chapter 6 of the ACS Instrument Handbook along with the documentation for our equations. Methods are the same, while the values have been updated.

Coronagraphic exposure with imaging filter

The ETC calculates what SNR and number of counts are achieved in a 1000 sec exposure when using the 3.0 arcsec coronagraphic occulting spot to mask a V=6.0 central star of spectral type F0V to observe a V=20.5 M6V star, at a separation of 4.25 arcsec. The HRC and f435w are used.

The flux of the reference source is 9.5×10^{-18} erg sec^{-1} cm^{-2} Å^{-1}, the sensitivity at 4480 Å (which is the effective wavelength of this observation) is 1.49×10^{18} counts sec^{-1} Å^{-1} per incident erg sec^{-1} cm^{-2} Å^{-1} and the FWHM is 728.5 Å. For a ~0.25 arsec box size the encircled energy fraction is 72% , the total counts from the star are approximately $9.5 \times 10^{-18} \times 1.49 \times 10^{18} \times 0.72 \times 1000 = 10191$, which becomes 4841 when accounting for the 47.5% throughput of the coronagraph (see the ACS Instrument Handbook, Section

5.2.6). For comparison, Synphot calculates for the source (in an infinite aperture) 8.35 counts sec^{-1} (already accounting for the throughput of the coronagraph), which becomes, integrating over 1000 sec. and applying the 72% correction as above, 6009 counts, very well in agreement with the ETC result. The more precise result obtained by the ETC, which integrates over the bandpass, is 6013 counts for a 9x9 pixel boxsize. The detector dark is calculated as 81x0.0025x1000=202.5, the read noise is equal to 81 x 2 x 4.7^2= 3578.58 (for CRSplit=2), and the sky background is 198.10. This value for the average sky is computed as one half the continuum high sky background of 7.9×10^{-18} erg $sec^{-1}cm^{-2}Å^{-1}$ $arcsec^{-2}$ from Table 6.7 of the ACS Instrument Handbook. This yields: 0.5 x 7.9×10^{-18} x 1.49×10^{18} x (0.02842 x 0.02549) x 728 x 81 x 1000= 344 electrons, which becomes 163. accounting for the 47.5% coronagraphic throughput. The more precise value of 198. calculated by the ETC is derived by doing the integral over wavelength. In coronagraphic exposures there is another contribution to the sky background, given by the wings of the central source PSF at the separation of the reference star. This is calculated by applying a coronagraphic profile to the central source flux; the flux of the central source in this case is 3.37×10^{7} erg sec^{-1} cm^{-2} $Å^{-1}$ and the coronagraphic profile as derived from Figure 5.8 in the Instrument Handbook is 6.11×10^{-6}. If we multiply these two terms and multiply them by the area of the considered aperture and by the 1000 seconds, we obtain 12082, which is exactly what the ETC calculates. The brightest pixel per exposure can be calculated by scaling the total source counts by the fraction of energy ensquared in the 1x1 boxsize: [(0.11/0.72) x 6012.74 + (198.1/81) + (202.5/81) + (12082.32/81)]/2=538. (like the ETC). Finally, we apply the usual signal to noise ratio equation and obtain SNR=40.47 , which is what the ETC calculates.

5. Exposure time estimates for red targets in F850LP

At wavelengths greater than 7500 Å (HRC) and greater than about 9000 Å (WFC), ACS CCD observations are affected by a red halo due to light scattered off the CCD substrate. An increasing fraction of the light as a function of wavelength is scattered from the center of the PSF into the wings. The encircled energy depends the most on the underlying spectral energy distribution for the very broad z-band, F850LP, filter. Such an effect has never been incorporated in the old CGI ETC and is improved in the APT ETC. The CGI ETC uses the pivot wavelength of the observing mode to derive the fraction of enclosed energy that gets multiplied to the source rate for an infinite aperture. The pivot wavelength is the weighted average of the system throughput ONLY. The APT ETC, instead, is more accurate, as the encircled energy fraction is at the effective wavelength which takes into account the source spectral distribution. This fraction is then multiplied by the source counts. The effective wavelength is the weighted average of the system throughput AND source flux distribution integrated over wavelength. However, this does not account for the variation in enclosed energy with wavelength.

In order to obtain better estimated count rates for red targets, observers are advised to use the Synphot package in IRAF/STSDAS for which a proper integration over wavelength has now been incorporated for encircled energy (see also the April 2003 STAN, also found at http://www.stsci.edu/hst/acs/documents/newsletters/stan0302.html and Chapter 6 in the ACS Instrument Handbook). To quantify this new Synphot capability, we compare results from both ETCs with Synphot for a set of different spectral energy distributions with the observation mode WFC,F850LP. In the following table, the spectral type is listed in the first column. The fraction of light with respect to the total integrated to nfinity is listed in the other three columns, for the CGI ETC, for the APT ETC and for Synphot calculations, respectively. These values are derived for a 7x7 pixel box for the CGI ETC calculations and for a 0.2 arcsec aperture for the APT ETC and for Synphot:

Table 5: Ratios of source counts for a selected aperture vs. infinite aperture

SP. Type	CGI ETC	APT ETC	Synphot
O	0.76	0.76	0.74
M	0.76	0.71	0.70
L	0.76	0.69	0.68
T	0.76	0.61	0.60

The CGI ETC results differ by 3% (O star), 9% (M star), 12% (L star), and 27% (T star) and the APT ETC by 3% (O star) and by 2% (M and L stars) and by 1% (T star). If this small effect is relevant to particular observations, then the Synphot software package should be used. A new Synphot keyword has been implemented to call for the encircled energy tables. The keyword is "aper". The user is allowed to select an aperture (radius in arcsec) and indicates this value by typing "aper#value". Currently, the following apertures are supported: every tenth of arcsec between 0. and .6 arcsec, 0.8, 1., 1.5, 2. and 4. arcsec. When calling "aper#0", the user will obtain the number of counts in the brightest pixel, i.e. the peak counts of the source centered at that pixel.

Arbitrary aperture sizes are also permitted but are not recommended, because Synphot provides only a linear interpolation between supported apertures, which is a poor approximation, especially at small apertures. A typical Synphot obsmode would now read like: acs,wfc1,aper#0.2,f850lp. From the command line such an obsmode should be entered within quotes, or synphot issues a warning:

```
cl> calcphot "acs,wfc1,aper#0.2,f850lp"
```

GOs can always "epar" the program they want to run, or use Pyraf instead of cl. Users can also provide their own input spectrum, which has to be in the same format as the user's provided spectrum for the ETC. Please refer to the ETC help pages for more specific information about this format. The file should be placed in the local directory for Synphot.

Acknowledgements

We would like to thank the entire APT ETC group for their support in the development of these calculators and the APT ETC User group for discussions. We also thank Doug VanOrsow for setting up the ACS ETC webpages.

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