Version 1.1
January 2007

Synphot Data User's Guide

SPACE TELESCOPE SCIENCE INSTITUTE

Space Telescope Science Institute
3700 San Martin Drive
Baltimore, Maryland 21218
help@stsci.edu

Operated by the Association of Universities for Research in Astronomy, Inc., for the National Aeronautics and Space Administration

User Support

For prompt answers to any question, please contact the STScI Help Desk.

- **E-mail:** help@stsci.edu
- **Phone:** (410) 338-1082
  (800) 544-8125 (U.S., toll free)

World Wide Web

Information and other resources are available on the STSDAS World Wide Web site:

- **URL:**

  http://www.stsci.edu/resources/software_hardware/stsdas

Synphot Data User's Guide History

Version	Date	Editor
1.0	February 2005	Vicki Laidler
1.1	January 2007	Vicki Laidler

Contributors:

Francesca Boffi, Tom Brown, Scott Friedmann, Sebastian Jester, Vicki Laidler, Jesus Maiz Apellaniz, Charles Proffitt

Citation:

In publications, refer to this document as:
Laidler et al, 2007, "Synphot Data User's Guide" (Baltimore, STScI)

Send comments or corrections to:
Space Telescope Science Institute
3700 San Martin Drive
Baltimore, Maryland 21218
E-mail:help@stsci.edu

Table of Contents

List of Tables

Preface

Although **synphot** is a general purpose package for synthetic photometry, much of its utility for Hubble Space Telescope users arises from the detailed models of HST instrument throughputs that are stored in the Calibration Data Base system (CDBS) and available for download at:

`www.stsci.edu/resources/software_hardware/stsdas/synphot`

Available keywords for **synphot** tasks are defined by the graph and component tables (located in `mtab$`), and actual response curves for supported bandpasses, including throughputs for all past and present instrument modes for HST as well as groundbased photometric systems, are stored in throughput tables (located in `comp$`).

This document describes the use of **synphot** tasks with the observing modes available using these associated data files, as well as some specific issues affecting particular HST instruments.

This document is not a general guide to **synphot**. For more information on **synphot** tasks and capabilities, please see the **Synphot** User's Guide, available for download at:

`www.stsci.edu/resources/software_hardware/stsdas/synphot/SynphotManual.pdf`

For more information about HST instruments and data reductions, see the Instrument Handbooks and Data Handbook available at:

`www.stsci.edu/hst/HST_overview/documents`

CHAPTER 1:

Quick Reference Guide

In this chapter. . .

***Hint: The* synphot *task* `obsmode` *can be used to quickly look up legal completions of a given obsmode. For example, to determine the available set of central wavelengths for the G230m grating for STIS, one may type* `obsmode stis,g230m`.**

1.1 Current Instruments

This section describes the keywords available for the science instruments installed on HST as of January, 2007: the Advanced Camera for Surveys (ACS), the Fine Guidance Sensor (FGS), the Near Infrared Camera and Multi-Object Spectrograph (NICMOS), the Space Telescope Imaging Spectrograph (STIS), and the Wide Field Planetary Camera 2 (WFPC2).

1.1.1 ACS

The ACS keywords consist of a list of detectors, filters, and extraction apertures. The coronagraphic mode may be used only with the HRC detector.

Table 1.1: ACS Keywords

Detectors	hrc sbc wfc1wfc2
Filters for hrc:	f220w f250w f330w f344n f435w f475w f502n f550m f555w f606w f625w f658n f660n f775w f814w f850lp f892n pol_uv pol_v
Ramp filters for hrc:	fr388n fr459m fr505n fr656n fr914m
Dispersers for hrc:	g800l pr200l
Filters for wfc:	f435w f475w f502n f550m f555w f606w f625w f658n f660n f775w f814w f850lp f892n pol_uv pol_v
Ramp filters for wfc:	fr1016n fr388n fr423n fr459m fr462n fr505n fr551n fr601n fr647m fr656n fr716n fr782n fr853n fr914m fr931n Dispersers for wfc:g800l
Filters for sbc:	f115lp f125lp f140lp f150lp f165lp f122m
Dispersers for sbc:	pr110l pr130l
Encircled energy radius values:	aper#0.0 aper#0.1 aper#0.2 aper#0.3 aper#0.4 aper#0.5 aper#0.6 aper#0.8 aper#1.0 aper#1.5 aper#2.0 aper#4.0
Other	coron

1.1.2 FGS

The FGS instrument keywords consist of a list of filters plus a coordinate axis. Some of the filter names are aliases for other filters. "astroclear" is an alias for "F605W", "clear" is an alias for "F583W", "red" is an alias for "F650W", and "yellow" is an alias for "F550W". One example of an FGS observation mode string would be "`FGS,F583W,Y`".

Table 1.2: FGS Keywords

Filter	f550w (yellow) f583w (clear) f605w (astroclear) f650w (red) nd5 pupil
Axis	x y

1.1.3 NICMOS

The NICMOS keywords consist of a list of filters, grisms, polarizers, and detectors. Both the filter name and camera number are required in the observation mode. (The detector keyword `tacq` is another way to specify detector 2.)

The `dn` keyword is used to divide throughputs by the analog-to-digital converter (ADC) gain ratio, which transforms results from units of electrons to data numbers (DNs).

For thermal calculations, all component keywords except the detector may be parameterized for temperature. For more information, see Section 2.5, “Temperature specification (NICMOS, WFC3),” on page 19.

Table 1.3: NICMOS Keywords

Detectors	1 2 3 tacq
Filters for Camera 1	blank f090m f095n f097n f108n f110m f110w f113n f140w f145m f160w f164n f165m f166n f170m f187n f190n pol0s pol120s pol240s
Filters for Camera 2	blank f100w f160w f165m f171m f180m f187n f187w f190n f204m f205w f207m f212n f215n f216n f222m f237m pol0l pol120l pol240l
Filters for Camera 3	blank f108n f110w f113n f150w f160w f164n f166n f175w f187n f190n f196n f200n f212n f215n f222m f240m g096 g141 g206
ADC gain	dn
Thermal components	spider primary pads hole sec edge bend1 reimag pupil image para1 para2 bend dewar cmask dqe

1.1.4 STIS

The available keywords for STIS include filters, apertures, gratings, central wavelengths, and ADC gains. Each grating or imaging mirror can be used with only one of the three STIS detectors (CCD, NUVMAMA, or FUVMAMA); specifying the grating automatically determines the detector. If no central wavelength is specified, results will be calculated for the entire bandpass of the grating. The ADC gain keywords only apply to the STIS CCD modes and are used to convert results from units of electrons to DNs.

In addition to the aperture names as given in Table 1.4, **synphot** will recognize aperture names as given in the format used for phase 2 proposals. For example, the aperture name "52X0.05" is equivalent to the aperture "s52x005" listed in the table.

The `mjd` keyword is used to specify the Modified Julian Date which is used to account for time-dependent sensitivity of the FUV and NUV MAMAs. For more details, see Section 2.3, “Modified Julian Date (STIS),” on page 17.

For important additional details about specifying STIS obsmodes, see Section 3.2, “Specifying STIS observation modes,” on page 24.

As of January, 2007, STIS is in safe mode due to the failure of the Side 2 power supply in August 2004 (Side 1 had failed in 2001). However, replacement of the Side 2 electronics of STIS is planned during the upcoming HST Servicing Mission 4. If this is successful, STIS will be back in operation.

Table 1.4: STIS Keywords

Filters	25mama 50ccd 50coron f25ciii f25cn182 f25cn270 f25lya f25mgii f25nd3 f25nd5 f25ndq1 f25ndq2 f25ndq3 f25ndq4 f25qtz f25srf2 f28x50lp f28x50oii f28x50oiii
Apertures	s005x29 s005x31nda s005x31ndb s009x29 s01x003 s01x006 s01x009 s01x02 s02x005nd s02x006 s02x006fpa s02x006fpb s02x006fpc s02x006fpd s02x006fpe s02x009 s02x02 s02x02fpa s02x02fpb s02x02fpc s02x02fpd s02x02fpe s02x05 s02x29 s03x005nd s03x006 s03x009 s03x02 s05x05 s10x006 s10x02 s2x2 s31x005nda s31x005ndb s31x005ndc s36x005n45 s36x005p45 s36x06n45 s36x06p45 s52x005 s52x01 s52x02 s52x05 s52x2 s6x006 s6x02 s6x05 s6x6
Gratings	e140h e140hb e140m e140mb e230h e230m g140l g140lb g140m g140mb g230l g230lb g230m g230mb g430l g430m g750l g750m prism x140 x140m x230 x230h
Mirrors	acq ccd fuvmama nuvmama
Central wavelengths	all c1687 c1769 c1851 c1933 c2014 c2095 c2176 c2257 c2338 c2419 c2499 c2579 c2659 c2739 c2818 c2898 c2977 c3055 c3134 i1884 i2600 i2800 i2828 c1713 c1854 c1995 c2135 c2276 c2416 c2557 c2697 c2836 c2976 c3115 i2794 c1978 c2707 i2124 i2269 i2415 i2561 c1763 c2013 c2263 c2513 c2762 c3012 i1813 i1863 i1913 i1963 i2063 i2113 i2163 i2213 i2313 i2363 i2413 i2463 i2563 i2613 i2663 i2713 i2812 i2862 i2912 i2962 c3165 c3423 c3680 c3936 c4194 c4451 c4706 c4961 c5216 c5471 i3305 i3843 i4781 i5093 c1173 c1222 c1272 c1321 c1371 c1420 c1470 c1518 c1567 c1616 c1665 c1714 i1218 i1387 i1400 i1540 i1550 i1640 c1425 c1234 c1416 c1598 i1271 i1307 i1343 i1380 i1453 i1489 i1526 i1562 c7751 c8975 c10363 c10871 c5734 c6252 c6768 c7283 c7795 c8311 c8825 c9336 c9851 i6094 i6581 i8561 i9286 i9806
ADC Gains	a2d1 a2d2 a2d3 a2d4
Modified Julian Date	mjd#

1.1.5 WFPC2

The WFPC2 keywords consist of a list of detectors, filters, and miscellaneous keywords. The miscellaneous keywords include the ADC gain keywords `a2d7` and `a2d15`, which convert results from units of electrons to data numbers (DNs); `cal`, which accounts for the flat-field response; `lrf#`, which is used for the linear ramp filters; and `cont#`, which accounts for changes in throughput between decontamination events (see Chapter 2:Parameterized Keywords for more details on the latter two).

The WFPC2 has twelve filter wheels, each of which has five positions, including a clear position. Detector 1 is the PC chip; detectors 2 through 4 are the Wide Field chips. If a detector is not specified, the default is #4. A typical WFPC2 observation mode string would be "`WFPC2,F450W,2`".

Table 1.5: WFPC2 Keywords

Detectors	1 2 3 4
Miscellaneous	a2d7 a2d15 cal cont#
Filter Wheel 1	f122m f157w f160bw f953n
Filter Wheel 2	f130lp f165lp f785lp f850lp
Filter Wheel 3	f336w f410m f467m f547m
Filter Wheel 4	f439w f569w f675w f791w
Filter Wheel 5	f343n f375n f390n f437n
Filter Wheel 6	f469n f487n f502n f588n
Filter Wheel 7	f631n f656n f658n f673n
Filter Wheel 8	f170w f185w f218w f255w
Filter Wheel 9	f300w f380w f555w f622w
Filter Wheel 10	f450w f606w f702w f814w
Filter Wheel 11	f1042m fqunv fqunv33 fqch4n fqch4n33 fqch4n15 fqch4p15 polq polq_par polq_perp polqn33 polqn18 polqp15
Filter Wheel 12	lrf#

1.2 Future Instruments

This section describes the keywords available for the science instruments planned for installation on HST during Servicing Mission 4: the Cosmic Origins Spectrograph (COS) and the Wide Field Camera 3 (WFC3). As of this writing (Jan. 2007), **synphot** support for these instruments is now (with preliminary values for the throughput tables) available.

1.2.1 COS

The COS keywords consist of a list of detectors, apertures, mirrors, gratings, and central wavelengths. FUV spectral simulations are performed by specifying one of the FUV gratings along with a central wavelength. NUV spectral simulations are performed by specifying one of the NUV gratings along with a central wavelength. Imaging simulations are performed by specifying one of the mirrors (`mirrorb` for bright objects) with the NUV detector.

In most cases, the **synphot** calculation includes all three stripes on the detector for a given observing mode. For the NUV G230L grating only, both first and second order light on stripe C are detectable. The second order bandpass overlaps the stripe A bandpass for some central wavelengths.

Therefore, for G230L, separate keywords are used to designate stripes a, b, c1, and c2, where c1 and c2 refer to the first and second orders of stripe C, respectively. Consequently, it is necessary to perform the desired **synphot** ***calculation four times, changing the spectral element keyword in the*** `obsmode` ***each time, in order to obtain complete results for G230L simulations.***

Either the Primary Science Aperture (`psa`) or the Bright Object Aperture (`boa`) may be specified with any simulation; the Primary Science Aperture will be included by default if neither is specified.

Table 1.6: COS Keywords

Detectors	fuv nuv
Apertures	boa psa
Mirrors	mirrora mirrorb
FUV gratings	g130m g140l g160m
Central wavelengths for g130m	c1291 c1300 c1309 c1318 c1327
Central wavelengths for g140l	c1105 c1230
Central wavelengths for g160m	c1577 c1589 c1600 c1611 c1623
NUV gratings	g185m g225m g230la g230lb g230lc1 g230lc2 g285m
Central wavelengths for g185m	c1786 c1817 c1835 c1850 c1864 c1882 c1890 c1900 c1913 c1921 c1941 c1953 c1971 c1986 c2010
Central wavelengths for g225m	c2186 c2217 c2233 c2250 c2268 c2283 c2306 c2325 c2339 c2357 c2373 c2390 c2410
Central wavelengths for g230l	c2635 c2950 c3000 c3360
Central wavelengths for g285m	c2617 c2637 c2657 c2676 c2695 c2709 c2719 c2739 c2850 c2952 c2979 c2996 c3018 c3035 c3057 c3074 c3094

1.2.2 WFC3

The WFC3 keywords consist of a list of detectors, filters, and extraction apertures for each of its two channels.

The `dn` keyword is used to divide throughputs by the analog-to-digital converter (ADC) gain ratio, which transforms results from units of electrons to data numbers (DNs).

The `qyc` keyword is used to apply a wavelength-dependent quantum yield correction. For more detail, see Section 2.6, "Quantum Yield Correction (WFC3)," on page 20.

The `bkg` keyword is used to perform an accurate background calculation for observing modes that use a grism. For more detail, see Section 2.7, "Background Calculation (WFC3)," on page 20.

The `aper` keyword is used to perform encircled energy calculations. For more detail, see Section 2.4, "Encircled energy (ACS, WFC3)," on page 17.

Table 1.7: WFC3 Keywords

Detectors	uvis1 uvis2 ir
UVIS Filters	f200lp f218w f225w f275w f280n f300x f336w f343n f350lp f373n f390m f390w f395n f410m f438w f467m f469n f475w f475x f487n f502n f547m f555w f600lp f606w f621m f625w f631n f645n f656n f657n f658n f665n f673n f680n f689m f763m f775w f814w f845m f850lp f953n fq232n fq243n fq378n fq387n fq422m fq436n fq437n fq492n fq508n fq575n fq619n fq634n fq672n fq674n fq727n fq750n fq889n fq906n fq924n fq937n
UVIS Grism	g280
IR Filters	f098m f105w f110w f125w f126n f127m f128n f130n f132n f139m f140w f153m f160w f164n f167n
IR Grisms	g102 g141
Data numbers	dn
Quantum yield correction	qyc
Background calculation	bkg
Encircled energy radius values	aper#0.00 aper#0.10 aper#0.15 aper#0.20 aper#0.25 aper#0.30 aper#0.40 aper#0.50 aper#0.60 aper#0.80 aper#1.00 aper#1.50 aper#2.00

1.3 Non-HST Filter Systems

In addition to the HST instrument components, the graph table also supports various standard filter system passbands. The passband keyword string consists of the name of the system plus the passband name. An example of a passband observation mode string would be "`COUSINS,I`". If no system name is given for any of the UBVRIJHK bands, the defaults are Johnson UBV, Cousins RI, and Bessell JHK. For example, "v - r" will result in Johnson V minus Cousins R.

For a more detailed description of these filter systems, including the classification of photometric systems into "supported" and "unsupported", see Section 3.3, "Non-HST Photometric Systems," on page 25.

Table 1.8: Non-HST Filter Systems

System	ans baum bessell cousins eso johnson kpno landolt sdss steward stromgren walraven	unsupported
ANS Bands	1550 1550n 1800 2200 2500 3300	unsupported
Baum Bands	f336w f439w f547m f555w f569w f606w f622w f675w f702w f725lp f785lp f791w f814w f850lp f1042m	unsupported
Bessell Bands	J H K	unsupported
Cousins Bands	R I	supported
ESO Bands	(There are 530 numbered bands)	unsupported
Johnson Bands	U B V R I J K	partially supported
KPNO Bands	J H K	unsupported
Landolt Bands	U B V R I (= Johnson UBV + Cousins RI)	supported
SDSS Bands	u g r i z	supported
Steward Bands	J H K	unsupported
Stromgren Bands	u v b y	supported
Walraven Bands	V B L U W	unsupported

1.4 Retired Instruments

The instruments which have previously flown on HST but have been replaced by more modern detectors are included here for completeness.

The complete list of allowed component names that represent the telescope, COSTAR, and science instruments is:

- Telescope: ota noota
- COSTAR: costar nocostar
- Instruments: acs cos fgs foc fos hrs hsp nicmos pc stis wf wfc wfc3 wfpc wfpc2.

As of September 1993, the default modes for the Telescope and COSTAR components were "ota" and "nocostar", respectively. Soon after COSTAR was installed in the telescope, the default mode was changed to "costar" for original instruments. Once the second-generation instruments were installed, with their built-in optical corrections, the default mode for "costar" or "nocostar" became instrument-specific. Note that for the WF/PC-1 instrument the names "wf", "wfc", and "wfpc" are all equivalent and correspond to the WFC mode of the WF/PC-1 instrument.

1.4.1 FOC

The FOC keywords consist of a list of detectors, filters, and miscellaneous keywords. The f/48 has two filter wheels and the f/96 detector has four filter wheels. Some of the filters have aliases. "fuvop" is an alias for PRISM1, "nuvop" is an alias for PRISM2, "fopcd" is an alias for PRISM3, "g450m" is an alias for F305LP, "g225m" is an alias for F220W, and "g150m" is an alias for F140W. The miscellaneous keywords include the COSTAR and the occulting fingers. An example of an FOC observation mode string would be "`FOC,COSTAR,F/96,F410M`".

Table 1.9: FOC Keywords

Detector	f/48 f/96 f/288 spec
f/48 Wheel 1	f140w (g130m) f150w (g150m) f175w f195w f220w (g225m) f305lp (g450m) prism3 (fopcd) (grat-prism)
f/48 Wheel 2	f130lp f180lp f275w f342w f430w prism1 (fuvop) prism2 (nuvop)
f/96 Wheel 1	f600m f630m f2nd f4nd f6nd f8nd pol0 pol0_par pol0_per pol0_unp pol60 pol60_par pol60_per pol60_unp pol120 pol120_par pol120_per pol120_unp prism1 (fuvop) prism2 (nuvop)
f/96 Wheel 2	f140w f175w f220w f275w f320w f342w f370lp f430w f480lp f486n f501n
f/96 Wheel 3	f120m f130m f140m f152m f165w f170m f190m f195w f210m f231m f1nd
f/96 Wheel 4	f130lp f253m f278m f307m f346m f372m f410m f437m f470m f502m f550m
f/48 Image Formats	x48n256 x48n256d x48n512 x48nlrg x48zlrg x48zrec
f/96 Image Formats	x96n128 x96n256 x96n512 x96nlrg x96z512 x96zlrg
Spectral Order	order1 order2 order3 order4
Occulting Fingers	occ0p23 occ0p4 occ0p8
Detector Formats	x48n256 x48n256d x48n512 x48nlrg x48zlrg x48zrec x96n128 x96n256 x96n512 x96z512 x96nlrg x96zlrg

Note that the spectroscopic capabilities, and hence the related keywords spec, order1, order2, order3, and order4, are only available for the f/48 camera. Furthermore, the occ0p23 keyword is only available with the f/48 camera, and the occ0p4 and occ0p8 keywords are only available with the f/96 camera.

The x48* and x96* keywords are used to account for the known dependency of DQE on the detector format (see the FOC Instrument Handbook for more details). These keywords invoke throughput tables that contain the (wavelength-independent) relative sensitivities for each format, where the 512x512 format (x48n512 and x96n512) is set to 1.0. The associations between formats and **synphot** keywords is listed in Table 1.9.

Table 1.10: FOC Detector Format Keywords

Camera	Synphot Keyword	Camera Format
f/96	x96n128	128 x 128
	x96n256	256 x 256
	x96n512	512 x 512
	x96z512	512z x 512
	x96zlrg	512z x 1024
f/48	x48n256	256 x 256
	x48n512	512 x 512
	x48zrec	256z x 1024
	x48nlrg	512 x 1024
	x48zlrg	512z x 1024

1.4.2 FOS

The FOS keywords consist of a list of detectors, apertures, gratings, and polarimeter waveplates and waveplate position angles. The waveplate keywords indicate whether waveplate A or B is being used and the angle of the waveplate. An example of an FOS observation mode string would be "`FOS,BLUE,G160L`".

Table 1.11: FOS Keywords

Detectors	blue red
Apertures	0.3 0.5 1.0 4.3 0.1-pair 0.25-pair 0.5-pair 1.0-pair upper lower 0.25x2.0 0.7x2.0-bar 2.0-bar blank fail-safe
Gratings	g130h g190h g270h g400h g570h g780h g160l g650l mirror prism order0
Waveplates	pol0-a pol0-b pol22.5-a pol22.5-b pol45-a pol45-b pol67.5-a pol67.5-b pol90-a pol90-b pol112.5-a pol112.5-b pol135-a pol135-b pol157.5-a pol157.5-b pol180-a pol180-b pol202.5-a pol202.5-b pol235-a pol235-b pol257.5-a pol257.5-b pol270-a pol270-b pol292.5-a pol292.5-b pol315-a pol315-b pol337.5-a pol337.5-b
COSTAR	costar nocostar

The upper and lower aperture keywords are only recognized when used in conjunction with one of the paired apertures, e.g., "`FOS,BLUE,G130H,UPPER,1.0-PAIR`". The order0 keyword is only available in conjunction with the g160l grating and the blue detector. The waveplate keyword syntax is POLpa-wp, where pa is the position angle in degrees, and wp is the A or B waveplate.

1.4.3 HRS

The HRS keywords consist of a list of detectors, apertures, gratings or mirrors, and Echelle mode orders. The Echelle mode orders are used with the keywords ECHA and ECHB. Orders 18 to 33 are valid with Echelle mode B, while orders 33 to 53 are valid with Echelle mode A. An example of a typical HRS abbreviation mode string would be "`HRS,LSA,G160M`".

Table 1.12: HRS Keywords

Apertures	lsa ssa
Gratings	echa echb g140l g140m g160m g200m g270m
Mirrors	a1 a2 n1 n2
Echelle Orders	18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 all
COSTAR	costar nocostar

1.4.4 HSP

The HSP keywords consist of a list of detectors, filters, apertures, and beams. The beams refer to the two beams that come out of the beam splitter. Not all apertures can be used with all detectors. Refer to the HSP Instrument Handbook for further information. The polarization detector also has angle and type keywords. An example of an HSP observation mode string would be "`HSP,UV1,F220W,C`".

Table 1.13: HSP Keywords

Detectors	pmt pol uv1 uv2 vis
POL Filters	f160lp f216m f237m f277m f327m
UV1 Filters	f122m f135w f140lp f145m f152m f184w f218m f220w f240w f248m f278n prism
UV2 Filters	f122m f140lp f145m f152m f160lp f179m f184w f218m f248m f262m f278n f284m prism
· VIS Filters	f160lp f184w f240w f262m f355m f400lp f419n f450w f551w f620w prism
Relay mirror	norelay relay
Apertures	a b c d e f h j s t
Beams	blue red
Polarization Angles	0 45 90 135
Polarization Types	ext ord par per

1.4.5 WF/PC-1

The WF/PC-1 keywords consist of a list of filters, detectors, and miscellaneous keywords. The miscellaneous keywords include `baum`, which accounts for the Baum spot; `dn`, which converts units from electrons to data numbers (DNs); `cal`, which accounts for the flat-field correction; and `cont#`, which accounts for changes in sensitivity between decontamination events (see section 2.2).

The WF/PC-1 has twelve independently positionable filter wheels, each of which has five positions, including a clear position. Detectors 1 through 4 correspond to the Wide Field camera, while 5 through 8 are the Planetary camera. A typical WF/PC-1 observation mode string would be `"WFPC,F550W,4,DN"`.

Table 1.14: WFPC1 Keywords

Instrument	wfpc, wfc, wf (all equivalent), pc
Detectors	1 2 3 4 5 6 7 8
Miscellaneous	baum dn cal cont#
Filter Wheel 1	f673n f8nd g450 g800
Filter Wheel 2	f122m f336w f439w g200 g200m2
Filter Wheel 3	pol0 pol60 pol120 f1083n
Filter Wheel 4	f157w f194w f230w f284w
Filter Wheel 5	f569w f658n f675w f791w
Filter Wheel 6	f631n f656n f664n f702w
Filter Wheel 7	f375n f437n f502n f588n
Filter Wheel 8	f368m f413m f492m f622w
Filter Wheel 9	f547m f555w f648m f718m
Filter Wheel 10	f785lp f814w f875m f1042m
Filter Wheel 11	f128lp f469n f487n f517n
Filter Wheel 12	f606w f725lp f850lp f889n

The detector specifications 1 through 4 are valid only when used in conjunction with the wf, wfc, or wfpc instrument keywords, and detectors 5 through 8 are only valid when used with the pc keyword. If a detector number is not specified, the default detector for WF is #2, and the default for PC is #6.

CHAPTER 2:

Parameterized Keywords

In this chapter. . .

Parameterized keywords are generally used to access throughput tables for which the throughput is a function of some other variable in addition to wavelength. The syntax for a parameterized keyword is `keyword#value`, where value is a numeric (integer or float) value for the keyword to take. The hash sign # indicates to **synphot** that a parameterized keyword is being used.

Parameterized throughput tables contain several throughput columns, each for a specified value of the parameterized component. The user may specify an arbitrary value, however, and **synphot** will linearly interpolate between the two closest values. If no parameterized keyword is used in the obsmode, a default value will be used.

2.1 Ramp filters (ACS, WFPC2)

2.1.1 ACS

Fifteen ramp filters are available for use with the WFC detector, and six are available for use with the HRC detectors. To use the ramp filters in simulations, use the keyword syntax `ffff#wwww`, where ffff is the filter and wwww is the desired central wavelength, specified in Angstroms, e.g., obsmode="`acs,wfc,fr388n#3880`".

2.1.2 WFPC2

Filter wheel 12 contains four linearly variable narrowband ramp filters, which together cover a total wavelength range of 3700 to 9800 Å. The FWHM of the throughput at a given wavelength is typically about 1% of the central wavelength. The ramp filters have been implemented as a parameterized component in **synphot**. To use the ramp filters in simulations, use the keyword syntax `lrf#wwww`, where wwww is the desired central wavelength,, specified in Angstroms, e.g., obsmode="`wfpc2,3,lrf#4861`".

2.2 Contamination (WFPC1, WFPC2)

The `cont#` keyword references the Modified Julian Date, which is used to account for the gradual decline in throughput between decontamination events, as well as for the sudden increase in throughput immediately after a decontamination.

For WFPC1, data exists for 48384.0 < MJD < 49329.0 (8 May 1991 to 8 December 1993), in intervals of 20-30 days.

For WFPC2, data currently exists from MJD 49347.0 onwards (26 December 1993), in intervals of approximately 30 days.

The **synphot** expression evaluator interpolates between the dates for which data exists in the table to arrive at an estimate of the throughput on the requested date.

2.3 Modified Julian Date (STIS)

The `mjd` keyword applies only to the MAMA grating and imaging modes (the MJD keyword has not yet been implemented in **synphot** for the MAMA echelle modes) and is used to handle the time dependent sensitivity of the FUV and NUV MAMAs. To use this capability in simulations, include the string `mjd#ddddd` in your obsmode specification, where ddddd is the desired MJD value (which can be given as either an integer or real value).

For example, to get the efficiency on MJD 49486, use "`mjd#49486`" as part of your obsmode string. When specifying the `mjd` keyword in command line input to **synphot**, it may be necessary to enclose the obsmode string in quotes to ensure that the **synphot** expression evaluator properly interprets the obsmode string.

The **synphot** expression evaluator interpolates between the dates for which data exists in the table to arrive at an estimate of the throughput on the requested date. The default is to use the latest set of throughput values without any extrapolation. The values are expected to be updated approximately yearly, so the default result should not differ by more than 2 percent from those that use the current date.

2.4 Encircled energy (ACS, WFC3)

2.4.1 Background

In April 2003, a new capability was introduced in **synphot** for use with the Advanced Camera for Surveys (ACS) imaging modes. This functionality is new to **synphot** and is currently only available for ACS and WFC3. Users are now able to specify a circular aperture (radius in arcsec) to calculate the source counts within this aperture. If no aperture is defined (or if a 4.0 arcsec radius is specified), **synphot** calculates the total number of counts in an infinite aperture.

This makes **synphot** more flexible and accurate, particularly in cases such as red targets that are observed at long wavelengths. At wavelengths greater than 7500 A (HRC) and about 9000 A (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. This problem affects particularly the very broad z-band F850LP filter, for which the encircled energy depends on the underlying spectral energy distribution the most.

In the currently available APT ETC, the treatment of such an effect has been ameliorated but not solved. In fact, 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, that is,

$$\frac{\int f_\lambda P_\lambda \lambda^2 \, d\lambda}{\int f_\lambda P_\lambda \lambda \, d\lambda}$$

where P_λ is the (dimensionless) passband throughput, and f_λ is the source flux distribution.

However, this does not account for the variation in enclosed energy with wavelength. As a consequence, to obtain correct estimated count rates for red targets, observers are advised to use the **synphot** package in IRAF/STSDAS for which this proper integration over wavelength has now been incorporated for encircled energy.

To quantify this new **synphot** capability, we compare APT ETC results with **synphot** for a set of different spectral energy distributions and 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 infinity is listed in the other two columns, for the ETC and **synphot** calculations respectively. These values are derived for a 0.2 arcsec radius aperture for the ETC and **synphot** calculations.

Sp. Type	ETC	synphot
O	0.76	0.74
M	0.71	0.7
L	0.69	0.68
T	0.61	0.6

The ETC results are off by up to 3% (O star), 2% (M and L stars), and 1% (T star). If this small effect is relevant to particular observations, then the **synphot** software package can be used.

2.4.2 Usage

The "`aper`" keyword allows the user to select an aperture (radius in arcsec) and indicate this value by typing "`aper#value`". 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.

A typical obsmode would now read:
`acs,wfc1,aper#0.2,f850lp`.

From the cl command line such an obsmode should be entered within quotes, or **synphot** complains:
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 must be in the same format as the user-provided spectrum for the ETC. The file should be placed in the directory from which **synphot** is run. Please refer to the ETC help pages for more specific information about this format.

Supported apertures depend on each instrument, and are listed below.

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.

2.4.3 Supported ACS Aperture Sizes

Currently, the following apertures are supported: every tenth of arcsec between 0. and .6 arcsec, 0.8, 1., 1.5, 2. and 4. arcsec.

2.4.4 Supported WFC3 Aperture Sizes

Currently, the following apertures are supported: every 0.05 arcsec between 0.1 and 0.3 arcsec; every tenth of arcsec between 0.3 and 0.6; 0.8, 1.0, 1.5, and 2.0 arcsec.

2.5 Temperature specification (NICMOS, WFC3)

With the release of STSDAS 3.0, support for thermal calculations was added to **synphot** with the new task **thermback**. At present, this capability has only been fully implemented for NICMOS. For WFC3, thermback calculates the thermal background, but only does so at the default temperatures within the instrument (parameterized keywords do not yet apply to WFC3).

2.5.1 NICMOS

Additional keywords, including opaque but thermally emitting components of the OTA, were added, and all keywords except the detector keywords became parameterizable for temperature. Thus, to compute the thermal background assuming the primary mirror temperature is 290K, one would specify an obsmode `nicmos,3,f222m,primary#290.0`.

If no temperature value is specified, the default temperature for each component is used. The default temperature is stored as a header keyword (DEFT) in the thermal file for each component, which also contains the emissivity tables as a function of wavelength.

Most of the NICMOS optical elements are contained in the dewar, and are therefore at the same temperature. The software does not enforce this however: the user must specify the new temperature for each component individually. The keywords for the NICMOS components located in the dewar are `reimag pupil image para1 para2 bend dewar cmask`.

2.5.2 WFC3

No parameterized keywords are yet supported for WFC3. The default temperature is always used.

Note that for observation modes using a grism, the `bkg` keyword should always be specified with **thermback**, as discussed in section 2.7.

2.6 Quantum Yield Correction (WFC3)

The `qyc` keyword is used to apply a wavelength-dependent quantum yield correction.

At short wavelengths, the UVIS detector has a finite chance of producing two elections for one incoming photon. By default, **synphot** reports the raw count rate in electrons (if the `dn` keyword is not specified) or data numbers (if the `dn` keyword is specified), but the appropriate count rate for signal-to-noise calculations should be in electrons with a correction for this quantum yield effect.

For signal-to-noise calculations, users should specify the `qyc` keyword but not specify the `dn` keyword.

We expect to implement this functionality for other instruments in the future.

2.7 Background Calculation (WFC3)

The `bkg` keyword is used to perform throughput and emission calculations pertaining to the background signal component of grism observations.

In grism observations, a given detector pixel will receive source signal from only a small wavelength interval of the dispersed source spectrum, but it will receive background signal from the entire bandpass of the grism. A special throughput table must therefore be used to correctly compute the detected signal from a background spectrum, which gives the transmission of the grism over its entire bandpass.

The `bkg` keyword is only valid when grisms are specified as part of the obsmode.

We expect to implement this functionality for grism modes in other HST instruments in the future.

CHAPTER 3:

Further Discussions

In this chapter. . .

More information about all the HST Science Instruments can be found in their respective Instrument and Data Handbooks.

3.1 WFPC2 Quad filters

Filter wheel 11 contains 3 specialized quadrant (quad) filters in which each quadrant corresponds to a facet of the pyramid, and therefore to a distinct camera relay. One quad filter, fquvn, contains four narrowband, redshifted [OII] filters. The second, fqch4n, contains four methane (CH4) band filters, and the third, polq, contains four polarizing elements. The instrument graph table is constructed so that distinct throughput values are automatically selected for a given quadrant of the fquvn and fqch4n filters based on the selected detector.

Note that all three of the quad filters were designed to map onto a four-faceted WFC configuration. However, in the final design of the instrument, with WF quadrant 1 replaced by the PC, it is necessary to rotate the quad filters by 33° in order to bring filter quadrant 1 into the WF 2 and 3 relays. In addition, partial rotations of 15° and +15° have been implemented for the methane (CH4) filter in order to bring two of its quadrants into the PC relay, and partial rotations of 18° and +15° have been implemented for the polarizer (pol) filter in order to allow observations with different polarization angles (see the WFPC2 Instrument Handbook for more details). Unique component keywords have been implemented in the instrument graph for the nominal and rotated positions of each of these filters. The nominal positions are designated as fquvn, fqch4n, and polq. The rotated positions are designated as fquvn33 (-33°), fqch4n33 (-33°), fqch4n15 (-15°), fqch4p15 (+15°), polqn33 (-33°), polqn18 (-18°), and polqp15 (+15°).

3.2 Specifying STIS observation modes

In the STIS instrument, imaging mirrors and gratings are contained in the mode select mechanism (MSM) while filters and slits are in the aperture wheel. Each grating or imaging mirror is intended for use with only one of the three STIS detectors (CCD, NUVMAMA, or FUVMAMA).

In principle, any filter or slit (aperture) could be used with any grating or mirror, although in practice certain combinations are restricted or forbidden.

Since the slits and filters are in the same wheel, it is not possible to use both a slit and a filter at the same time. (Some small slits contain built in neutral density filters.)

The ADC gain keywords only apply to the STIS CCD modes and are used to convert results from units of electrons to DNs.

In a **synphot** observation mode string, specifying the grating automatically determines the detector used.

- If no aperture or filter is specified, the calculation is done for the clear aperture case. So the observation mode string `"stis,g430l"` is equivalent to either `"stis,ccd,g430l"` or `"stis,ccd,g430l,50ccd"`, (50CCD being the unobstructed full field aperture for the CCD detector).
- If the detector name is specified without a grating, e.g., `"stis,ccd,f28x50lp"`, it is assumed that an imaging mirror is being used.
- If no central wavelength is specified, e.g., `"stis,ccd,g430m,52X0.2"`, results for the entire bandpass of the instrument will be calculated, while if a central wavelength is included, e.g., `"stis,ccd,g430m,52X0.2,c4451"`, the calculation will be restricted to the actual wavelength range covered by that wavelength setting.

Each central wavelength is intended for use with a particular grating. See the STIS Instrument Handbook for a listing of which central wavelengths are allowed with each grating. The low order gratings, G140L, G230L, G230LB, G430L, and G750L have only one allowed setting and a central wavelength should not be specified in the observation mode string.

3.3 Non-HST Photometric Systems

This section provides references and some further discussion on various non-HST photometric systems that are characterized in the Calibration Database (CDBS).

The Cousins R and I throughputs are taken from Bessell (1983), Table AII, and have been transformed into photon-counting form.

The throughput data for the Johnson UBV bands have been obtained from Maíz Apellániz (2006), while the Johnson RIJK are from Johnson (1965), Table A1.

The Landolt photometric system is defined as the Johnson UBV bands plus the Cousins RI bands.

The Sloan Digital Sky Survey (SDSS) ugriz filter throughputs were provided by Sebastian Jester on behalf of the SDSS team. They are described in the Photometry White Paper by Gunn et al. (2001). See further discussion below. Figures showing the filter response can be seen at:

http://www.sdss.org/dr1/instruments/imager/index.html#filters.

The filter throughputs for the Strömgren system are taken from Maíz Apellániz (2006).

3.3.1 Comparing synphot results with observed non-HST photometry

There are two issues that are sometimes overlooked when comparing synthetic and observed photometry.

Firstly, one should be careful whether the throughput data have been defined for a photon-counting or an energy-integrating detector. **Synphot** always assumes that throughputs are of the first type. In particular, some authors in the past have defined throughput curves for photomultipliers as if these detectors were energy integrators, which they are not. Such curves have to be converted into photon-counting form before they can be correctly used by **synphot** (Maíz Apellániz 2006). Using the wrong definition can lead to errors of a few percent for broad-band filters.

Secondly, many systems (e.g. Johnson UBV) use Vega as a reference spectrum, but have been calibrated using secondary standards, leading to the existence of finite zero points. In some systems (e.g. Strömgren), those zero points are not even close to 0.0 for some filters. We provide in Table 3.1, "Zeropoint Corrections for Groundbased Filter Systems," on page 26 some recent measurements of zero points collected from the literature.

These values should be added to the vegamag* synphot *magnitudes before they are compared with the observed data.

The existence of these issues has led us to divide the non-HST photometric systems into supported and non-supported. The first category refers to those systems for which there are recent analyses in the literature that deal with these issues and, therefore, we can be reasonably confident that the possible systematic errors in the **synphot** results are small. The systems in that category are Cousins RI, Johnson UBV (but not RIJK), Landolt UBVRI, SDSS ugriz, and Strömgren uvby. The second category (non-supported filter systems) includes the rest of the filter systems in this section.

Table 3.1: Zeropoint Corrections for Groundbased Filter Systems

Filter/Color/Index (mag)	Zero point	Reference
Johnson/Landolt V	0.026	1
Johnson/Landolt B-V	0.010	2
Johnson/Landolt U-B	0.020	2
Cousins/Landolt V-R	-0.012	3
Cousins/Landolt V-I	-0.002	3
Strömgren y	0.038	3
Strömgren b-y	0.007	2
Strömgren m_1	0.154	2
Strömgren c_1	1.092	2

1. Bohlin & Gilliland (2004).
2. Maíz Apellániz (2006).
3. Holberg & Bergeron (2006).

3.3.2 Further detail on the SDSS filter curves

The throughput data for the SDSS ugriz bands give the system photon response to point sources of the 2.5m SDSS survey telescope, including extinction through an airmass of 1.3 at Apache Point Observatory (to which all SDSS photometry is referenced). Originally, the ugriz system was intended to be identical to the u’g’r’i’z’ system described in Fukugita et al. (1996)and defined by the standard star system in Smith et al. (2002). However, in the course of processing the SDSS data, the unpleasant discovery was made that the filters in the 2.5m telescope have significantly different effective wavelengths from the filters in the USNO telescope, which was used to observe the u'g'r'i'z' standards (the difference originates from the USNO filters being exposed to ambient air, while the survey-telescope filters live in the vacuum of the survey camera). Therefore, it became necessary to distinguish between the primed and unprimed SDSS filter sets.

The response curves in r and i are slightly different for large extended sources (larger than about 80 pixels in size) because the extended infrared scattering wings in these bands, which do not affect the photometry of point sources, begin to be included. The modified curves are available from the SDSS web site:

http://www.sdss.org/dr3/instruments/imager/#filters.

The SDSS photometry is intended to be on the AB system (Oke & Gunn 1983), by which a magnitude 0 object should have the same counts as a source of Fnu = 3631 Jy (except that it used the so-called asinh magnitudes defined by Lupton, Gunn, & Szalay (1999) instead of conventional "Pogson" magnitudes). However, this is known not to be exactly true, such that the photometric zeropoints are slightly off the AB standard. The SDSS team continues to work to pin down these shifts. Their present estimate, based on comparison to the STIS standards of Bohlin, Dickinson, & Calzetti (2001) and confirmed by SDSS photometry and spectroscopy of fainter hot white dwarfs, is that the u band zeropoint is in error by 0.04 mag, u_AB = u_SDSS - 0.04 mag, and that g, r, and i are close to AB. These statements are certainly not precise to better than 0.01 mag. The z band zeropoint is not as certain at the time of this writing (Jan. 2005), but there is mild evidence that it may be shifted by about 0.02 mag in the sense z_AB = z_SDSS + 0.02 mag.

The reader is referred to Holberg & Bergeron (2006) for a calibration of SDSS magnitudes using Vega as a reference spectrum.

Further information about SDSS photometric calibration and the asinh magnitude system can be found at:

http://www.sdss.org/dr3/algorithms/fluxcal.html

3.3.3 Unsupported bandpass systems

As of March 2006, the following non-HST bandpass systems were deprecated, for the reasons described in section 3.3.1. We have no plans to remove them from the system, for backwards compatibility; but we also have no plans to attempt to update them.

The ANS system is a set of ultraviolet filters used by the Astronomical Netherlands Satellite, described in van Duinene et al. (1975).

The Baum filter set is a set of 15 broadband and intermediate-band filters that are copies of some of the onboard WF/PC-1 filters and were used as part of a ground-based observing campaign to determine calibrations for the WF/PC-1 instrument. In order to match the response of the WF/PC-1 flight passbands as closely as possible, the throughputs for the Baum filters have been multiplied by the spectral response curve of the ground-based CCD (measured in the laboratory) and twice by the spectral reflectance of aluminum (see Harris et al., 1991, for details).

The Bessell JHK filter curves are taken from data in TableIV of Bessell and Brett (1988). These curves include mean atmospheric transmission equivalent to 1.2 air masses of a standard KPNO atmosphere.

The ESO band throughput tables were received from Jan Koornneef in 1990. There are 530 of these bandpasses; interested users should use the **obsmode** task to obtain the complete listing.

The KPNO JHK filter curves are taken from tracings of the Simultaneous Quad Infrared Image Device (SQIID) filter set, which were provided by Richard Joyce (KPNO).

The Steward Observatory JHK filter curves are from data provided by Marcia Rieke (Steward Observatory).

The throughput data for the Walraven bands are from Lub and Pel (1977), Table 6.

APPENDIX A:

On-Line Catalogs and Spectral Atlases

In this appendix . . .

There are several spectral atlases consisting of both observed and model data that are available in FITS table format for use with **synphot**. These are available at STScI on all science computing clusters in the `crrefer` directory areas. Off-site users can obtain these data via anonymous ftp on the node `ftp.stsci.edu` where they are located in several subdirectories under the /`cdbs` directory.

Current descriptions and access to all available calibration spectra and astronomical catalogs can also be found at the CDBS web site, which is updated more frequently than this manual:

http://www.stsci.edu/hst/observatory/cdbs/astronomical_catalogs.html.

The subdirectories /`cdbs/calspec/` and /`cdbs/grid/` contain the data tables for all of the atlases described here. For easy access from the **synphot** tasks, the on-line directories containing the various atlases are defined via environment variables within STSDAS. All subdirectories are defined relative to the `crrefer$` directory environment variable, which is set in the IRAF file `hlib$extern.pkg`. Off-site users should define `crrefer` in this file to point to the local directory area that contains the atlas tables. The environment variables `crcalspec$`, `crgridbk$`, `crgridbpgs$`, `crgridbz77$`, `crgridgs$`, and `crgridjac$` are subsequently defined in the STSDAS file `stsdaslib$zzsetenv.def` to point to subdirectories beneath `crrefer$` which contain the spectral data tables for each of the individual atlases.

A.1 HST Calibration Spectra

The directory `crcalcspec$` contains the composite stellar spectra that are the fundamental flux standards for HST calibrations. All files are in machine independent binary FITS table format. Information about the pedigree of a given spectrum is in the header of the FITS table file, which can be read with the IRAF hedit task or examined using pyFITS.

In some cases, the spectrum is truncated in the blue (or in the red) at wavelength longer (shorter) than the sensitivity limit of the instrument. As a result, **synphot** may underestimate the total counts. Users should check that the wavelength range of the spectrum/model they are using is compatible with the wavelength range of the calculation they require.

Table A.1 below summarizes the set of recommended standard star spectra. Columns 2 and 3 give the V and B magnitudes of the stars. More documentation on these stars, e.g. coordinates, finding charts and spectral types can be found in Turnshek et al. (1990), Bohlin, Colina & Finley (1995), and Colina & Bohlin (1997). Column 4 is the computer compatible file name with the plus and minus signs converted to underscores. Thus, the actual CALSPEC file name is the prefix in column 4, plus one of the suffixes in columns 5-8, plus ".fits". For example, a standard that has STIS data is "bd_28d4211_stis_001.fits".

These spectra can be used with **synphot** tasks by setting either the `spectrum` or `spfile` task parameters to the name of the desired file, e.g., `crcalspec$alpha_lyr_stis_002.fits`. The unit of flux in all files is erg s^{-1} cm^{-2} A^{-1}.

The pure hydrogen WD model LTE spectra of Bohlin (2000) have been replaced by Hubeny NLTE models calculated with his Tlusty code (Bohlin 2003). These fundamental standards GD71, GD153, G191B2B, and HZ43 are listed by Calibration Data Base System (CDBS) suffix in column 5 of the Table and provide the basis for the secondary flux standards. The observational spectra from columns 5-8 can be compared with the models;

and in the case of G191B2B, there is ultraviolet line blanketing at the few percent level. The model calculations extend to 30 microns and cover the long wavelength limits of 2.7 microns for NICMOS, 1.1 microns for STIS and ACS, and 27 microns for JWST. Vega was observed by STIS (Bohlin & Gilliland 2004); and the new composite flux standard alpha_lyr_stis_002.fits consists of IUE data from 1255-1675A, STIS CCD fluxes from 1650-4200A, and a specially tailored Kurucz model longward of 4200A (Kurucz 2003) and from 900-1255A.

Column 6 lists the 20 CDBS suffix names for the second choice standard stars with STIS data from Bohlin, Dickinson, & Calzetti (2001). Tabulated in column 7 are the next best standard star flux distributions, which are composed of FOS spectra in the UV and Oke spectra at the longer wavelengths. Also appearing in column 7 are the three solar analogs that are comprised of FOS observation but do not have "_FOS" in the CALSPEC file name.

The names for the last, but largest, set of standard stars appear in column 8 of the Table. The application of corrections to the original IUE and optical fluxes produces a consistent set of spectrophotometric standards from 1150 to 9200A (Bohlin 1996 and references therein). This set of standards is composed of IUE+Oke data only.

CALSPEC also contains the ultraviolet to near-infrared absolute flux distribution of the Sun (filename: sun_reference_stis_001.fits) to 2.7 microns, which is used to model the IR spectrum of the three solar analog stars. The solar reference spectrum combines absolute flux measurements from satellites and from the ground with a model spectrum for the near-infrared (Colina, Bohlin, & Castelli 1996).

The `SUPPLEMENTAL_CALSPEC` directory contains previous CALSPEC versions and spectrophotometry that may be useful for special purposes.

The order of preference for the choice of a standard flux distribution is from left to right in the Table A.1, i.e. from the best in column 5 to the last choice with the lowest quality in column 8.

Table A.2 contains the spectral type of some of the HST calibration sources.

Table A.1: CDBS Flux Standards with Columns in Order of Preference

Star name (1)	V (2)	B-V (3)	CDBS name (4)	Model (5)	STIS (6)	FOS+Oke (7)	IUE+Oke (8)
AGK+81D266	11.94	-0.34	agk_81d266		_STIS_001		_005
ALPHA-LYR	0.03	0.00	alpha_lyr		_STIS_003		_004
BD+25D4655	9.69	-0.31	bd_25d4655				_002
BD+28D4211	10.51	-0.34	bd_28d4211		_STIS_001	_FOS_003	_005
BD+33D2642	10.83	-0.17	bd_33d2642			_FOS_003	_004
BD+75D325	9.55	-0.33	bd_75d325		_STIS_001	_FOS_003	_005
FEIGE110	11.83	-0.30	feige110		_STIS_001		_005
FEIGE34	11.18	-0.34	feige34		_STIS_001		_005
FEIGE66	10.51	-0.29	feige66				_002
FEIGE67	11.82	-0.34	feige67				_002
G191B2B	11.77	-0.33	g191b2b	_MOD_004	_STIS_001	_FOS_003	_005
G93-48	1 2.74	-0.01	g93_48				_004
GD108	13.56	-0.22	gd108				_005
GD153	13.35	-0.29	gd153	_MOD_004	_STIS_001	_FOS_003	
GD50	14.06	-0.28	gd50				_004
GD71	13.03	-0.25	gd71	_MOD_005	_STIS_001	_FOS_003	
GRW+70D5824	12.77	-0.09	grw_70d5824		_STIS_001		_005
HD93521	6.99	-0.27	hd93521		_STIS_001		_005
HZ21	14.69	-0.33	hz21		_STIS_001		_005
HZ2	13.88	-0.09	hz2				_005
HZ43	12.91	-0.31	hz43	_MOD_004	_STIS_001	_FOS_003	
HZ43B	14.30	...	hz43b		_STIS_001		
HZ44	11.67	-0.29	hz44		_STIS_001	_FOS_003	_005
HZ4	14.51	+0.09	hz4		_STIS_001		_004
LB227	15.32	+0.06	lb227				_004
LDS749B	14.68	-0.04	lds749b				_005
LTT9491	14.10	+0.03	ltt9491				_002
NGC7293	13.53	-0.37	ngc7293				_005
P041C	12.00	0.62	p041c		_STIS_001	_001	
P177D	13.47	0.66	p177d		_STIS_001	_001	
P330E	13.00	0.64	p330e		_STIS_001	_001	
SUN	-26.75	0.63	sun_reference		_STIS_001		

(1) The unit of flux in all files is erg s^{-1} cm^{-2} A^{-1}.

Table A.2: HST Calibration Spectra

Star	Type
AGK +81 266	sdO
alpha Lyra	A0 V
BD +28 4211	Op
BD +33 2642	B2 IV
BD +75 0325	O5p
Feige 34	DO
Feige 110	D0p
G93-48	DA3
G191-B2B	DA0
GD50	DA2
GD108	sdB?
GRW +70 5824	DA3
HD 93521	O9 Vp
HZ 2	DA3
HZ 4	DA4
HZ 21	DO2
HZ 44	sdO
LB 227	DA4
LDS 749B	DB4
NGC 7293	

A.2 Kurucz 1993 Atlas of Model Atmospheres

The atlas contains about 7600 stellar atmosphere models for a wide range of metallicities, effective temperatures and gravities. These new LTE models have improved opacities and are computed with a finer wavelength and temperature resolution than the previous Buser-Kurucz atlas installed in the CDBS (crgridbk). The micro-turbulent velocity is 2 km s^{-1}.

The new atlas installed in the CDBS is from the Kurucz database at Goddard Space Flight Center. The original atlas (CD-ROM No. 13) was created on August 22, 1993 and can be obtained from Dr. R. Kurucz.

The atlas includes models of abundances (log_Z) relative to solar of +1.0, +0.5, +0.3, +0.2, +0.1, +0.0, -0.1, -0.2, -0.3, -0.5, -1.0, -1.5, -2.0, -2.5,-3.0, -3.5, -4.0, -4.5, and -5.0. The grid of models cover the gravity range from log_g= 0.0 to +5.0 in steps of +0.5. The range in effective temperature from 3500 K to 50000 K is covered with an uneven grid (see Table A.3). The model spectra cover the ultraviolet (1000A) to infrared (10 microns) spectral range with non-uniform wavelength spacing (see Table A.4).

Table A.3: Grid of temperatures for the models

Temperature Range	Grid Step
K	K
3000 - 10000	250
10000 - 13000	500
13000 - 35000	1000
35000 - 50000	2500

Table A.4: Wavelength coverage for the models

Wavelength Range	Grid Step
microns	A
0.10 - 0.29	10
0.29 - 1.00	20
1.00 - 1.60	50
1.60 - 3.20	100
3.20 - 8.35	200
8.35 - 10.0	400

A.3 The HST/CDBS Version of the 1993 Kurucz Atlas

The atlas is divided in 19 independent subdirectories, according to metallicity. Within each subdirectory the stellar atmosphere models are given in STDAS multicolumn table format. Each table consist of 12 different columns, the first one containing the wavelength grid and each of the rest containing the spectrum of a star with the same effective temperature but different gravity, ranging from log_g= 0.0 to +5.0. Columns filled with zeros indicate that the model spectrum for that particular metallicity, effective temperature and gravity combination is not covered by the atlas.

The names of the table files are given as kszz_ttttt.fits where "k", for Kurucz, is the first letter of the atlas; "szz" is the metallicity of the model (zz) with its sign (s); and "ttttt" is the model's effective temperature, using four or five digits depending on the value. For instance, models for an effective temperature of 5000 K with log_Z= -0.5 and log_Z= +3.5 are indicated by ttttt= 5000, s= m, zz= 05 and ttttt= 5000, s= p, zz= 35, i.e. km05_5000.fits and kp35_5000.fits.

Within each individual table file, each column is named "gyy" where "yy" corresponds to 10*log_g. For example, log_g= +0.5 and log_g= +4.0 models are located in columns named g05 and g40, respectively.

See Table A.5 for an example of a standard header of a table file. In this example the name of the file is kp00_8000.fits and contains all the models for a star of metallicity log_Z= 0.0 and effective temperature T_{eff}= 8000 K. Models cover a range of gravities from log_g= +1.0 (g10 in the header) to log_g= +5.0 (g50 in the header). Models for gravities log_g= +0.0 and +0.5 are not available for this particular metallicity and effective temperature combination, and therefore do not appear listed in the header. Their corresponding columns (g00 and g05) are filled with zeros. The models are in FLAM surface flux units, i.e. ergs cm^{-2} s^{-1} A^{-1}.

Table A.5: Sample FITS Header from Kurucz 93 Model

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format defined in Astronomy and
COMMENT   Astrophysics Supplement Series v44/p363, v44/p371, v73/p359, v73/p365.
COMMENT   Contact the NASA Science Office of Standards and Technology for the
COMMENT   FITS Definition document #100 and other FITS information.
ORIGIN  = 'STScI-STSDAS/TABLES' / Tables version 1999-03-22
FILENAME= 'kp00_8000.fits'     / name of file
TEFF    =                 8000
LOG_Z   = 0.00000000000000E+00
HISTORY   g10
HISTORY   g15
HISTORY   g20
HISTORY   g25
HISTORY   g30
HISTORY   g35
HISTORY   g40
HISTORY   g45
HISTORY   g50
HISTORY   Kurucz model atmospheres (1993)
HISTORY   Fluxes tabulated in units of erg/s/cm^2/A
HISTORY   are surface fluxes. To transform to observed
HISTORY   fluxes multiply by (R/D)^2 where R is the
HISTORY   radius of the star and D the distance.
HISTORY   Each column in the table represents the
HISTORY   spectrum of a star for the same metallicity
HISTORY   and effective temperature but different gravity.
END
```

Physical fluxes of the spectra are given in FLAM surface flux units, i.e. ergs cm^{-2} s^{-1} A^{-1}. These flux units differ from those in the Kurucz CD-ROM by a factor of $3.336 \times 10^{-19} \times lambda^2 \times (4pi)^{-1}$, i.e. are converted from ergs cm^{-2} s^{-1} Hz^{-1} $steradian^{-1}$ to ergs cm^{-2} s^{-1} A^{-1}. To convert to observed flux at Earth, multiply by a factor of $(R/D)^2$ where R is the stellar radius, and D is the distance to Earth.

The names of the files located in each metallicity subdirectory are listed in the README file located in each subdirectory. The range in gravity covered by the models for the different temperatures is also indicated.

A.4 Use of Kurucz Atlas with SYNPHOT

Synphot tasks now permit the use of spectra selected from one of many columns in a single STSDAS table file. One does this by specifying as the "spectrum" parameter the name of the disk file (as before), and appending the name of the column containing the flux in brackets. Thus, to select any model spectrum characterized by a given metallicity, effective temperature, and gravity, specify a "spectrum" of the form: crgridk93$m_directory/kszz_ttttt.fits[gyy], where m_directory is the name of the subdirectory for a given metallicity. For example, to select the spectrum of a star with a metallicity of +0.1, a temperature of 10,000 K, and log gravity of 3.0, the specification would be: crgridk93$kp01/kp01_10000.fits[g30].

Alternatively, one may select a model spectrum within a **synphot** expression using the function **icat** (which interpolates between the nearest matching models) or **cat** (which simply selects the closest match). The syntax for the Kurucz models is icat(k93models,T_{eff},metallicity,logG). See Appendix A.4 for an example that includes the use of this function.

The **icat** task can give incorrect results without warning if it is used at the edges of the defined grid of models. See above for a discussion of the available ranges for these values, and exercise caution when selecting a value near one of the extremes.

Please note that the model spectra in the atlas are in surface flux units. Thus, if the number of counts or the calculated absolute flux is needed, the model spectrum must be renormalized appropriately. One can do this in **synphot** with the "rn" function.

Since the entire atlas occupies close to 70MB of disk space, many applications could be satisfied by a copy of the solar metallicity spectra, only.

A list of solar metallicity stars of different spectral types and luminosity classes together with their closest Kurucz model spectrum is presented in Table A.6. The physical parameters, T_{eff} and log_g, characterizing each star are taken from Schmidt-Kaler's compilation of physical parameters of stars (Schmidt-Kaler 1982, Landolt-Bornstein VI/2b). The U-B and B-V colors of the closest model agree with the characteristic color of each star (see Schmidt-Kaler 1982) to better than 0.06 magnitude.

Table A.6: Suggested models for specific stellar types

Type	T_{eff}	log_g	Kurucz model
O3V	52500	+4.14	kp00_50000[g50]
O5V	44500	+4.04	kp00_45000[g50]
O6V	41000	+3.99	kp00_40000[g45]
O8V	35800	+3.94	kp00_35000[g40]
B0V	30000	+3.9	kp00_30000[g40]
B3V	18700	+3.94	kp00_19000[g40]
B5V	15400	+4.04	kp00_15000[g40]
B8V	11900	+4.04	kp00_12000[g40]
A0V	9520	+4.14	kp00_9500[g40]
A5V	8200	+4.29	kp00_8250[g45]
F0V	7200	+4.34	kp00_7250[g45]
F5V	6440	+4.34	kp00_6500[g45]
G0V	6030	+4.39	kp00_6000[g45]
G5V	5770	+4.49	kp00_5750[g45]
K0V	5250	+4.49	kp00_5250[g45]
K5V	4350	+4.54	kp00_4250[g45]
M0V	3850	+4.59	kp00_3750[g45]
M2V	3580	+4.64	kp00_3500[g45]
M5V	3240	+4.94	kp00_3500[g50]
B0III	29000	+3.34	kp00_29000[g35]
B5III	15000	+3.49	kp00_15000[g35]
G0III	5850	+2.94	kp00_5750[g30]
G5III	5150	+2.54	kp00_5250[g25]
K0III	4750	+2.14	kp00_4750[g20]
K5III	3950	+1.74	kp00_4000[g15]
M0III	3800	+1.34	kp00_3750[g15]
O5I	40300	+3.34	kp00_40000[g45]
O6I	39000	+3.24	kp00_40000[g45]
O8I	34200	+3.24	kp00_34000[g40]
BOI	26000	+2.84	kp00_26000[g30]
B5I	13600	+2.44	kp00_14000[g25]
AOI	9730	+2.14	kp00_9750[g20]
A5I	8510	+2.04	kp00_8500[g20]
F0I	7700	+1.74	kp00_7750[g20]
F5I	6900	+1.44	kp00_7000[g15]
G0I	5550	+1.34	kp00_5500[g15]
G5I	4850	+1.14	kp00_4750[g10]
K0I	4420	+0.94	kp00_4500[g10]
K5I	3850	+0.34	kp00_3750[g05]
M0I	3650	+0.14	kp00_3750[g00]
M2I	3450	-0.06	kp00_3500[g00]

A.5 Bruzual Spectrum Synthesis Atlas

Gustavo Bruzual has provided 77 stellar spectra frequently used in synthesis of galaxy spectra. They are available in directory `crgridbz77$` and are stored in 77 individual tables called `bz_`*nn*`.fits`, where *nn* runs from 1 to 77. A list of the file names and spectral types is shown in Table A.7.

Table A.7: Bruzual Synthetic Spectral Atlas

File	Type	File	Type	File	Type
bz_1	O5 V	bz_31	K9 V	bz_61	M4 III
bz_2	O7 V	bz_32	M0 V	bz_62	M5 III
bz_3	O8 V	bz_33	M1 V	bz_63	M6 III
bz_4	O9 V	bz_34	M2 V	bz_64	O7 I
bz_5	B0 V	bz_35	M6 V	bz_65	O9.5 I
bz_6	B1 V	bz_36	O8 III	bz_66	B0 I
bz_7	B2 V	bz_37	O9 III	bz_67	B0.5 I
bz_8	B3 V	bz_38	B0.5 III	bz_68	B5 I
bz_9	B5 V	bz_39	B1 III	bz_69	B8 I
bz_10	B7 V	bz_40	B2 III	bz_70	A2 I
bz_11	B8 V	bz_41	B5 III	bz_71	F0 I
bz_12	B9 V	bz_42	B7 III	bz_72	F2 I
bz_13	A0 V	bz_43	B8 III	bz_73	F8 I
bz_14	A1 V	bz_44	B9.5 III	bz_74	G0 I
bz_15	A2 V	bz_45	A0 III	bz_75	G2 I
bz_16	A3 V	bz_46	A2 III	bz_76	G8 I
bz_17	A5 V	bz_47	A3 III	bz_77	M1M2 I
bz_18	A7 V	bz_48	A5 III		
bz_19	F2 V	bz_49	A7 III		
bz_20	F5 V	bz_50	F0 III		
bz_21	F6 V	bz_51	G0 III		
bz_22	F7 V	bz_52	G8 III		
bz_23	F8 V	bz_53	G9 III		
bz_24	G0 V	bz_54	K0 III		
bz_25	G1 V	bz_55	K2 III		
bz_26	G2 V	bz_56	K5 III		
bz_27	G5 V	bz_57	K6 III		
bz_28	K0 V	bz_58	M0 III		
bz_29	K3 V	bz_59	M1 III		
bz_30	K5 V	bz_60	M3 III		

A.6 Gunn-Stryker Spectrophotometry Atlas

This is an optical spectrophotometric catalog of 175 stars covering a complete range of spectral types and luminosity classes from the observations of Gunn and Stryker (1983). The spectra cover the wavelength range 3130 to 10800 Å and are located in the directory `crgridgs$`. The list of stars contained in this atlas is identical to the BPGS atlas, and are shown in Table A.8. Note that when referring to Table A.8 for the names of files in the Gunn-Stryker atlas, the names are of the form `gs_`*`nnn`*`.fits`, instead of `bpgs_`*`nnn`*`.fits`.

A.7 Bruzual-Persson-Gunn-Stryker Spectrophotometry Atlas

This is an extension of the Gunn-Stryker optical atlas where the spectral data have been extended into both the UV and the infrared. They are available as 175 STSDAS tables in the directory `crgridbpgs$`. The IR data are from Strecker et al. (1979) and other unpublished sources. The IR and optical data were tied together by the *V–K* colors.

Note that the spectral data for all of the stars in this atlas have been arbitrarily renormalized to a *V* magnitude of zero. Therefore in order to use these data for calculations of absolute photometry they must be renormalized to their appropriate absolute levels.

▽ The magnitudes and colors stored in header keywords in each of the tables in this atlas are *not* on the standard *UBVRI* system. They are “scanner” magnitudes and colors that were synthesized by the authors from the observed spectra (see Gunn and Stryker 1983).

The file names, star names, and spectral types for the BPGS atlas are listed in Table A.8.

Table A.8: Bruzual-Persson-Gunn-Stryker Spectral Atlas

File	Star	Type	File	Star	Type
bpgs_1	9 SGR	O5	bpgs_35	HD 35296	F8 V
bpgs_2	9 SGE	O8 F	bpgs_36	BD +26 3780	G0 V
bpgs_3	HR 8023	O6	bpgs_37	HD 148816	F9 V
bpgs_4	BD -01 0935	B1 V	bpgs_38	HD 155675	F8 V
bpgs_5	60 CYG	B1 V	bpgs_39	PRAESEPE 418	
bpgs_6	102 HER	B2 V	bpgs_40	HYAD 1	
bpgs_7	ETA HYA	B3 V	bpgs_41	HD 122693	F8 V
bpgs_8	IOTA HER	B3 V	bpgs_42	HD 154417	F8 V
bpgs_9	HR 7899	B4 V	bpgs_43	HYAD 2	
bpgs_10	38 OPH	A1 V	bpgs_44	HD 227547	G5 V
bpgs_11	HR 7174	B6 V	bpgs_45	HD 154760	G2 V
bpgs_12	9 VUL	B7 V	bpgs_46	HD 190605	G2 V
bpgs_13	HD 189689	B9 V	bpgs_47	HYAD 15	
bpgs_14	THETA VIR	A0 V	bpgs_48	HD 139777A	K0 V
bpgs_15	NU CAP	B9 V	bpgs_49	HD 136274	G8 V
bpgs_16	HR 6169	A2 V	bpgs_50	HYAD 26	
bpgs_17	HD 190849A	A1 V	bpgs_51	HD 150205	G5 V
bpgs_18	69 HER	A2 V	bpgs_52	HYAD 21	
bpgs_19	HD 190849B	A3 V	bpgs_53	BD +02 3001	G8 V
bpgs_20	58 AQL	A0 V	bpgs_54	HD 190571	G8 V
bpgs_21	78 HER	B9 V	bpgs_55	HYAD 183	
bpgs_22	HR 6570	A7 V	bpgs_56	HD 190470	K3 V
bpgs_23	HD 187754	A2 V	bpgs_57	HD 154712	K4 V
bpgs_24	THETA1 SER	A5 V	bpgs_58	HYAD 185	
bpgs_25	PRAESEPE 276		bpgs_59	BD +38 2457	K8 V
bpgs_26	PRAESEPE 114		bpgs_60	HYAD 173	
bpgs_27	PRAESEPE 154		bpgs_61	GL 40	M0 V
bpgs_28	HD 190192	A5 V	bpgs_62	HYAD 189	
bpgs_29	PRAESEPE 226		bpgs_63	HD 151288	K7 V
bpgs_30	PRAESEPE 37		bpgs_64	HD 157881	K7 V
bpgs_31	HD 191177	F4 V	bpgs_65	HD 132683	M0 V
bpgs_32	PRAESEPE 332		bpgs_66	GL 15A	M0 V
bpgs_33	BD +29 3891	F6 V	bpgs_67	GL 49	M2 V
bpgs_34	PRAESEPE 222		bpgs_68	GL 109	M4 V

Table A.8: Bruzual-Persson-Gunn-Stryker Spectral Atlas

File	Star	Type	File	Star	Type
bpgs_69	GL 15B	M6 V	bpgs_104	HD 56176	G7 IV
bpgs_70	GL 83.1	M8 V	bpgs_105	HD 227693	G5 IV
bpgs_71	GL 65	M5 V	bpgs_106	HD 199580	K2 IV
bpgs_72	HR 7567	B1 IV	bpgs_107	HD 152306	G8 III
bpgs_73	HR 7591	B2 III	bpgs_108	PRAESEPE 212	
bpgs_74	20 AQL	B3 IV	bpgs_109	THETA1 TAU	G8 III
bpgs_75	HR 7467	B3 III	bpgs_110	HD 170527	G5 IV
bpgs_76	IOTA LYR	B7 IV	bpgs_111	HD 136366	K0 III
bpgs_77	HR 7346	B7 III	bpgs_112	HD 191615	G8 IV
bpgs_78	59 HER	A3 III	bpgs_113	HD 124679	K0 III
bpgs_79	HR 6642	A0 IV	bpgs_114	HD 131111	K0 III
bpgs_80	11 SGE	B9 IV	bpgs_115	HD 113493	K0 III
bpgs_81	60 HER	A3 IV	bpgs_116	HD 4744	G8 IV
bpgs_82	HD 192285	A4 IV	bpgs_117	HD 7010	K0 IV
bpgs_83	ALPHA OPH	A5 III	bpgs_118	46 LMI	K0 III
bpgs_84	HD 165475B	A5 IV	bpgs_119	91 AQR	K0 III
bpgs_85	HD 165475	A5 IV	bpgs_120	M67 F141	
bpgs_86	XI SER	F0 IV	bpgs_121	HR 8924A	K3 III
bpgs_87	HD 5132	F0 IV	bpgs_122	HD 140301	K0 IV
bpgs_88	HD 508	A9 IV	bpgs_123	HD 95272	K0 III
bpgs_89	HD 210875	F0 IV	bpgs_124	HD 72184	K2 III
bpgs_90	RHO CAP	F2 IV	bpgs_125	HD 119425	K2 III
bpgs_91	HD 7331	F7 IV	bpgs_126	HD 106760	K1 III
bpgs_92	BD +63 0013	F5 IV	bpgs_127	PSI UMA	K1 III
bpgs_93	HD 13391	G2 IV	bpgs_128	PHI SER	K1 III
bpgs_94	HD 154962	G8 IV	bpgs_129	HD 136514	K3 III
bpgs_95	HD 192344	G4 IV	bpgs_130	MU AQL	K3 III
bpgs_96	HR 6516	G6 IV	bpgs_131	HR 5227	K2 IIIp
bpgs_97	HR 7670	G6 IV	bpgs_132	HD 154759	K3 III
bpgs_98	HD 128428	G3 IV	bpgs_133	20 CYG	K3 III
bpgs_99	31 AQL	G8 IV	bpgs_134	ALPH SER	K2 III
bpgs_100	BD -02 4018	G5 IV	bpgs_135	MU LEO	K2 III
bpgs_101	M67 F143?		bpgs_136	BD +01 3131	K0 III
bpgs_102	HD 11004	G5 IV	bpgs_137	M67 F170	
bpgs_103	HD 173399A	G5 IV	bpgs_138	18 LIB A	K2 IIIp

Table A.8: Bruzual-Persson-Gunn-Stryker Spectral Atlas

File	Star	Type	File	Star	Type
bpgs_139	BD +28 2165	K1 IV	bpgs_161	BD -01 3097	M2 III
bpgs_140	NGC 188 1-69		bpgs_162	TX DRA	
bpgs_141	BD +30 2344	K3 III	bpgs_163	Z CYG	M8 III
bpgs_142	HD 83618	K3 III	bpgs_164	BD +01 3133	M5 III
bpgs_143	HD 158885	K3 III	bpgs_165	BD -02 3886	M5 III
bpgs_144	HD 166780	K5 III	bpgs_166	W HER	M6 III
bpgs_145	HD 148513	K4 III	bpgs_167	TY DRA	M8
bpgs_146	M67 T626		bpgs_168	SW VIR	M7 III
bpgs_147	HD 127227	K5 III	bpgs_169	RZ HER	M6 III
bpgs_148	M67 IV-202		bpgs_170	R LEO	
bpgs_149	HD 50778	K4 III	bpgs_171	AW CYG	N
bpgs_150	HD 62721	K5 III	bpgs_172	WZ CAS	N
bpgs_151	HD 116870	M0 III	bpgs_173	69 CYG	B0 Ib
bpgs_152	HD 60522	M0 III	bpgs_174	HR 7699	B5 Ib
bpgs_153	BD -01 3113	K5 III	bpgs_175	HR 8020	B8 Ia
bpgs_154	BD +02 2884	K5 III			
bpgs_155	BD -02 3873	M0 III			
bpgs_156	HD 104216	M2 III			
bpgs_157	HD 142804	M1 III			
bpgs_158	HD 30959	M3 III			
bpgs_159	HD 151658	M2 III			
bpgs_160	BD -02 4025	M2 III			

A.8 Jacoby-Hunter-Christian Spectophotometry Atlas

This is an optical spectrophotometric atlas of 161 stars having spectral classes O through M and luminosity classes V, III, and I and are from the observations of Jacoby, Hunter, and Christian (1984). The spectra cover the wavelength range 3510 to 7427 Å at a resolution of approximately 4.5 Å. The spectra are available in STSDAS tables in the directory `crgridjac$`. The file names, star names, and spectral types for the JHC atlas are listed in Table A.9 .

Table A.9: Jacoby-Hunter-Christian Spectral Atlas

File	Star	Type	File	Star	Type
jc_1	HD 242908	O5 V	jc_35	SAO 57199	F6 V
jc_2	HD 215835	O5.5 V	jc_36	HD 24189	F6 V
jc_3	HD 12993	O6.5 V	jc_37	HD 5702	F7 V
jc_4	HD 35619	O7 V	jc_38	HD 107132	F7 V
jc_5	HD 44811	O7.5 V	jc_39	HD 107214	F7 V
jc_6	HD 242935	O8 V	jc_40	HD 6111	F8 V
jc_7	HD 236894	O8 V	jc_41	HD 31084	F9 V
jc_8	HD 17520	O9 V	jc_42	HD 107399	F9 V
jc_9	HD 12323	O9 V	jc_43	HD 28099	G0 V
jc_10	BD +62 0249	O9.5 V	jc_44	HD 17647	G1 V
jc_11	HD 158659	B0 V	jc_45	HD 66171	G2 V
jc_12	HD 237007	B0 V	jc_46	BD +58 1199	G3 V
jc_13	HD 35215	B1.5 V	jc_47	Tr A14	G4 V
jc_14	HD 37767	B3 V	jc_48	HD 22193	G6 V
jc_15	FEIGE 40	B4 V	jc_49	HD 27685	G7 V
jc_16	HD 240344	B4 V	jc_50	HD 33278	G9 V
jc_17	HD 30584	B6 V	jc_51	HD 29050	G9 V
jc_18	O 1015	B8 V	jc_52	HD 23524	K0 V
jc_19	HD 116608	A1 V	jc_53	HD 5351	K4 V
jc_20	FEIGE 41	A1 V	jc_54	SAO 76803	K5 V
jc_21	HD 124320	A2 V	jc_55	HD 260655	M0 V
jc_22	FEIGE 28	A2 V	jc_56	BD +63 0137	M1 V
jc_23	HD 190785	A2 V	jc_57	YALE 1755	M5 V
jc_24	HD 221741	A3 V	jc_58	HD 13505	F0 IV
jc_25	HD 9547	A5 V	jc_59	HD 83140	F3 IV
jc_26	HD 21619	A6 V	jc_60	HD 78277	G2 IV
jc_27	HD 23863	A7 V	jc_61	HD 70178	G5 IV
jc_28	HD 111525	A7 V	jc_62	HD 227018	O6.5 III
jc_29	HD 9972	A8 V	jc_63	SAO 11810	O7.5 III
jc_30	HD 23733	A9 V	jc_64	HD 191978	O8.5 III
jc_31	HD 10032	F0 V	jc_65	HD 16429	O9.5 III
jc_32	Hz 948	F3 V	jc_66	HD 13494	B1 III
jc_33	HD 23511	F4 V	jc_67	HD 12727	B2 III
jc_34	Hz 227	F5 V	jc_68	O 2311	B2 III

Table A.9: Jacoby-Hunter-Christian Spectral Atlas (Continued)

File	Star	Type	File	Star	Type
jc_69	SAO 11885	B2.5 III	jc_104	HD 110964	M4 III
jc_70	HD 166125	B3 III	jc_105	SAO 62808	M5 III
jc_71	HD 39136	B4 III	jc_106	HD 14357	B2 II
jc_72	HD 56183	B4 III	jc_107	BD -14 4956	B2 II
jc_73	HD 256413	B5 III	jc_108	BD -00 3227	F5 II
jc_74	BD +61 0339	B7 III	jc_109	HD 249384	G8 II
jc_75	HD 28696	B8 III	jc_110	HD 250368	G9 II
jc_76	HD 20023	B9 III	jc_111	HD 249826	K6 II
jc_77	HD 12027	A3 III	jc_112	BD +19 1947	M3 II
jc_78	HD 240296	A6 III	jc_113	BD +36 1963	M7 II
jc_79	HD 12161	A8 III	jc_114	BD -11 4586	O8 I
jc_80	HD 64191	F0 III	jc_115	HD 225160	O8 I
jc_81	HD 5211	F4 III	jc_116	HD 16808	B0.5 Ib
jc_82	BD +61 0367	F5 III	jc_117	HD 167451	B0.5 Ib
jc_83	HD 56030	F6 III	jc_118	BD -14 5030	B1.5 Ia
jc_84	SAO 20603	F7 III	jc_119	HD 209678	B2 Ib
jc_85	HD 9979	F8 III	jc_120	SAO 20899	B3 I
jc_86	HD 15866	G0 III	jc_121	HD 192832	B5 Ia
jc_87	BD +30 2347	G0 III	jc_122	BD +61 0220	B7 I
jc_88	HD 25894	G2 III	jc_123	HD 17145	B8 Ia
jc_89	HD 2506	G4 III	jc_124	LSI V P24	B9 Ib
jc_90	BD +28 1885	G5 III	jc_125	HD 209900	A0 Ib
jc_91	HD 112872	G6 III	jc_126	SAO 11344	A0 Ib
jc_92	HD 26514	G6 III	jc_127	SAO 12149	A1 I
jc_93	HD 29883	G6 III	jc_128	42 LSI	A2 I
jc_94	HD 249240	G7 III	jc_129	SAO 87716	A3 Ia
jc_95	HD 245389	G8 III	jc_130	SAO 12096	A4 I
jc_96	SAO 55155	G9 III	jc_131	HD 9167	A7 I
jc_97	SAO 55164	K0 III	jc_132	HD 842	A9 I
jc_98	HD 33506	K2 III	jc_133	SAO 37370	F0 Ib
jc_99	SAO 77849	K2 III	jc_134	BD +58 0204	F2 I
jc_100	HD 26946	K3 III	jc_135	HD 12842	F3 I
jc_101	HD 21110	K4 III	jc_136	SAO 21536	F4 I
jc_102	SAO 21753	K7 III	jc_137	HD 9973	F5 Iab
jc_103	SAO 63349	M3 III	jc_138	HD 8992	F6 Ib

Table A.9: Jacoby-Hunter-Christian Spectral Atlas (Continued)

File	Star	Type	File	Star	Type
jc_139	HD 17971	F7 I	jc_151	SAO 23888	M1 I
jc_140	HD 187428	F8 Ib	jc_152	HD 13136	M2 Ib
jc_141	HD 25361	G0 Ia	jc_153	HD 94028	F4 V
jc_142	SAO 21446	G1 I	jc_154	SAO 102986	F7 V
jc_143	BD +56 0084	G2 I	jc_155	SAO 81292	M4.5 Ve
jc_144	HD 191010	G3 Ib	jc_156	HD 16691	O5 If
jc_145	HD 187299	G5 I	jc_157	HD 108	O6 If
jc_146	HD 186293	K0 I	jc_158	BD +40 4220	O7 If
jc_147	SAO 37325	K1 Ib	jc_159	HD 13256	B1 Ia
jc_148	HD 1069	K2 I	jc_160	HD 50064	B1 Ia
jc_149	HD 1400	K5 I	jc_161	BD +51 0710	B5 Ib
jc_150	HD 14330	M1 Iab			

A.9 Bruzual-Charlot Atlas

This is a library of galaxy spectra computed by Bruzual and Charlot using their Isochrone Synthesis Spectral Evolutionary Code. The December 1995 version of the Bruzual-Charlot atlas consists of 21 instantaneous bursts characterized by different IMF slope functions, and mass limits. Each instantaneous burst contains 221 spectral energy distributions (SEDs) corresponding to 221 time steps from 0 to 20 Gyr.

The spectra represent bursts characterized by a Salpeter initial mass function (IMF) with different ranges in lower and upper mass limits, and at several ages (10E5, 25E5, 50E5, 76E5, 10E6, 25E6, 50E6, 10E7, 50E7, 10E8, 50E8, 10E9 years) after the burst. Spectra for instantaneous and composite bursts are available. Each spectrum has 1187 wavelength points covering the 100 Angstroms to 100 microns wavelength range, and the fluxes are given in units of solar luminosity per Angstrom. The nebular contribution to the spectral energy distribution, i.e., emission lines and nebular continuum, is not included in the spectra.

The spectra have names of the form `bc95_a_XXXX` through `bc95_g_XXXX` and are located in the `crgrid$bc95/templates/` directory.

A.10 Kinney-Calzetti Atlas

This atlas consists of an homogeneous set of 12 spectral templates of galaxies covering the ultraviolet, optical and near-infrared wavelength range up to about 1 micron. Templates include various morphological types and starburst galaxies. The ultraviolet range of the spectral templates has been obtained with the large aperture (10" by 20") and low resolution spectrographs of the IUE satellite. The optical spectra were obtained through a long slit with a 10" width, where a window of 20" long was extracted to mach the IUE aperture.

The spectral templates cover various galaxy morphological types from elliptical to late type spiral. Starburst templates for low (E(B-V) < 0.10) to high (0.61 < E(B-V) < 0.70) internal extinction are also available. Several of the starburst galaxies used in the construction of the starburst templates are classified as irregulars. Thus, although irregular galaxies are not explicitly covered, the starburst templates can be used to cover this morphological type.

The flux of the spectral templates has been normalized to a visual magnitude of 12.5 (STMAG system). Details about each individual template can also be found in the header of the STSDAS binary file. The spectra are located in the `crgrid$kc96/` directory.

A.11 Buser-Kurucz Atlas of Model Atmospheres

Roland Buser has provided an extensive collection of Kurucz model atmosphere spectra covering a wide range in metallicity, effective temperature, and gravity. They are organized into several atlases, A, B, C, D, M, and S, located in the directory `crgridbk$`.

This atlas contains models computed by Kurucz in 1979. For a more complete and updated library of stellar atmosphere models, use the Kurucz 1993 atlas described above.

The BK atlas is a library of stellar flux spectra calculated by Kurucz and Buser from theoretical model atmospheres. The spectra were computed for a wide range of physical parameters, covering essentially the whole HR diagram observed for galactic stars. For all the spectra, fluxes are given mostly with a resolution of 25 Å on a uniform grid of wavelengths from the UV to the infrared. The BK atlas is thus especially suited for synthetic photometry applications (cf. Buser 1986, and references below), which also plays a major role in the calibration and the interpretation of HST observations (Koornneef et al. 1986). Therefore, the BK atlas has been implemented in the Calibration Data Base System (CDBS) at STScI.

The BK atlas consists of 1434 files, each of which represents a metal-line blanketed flux spectrum for a theoretical stellar model atmosphere. There files were prepared from two original data libraries, K1200 and BKLATE.

The K1200 library was computed by Kurucz (1979a,b) from his "ATLAS" model atmospheres for early-type (O to G) stars. The 1200 models were computed from three different versions of the "ATLAS" code, allowing for changes or improvements in the underlying physics, as shown in Table A.10:

Table A.10: Kurucz K1200 Library

Models	**Code/Description**	**Reference**
K1200 1- 284	A /ATLAS6 original	Kurucz 1979a
K1200 285- 609	APR/ATLAS6 purely radiative	Kurucz 1979b
K1200 610-1200	AIC/ATLAS6 improved convective	Kurucz 1979b

K1200 models 1–284, including their flux spectra, have been fully published by Kurucz (1979a), while models 285–1200 were described by Kurucz (1979b), and have been widely distributed but not published.

The BKLATE library was computed by Buser and Kurucz (1985, 1988, 1992) for late-type (F to K) stars from published as well as unpublished "GBEN" model atmospheres calculated by Gustafsson et al. (1975) and by Eriksson et al. (1979), respectively. Line-blanketed flux spectra were computed following the same procedure and employing the same opacity source input as in Kurucz (1979a). In particular, all the spectra were calculated using the extensive "KP" atomic line lists compiled by Kurucz and Peytremann (1975), and assuming a fixed turbulent velocity, vturb=2.00 km/s, and a fixed helium abundance, N(He)=0.10 (i.e., a number fraction of 10%). The BKLATE library data have not been published yet.

For convenient use, the BK atlas flux spectra have been subdivided into separate blocks (or sub-atlases) corresponding to the physical distinctions of their underlying model atmospheres, as described above. Table A.11 summarizes the structure of the atlas.

Table A.11: BK Atlas

Block	Source of Spectra	# of Spectra	Models + Opacity	T_{eff}	Log G	[M/H]
A	K1200	279	A +KP	5500–50000	0.00–5.00	0/–1/–2
B	K1200	323	APR +KP	8000–20000	1.00–4.50	1/.5/–.5/–1
C	K1200	590	AIC +KP	5500– 8500	0.00–4.50	1 to –9.99
D	BKLATE	233	GBEN +KP	3750– 6000	0.75–5.25	.5 to –3
S	K1200	3	A/AIC+KP	5770,9400	4.44,3.95	0
	BKLATE	1	GBEN +KP	5780	4.44	0
M	K1200	5	A/APR+KP	9400–10000	3.90–4.30	0/.5/1

Notice that within each of blocks A through D, models are available for ranges of usually uniformly spaced parameter values. Models are not available, however, for all possible combinations of parameter values. Block S contains models for two of the most prominent standard stars: three models of the Sun, and one model of Vega. Block M contains five miscellaneous models with special parameter combinations.

The file names in the `crgridbk$` directory are of the form `bk_`*mnnnn*`.fits`, where *m* is the block code (a, b, c, d, s, or m), and *nnnn* is a running sequence number within the block. Within each block, the individual models are ordered starting with the lowest metallicity, [M/H], temperature, T_{eff}, and surface gravity, log G, and with log G increasing fastest and [M/H] increasing most slowly. A complete listing of all the BK atlas model spectra can be found in the README file in the `crgridbk$` directory.

For all 1434 models in the BK atlas, flux spectra are given for the same set of 342 wavelengths as was used with the published Kurucz (1979a) models. Most of these wavelength points cover the range between 229 Å in the UV and about 2 microns in the IR, with spacings between 25 and 100 Å.

▽ Fluxes in the BK atlas tables, tabulated in units of `fnu`, are *surface* fluxes. Therefore, calculations of absolute luminosities for the BK atlas models require additional assumptions about the radii of the stars represented by the models.

A number of synthetic photometry applications have already been made using the BK atlas, mainly for the hotter Kurucz models from the K1200 library. A few pertinent references for theoretical calibrations of photometric systems are Lub and Pel (1977) for the Walraven *VBLUW* system, Buser and Kurucz (1978) for the Johnson *UBV* system, Relyea and Kurucz (1978) and Lester et al. (1986) for the Stromgren *uvby* system, and Buser and Kurucz (1988, 1992) for the Johnson-Cousins *UBVRI* system.

A.12 AGN Atlas

This atlas consists of a few spectral templates of AGNs ranging from LINER to Seyfert and bright QSO. The LINER and Seyfert 2 templates have been obtained with the large aperture (10" by 20") and low resolution spectrographs of the IUE satellite. The optical spectra were obtained through a long slit with a 10" width, where a window of 20" long was extracted to match the IUE aperture (Calzetti 1995, private comm.). The flux of the LINER and Seyfert2 templates is normalized to a Johnson visual magnitude of 12.5 (STMAG).

The Seyfert1 template consists of an UV spectrum obtained with the IUE low resolution spectrographs and of a ground-based optical spectrum. The bright QSO template is a composite spectrum from the Large Bright Quasar Survey of Francie and collaborators (1991). The Seyfert1 and QSO spectral templates are normalized to a Johnson blue magnitude of 12.5 (STMAG).

The NGC 1068 template is a composite spectrum. The continuum contains the nebular, stellar, and power-law contributions. The observed fluxes and FWHM of the UV, optical and near-IR emission lines are also incorporated into the template (J.R. Walsh, private comm; read also the header of the FITS table for further details).

The spectra are located in the `crgrid$agn/` directory.

A.13 Galactic Atlas

This atlas consists of model spectra of the Orion Nebula and of the NGC 7009 planetary Nebula.

The continuum of the Orion Nebula's template contains the nebular contribution plus a combination of Kurucz model atmospheres to simulate the stellar contribution. The fluxes of the UV, optical and near-IR emission lines from different sources are also incorporated into the template (J.R. Walsh, private comm.).

The continuum of the planetary nebula has a nebular component and a hot stellar component simulated by an 80000K black body. The fluxes of the UV, optical and near-IR emission lines, from different sources, are also incorporated into the template (J.R. Walsh, private comm.).

The spectra are located in the `crgrid$galactic/` directory.

Bibliography

Bessell, M.S., 1983, *PASP*, 95, 480.

Bessell and Brett ,1988, *PASP*, 100, 134.

Bohlin, R. C., Dickinson, M. E., & Calzetti, D. 2001, *AJ*, 122, 2118.

Bohlin, R.C. & Gilliland, R.L., 2004, *AJ*, 127, 3508.

Buser, R. and Kurucz, R.L., 1978, *A&A*, 70, 555.

Fukugita et al, 1996, "The Sloan Digital Sky Survey Photometric System", *AJ* 111, 1748.

Gunn, Hogg, Finkbeiner, and Schlegel, 2001, "Photometry White Paper", http://www.sdss.org/dr3/algorithms/sdssphot.ps.

Harris, H., Baum, W., Hunter, D. and Kreidl, T., 1991, *AJ*, 101, 677.

Holberg, J.B. & Bergeron, P., 2006, *AJ*, 132, 1221.

Johnson, H.L., 1965, *ApJ*, 141, 923.

Landolt, A.U., 1983, *AJ*, 88, 439.

Lub, J. and Pel, J.W., 1977, *A&A*, 54, 137.

Lupton, Gunn, & Szalay 1999, *AJ* 118, 1406.

Maíz Apellániz, J., 2006, *AJ*, 131. 1184.

Matsushima, S., 1969, *ApJ*, 158, 1137.

Oke, J.B., and Gunn, J.E., 1983, *ApJ*, 266, 713.

Schneider, D.P., Gunn, J.E., and Hoessel, J.G., 1983, *ApJ*, 264, 337.

Smith et al., 2000, *AJ*, 123, 2121.

van Duinen et al, 1975, *A&A*, v39, 1 p. 159-163.