CHAPTER 8: Calibration and Data Reduction

In This Chapter...

8.1 Calibration Observations and Reference Data

Standard calibration observations are obtained and maintained in the HST archive at the STScI, and can be obtained by external users using StarView. This includes those flat field, dark, and bias frames needed to operate the Post Observation Data Processing System (PODPS; sometimes called OPUS, and usually just called the "pipeline"), photometric calibration derived from standard star observations and the measured filter profiles, and derived determinations of the plate scale, distortion, and so on. The first set of these calibrations was provided to the STScI by the WFPC2 IDT from the Servicing Mission Observatory Verification (SMOV) and System Level Thermal Vacuum (SLTV) testing periods, and has been maintained and updated thereafter by the STScI with assistance from the IDT as part of the long term calibration program. For measurements requiring more precise calibrations, special calibration observations may need to be obtained as part of the observing proposal. Please consult the STScI WFPC2 Instrument Scientists for guidance if the routine calibration appears unlikely to support the requirements of a proposed observation. Individual GO programs requiring special calibrations must directly request these observations as part of their Phase I proposal.

A database of laboratory characterizations of optical components, CCD sensors, filters, and the flat field channel has been collected to support the instrument calibration. On-orbit pointed calibrations require large HST resources, taking time that could otherwise be used for direct scientific observations. They can also be unsatisfactory due to the limitations of the available astronomical reference sources. For WFPC2, the inherent stability and uniformity of the CCD sensors, the well calibrated filters, the internal flat field calibration system, and an archive populated with flat field images obtained in SLTV prior to launch improve the scientific data analysis and productivity. Hence the need for on-orbit calibrations has been minimized.

8.2 Flat Fields

The process of correcting for the effect of the variation in the sensitivity of the WFPC2 with field position is usually known as flat-fielding, or flattening. A "flat field" (an exposure of a spatially uniform source) needs to be observed through the telescope and desired filter. Real flat fields are always external; however, the WFPC2 has an internal calibration channel which produces a reasonably flat illumination pattern down to about 1800Å. This channel is used to monitor and correct for changes in the flat fields. The instrument flat field is also coarsely monitored using the internal flat channel, using exposures called INTFLATS. Flat fields in narrow bandpass filters are obtained using the sunlit Earth (Target = EARTH-CALIB) as part of routine calibration in order to provide an absolute reference for the internal calibrations (and remove the low frequency effects of variations in the OTA illumination pattern).

The Earth is an imperfect flat field target because it is too bright for the WFPC2 in the broad-band green and red filters. The rapid motion of the HST also creates streaks across the flat field images. The removal of the streaks requires the combination of multiple Earth observations with the streaks at different angles on the CCDs. An extensive discussion of the generation of Earth flat fields is available in Chapter 6 of the WF/PC-1 IDT OV/SV Report.

The flat field calibration system works by imaging an illuminated diffuser plate onto the WFPC2 exit pupil (relay secondary) by means of an MgF_2 lens. Two lamps provide optical and FUV illumination, providing a flat field which resembles the input beam from the OTA between 1600Å and 10000Å. During SLTV, flat fields were obtained using both the flat field calibration module and the WFPC2 optical stimulus (HST simulator), to generate a database of ratio images which link the internal flats to external flats.

The external stimulus flats have been updated by comparison against on-orbit streak flats, obtained for a small subset of narrow band filters (F375N, F502N and F953N). These were obtained during the initial in-flight calibration of the instrument, to effectively calibrate low frequencies in the internal flat-fielding source. Eventually, sky flats for the broad photometric filters will be made by combining many frames.

Flat fields have been obtained for all filters by combining information from SLTV test flats (which are good for all but the lowest spatial frequencies), and Earth flats in a limited number of filters (which fix the low frequency terms). The calibration channel monitors for time dependent changes in the flat fields, and none have been seen to date in the visible filters. Some redundancy is provided by the internal flat channel, but it does not form a part of the baseline calibration.

During early 1996 flat fields for many filters were updated using an improved illumination pattern derived from large numbers of streak flats. Corrections were typically ≤1%, though the outermost corner of WF2 showed a 7% correction. The improved flats compared very favorably with sky flats.

Note that the flat fields presently used in the pipeline are based on gain 14 data. The gain ratios are not constant from chip to chip, and therefore a small correction to photometric results derived from gain 7 data should be applied (see Table 4.3 on page 82). (See Biretta 1995 for further discussion of WFPC2 flat fields; also see the *HST Data Handbook*.)

8.3 Dark Frames

Dark frames are long exposures that are taken with no light incident on the CCDs. They are used to detect CCD counts (the dark current) caused by thermal generation (at the interfaces between the silicon and oxide layers), and the rate of charged particle and secondary radiation events. Estimated dark current and cosmic ray event rates are given in section 4.8, "Dark Backgrounds", on page 71 and section 4.9, "Cosmic Rays", on page 75, respectively. Observers are cautioned that the calibration provided by the pipeline may not use the most up-to-date dark frames (partly because constructing these may involve data taken after the observation). This matters because new hot pixels are being generated all the time. Data to construct improved super-darks is available in the archive with at least 5 long dark exposures being taken weekly.

8.4 Bias Frames

Bias frames are readouts of the CCDs without an exposure (so the dark current is negligible). They are used to measure the DC offset built into the signal chain which ensures that the ADC input is above zero. They fix the constant that is subtracted from the raw data prior to dark subtraction and flat fielding in Routine Science Data Processing (RSDP).

8.5 Data Reduction and Data Products

The routine processing of WFPC2 science data consists of the pipeline functions described below. The resulting images will be available on magnetic tape in FITS format, and as greyscale printouts. The reformatted raw data will also be available, along with the relevant calibration data. The *STSDAS Calibration Guide* should be consulted for a more complete description than the summary presented here.

The following data are supplied to observers on FITS tapes:

- Edited Image and DQF (uncalibrated): `d0h`,`.q0h`
- Standard Header Packet: `.shh`
- Extracted Engineering Data and DQF: `.x0h`,`.q1h`
- Trailer File (ASCII file): `.trl`
- Calibrated Image and DQF: `.c0h`,`.c1h`

In addition, a histogram file used for monitoring of the signal chain (`.c2h` file), and a calibration file which gives the throughput curve used in populating the photometric keywords (`.c3t` file) are included.

Further data reduction and analysis can be performed under the STScI's science data analysis software system (STSDAS). Standard routines are available, operating under IRAF, for the analysis of data for image photometry, spectral analysis, astrometry, and the generation of the calibration data files.

8.6 Pipeline Processing

The pipeline processing of WFPC2 data sets reformats the telemetry received from HST into group FITS format images, generates headers containing a large number of keywords taken from both the HST and WFPC2 telemetry streams, in addition to various STScI ground system databases, and applies the calibration described below. This calibration is done with a module known as "CALWP2" which is written in the IRAF SPP language and is available, in identical form, to users of the STSDAS system. Therefore, off-line recalibration of observations is fairly easy, and will use the same program as the PODPS system. Documentation is available in the *HST Data Handbook*, and the *STSDAS User's Guide*.

CALWP2 performs the following operations if required by the observation:

- ADC correction
- Bias level removal
- Bias image subtraction (depending on the gain channel in use)
- Dark image scaling and subtraction
- Shutter shading correction

- Flat field image correction
- Population of various photometric calibration keywords

In addition, the following conditions are flagged in the Data Quality File (DQF):

- Transmission failures and other possible failures
- Known bad pixels (e.g. blocked columns)
- Pixels at or above the maximum A/D converter level (i.e. saturated)
- Bad pixels in reference images

8.7 Fluxes and Standard Magnitudes

The pipeline calibrated data are not flux calibrated and the data are in units of Data Numbers (DN). However a flux calibration is implicit in the header. To get flux density, multiply DN by the value of the keyword PHOTFLAM in the calibrated (`.c0h`) science header file, and divide by the value of the keyword EXPTIME.

The magnitude of an object can be determined using the photometric zero-point keyword PHOTZPT as .

$$m = -2.5\log_{10}\left(PHOTFLAM \times \frac{DN}{EXPTIME}\right) + PHOTZPT$$

where *m* is in the STMAG system which is based on a spectrum with constant flux per unit wavelength set to roughly match the Johnson system at V. The more conventional systems are based on Vega's spectrum. Table 8.1 was generated using SYNPHOT to provide rough conversions to the Johnson UBVRI and Cousins RI systems. Typical uncertainties are 5%, and probably much worse for the U filter. The correction depends on the spectrum of the object, hence the table was generated using a wide range of Bruzual models.

For example, to convert to the Cousins I band for an object on WF4, get PHOTZPT=-21.1 and PHOTFLAM=2.6044 x 10^{-18} from the header. Then convert from WFPC2 counts to magnitudes in Cousins I using:

$$I_c = -2.5\log_{10}\left(2.6044 \times 10^{-18}\frac{DN}{EXPTIME}\right) - 21.2 - 1.21$$

Note that the Cousins I filter is much closer to the F814W filter than Johnson I, as shown by the nearly constant correction as a function of spectral type (i.e. color term).

Table 8.1: Conversion from STMAG to Johnson UBVRI and Cousins RI.

	U-F336W	B-F439W	V-F555W	R_J-F675W	I_J-F814W	R_C-F675W	I_C-F814W
O5V	0.53	0.67	0.05	-0.67	-1.11	-0.71	-1.22
B0V	0.46	0.66	0.05	-0.67	-1.13	-0.70	-1.22
A0V	-0.08	0.67	0.02	-0.68	-1.22	-0.67	-1.21
F2V	-0.03	0.62	-0.00	-0.69	-1.28	-0.63	-1.22
G0V	-0.02	0.58	-0.01	-0.70	-1.31	-0.60	-1.23
K0V	-0.10	0.53	-0.01	-0.69	-1.32	-0.58	-1.23
M0V	-0.04	0.43	-0.00	-0.78	-1.48	-0.54	-1.22
M6V	0.05	0.29	-0.03	-1.05	-1.67	-0.56	-1.21

This procedure will provide typical accuracies of about 0.05 mag (worse in the UV). More accurate photometry will require a variety of corrections (e.g., CTE effect, contamination and red leaks for the UV filters, variable gains on different chips, color terms, geometric distortions) which are discussed in detail in Holtzman et al. (P.A.S.P., 1995b).

8.8 Color Transformations of Primary Photometric Filters

The WFPC2 UBVRI system is fairly close as regards effective wavelengths to the Johnson UBVRI system, but cross-calibration is necessary to convert to Johnson magnitudes. See the IDT OV/SV Report and Harris et al., A.J. 101, 677 (1991) for examples in the case of WF/PC-1. Figures 8.1 through 8.5 show the results of regression fits between these two systems on the main sequence stars in the Bruzual, Persson, Gunn, Stryker atlas that is installed in the calibration database system (CDBS).

These fits should be used with caution for quantitative work. The zero-points in all cases are defined so that Vega's spectrum integrated over the bandpass is exactly magnitude zero (VEGAMAG in XCAL). The zero-points of the canonical Johnson-Cousins system differ from this by up to 0.02 magnitudes. The zero-points thus defined for the HST filters do not coincide with the STMAG definition used in the previous section. In addition, the ground based filter curves used, which are taken from Bessel (P.A.S.P. 102, 1181), give a good approximation to the standard Johnson-Cousins system, but are not as accurate as taking Landolt's curves and applying his color corrections to transform to the standard system. The latter procedure was used to derive the transformations

Figure 8.1: F336W-F439W against Johnson U-B for the BPGS atlas of MS dwarf spectra. The change in slope in the transformation for U-B greater than about 0.1 is due to red leak in the F336W filter. For hotter stars, the transformation is quite linear.

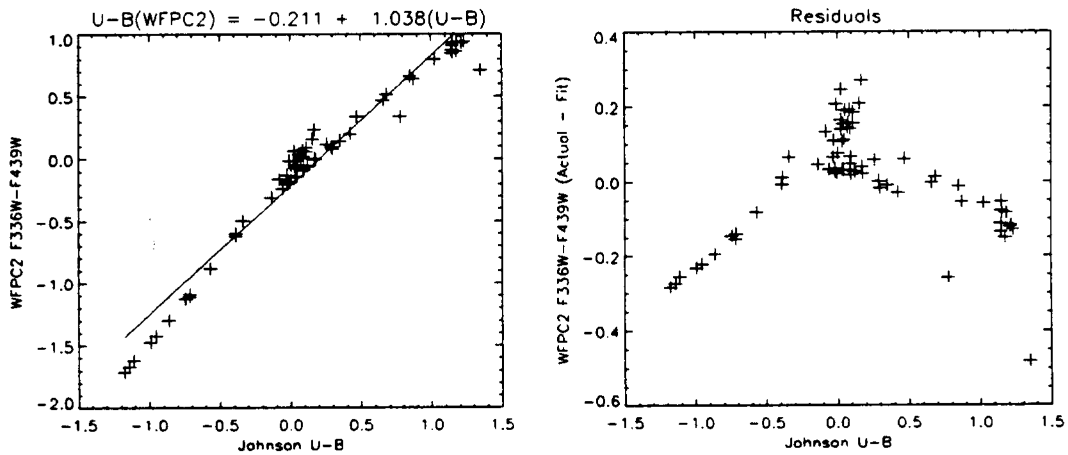


Figure 8.2: F439W-F555W against Johnson B-V. The residuals from the best linear fit are quite similar to those that apply if F569W (instead of the preferred F555W) is chosen for a WFPC2 passband.

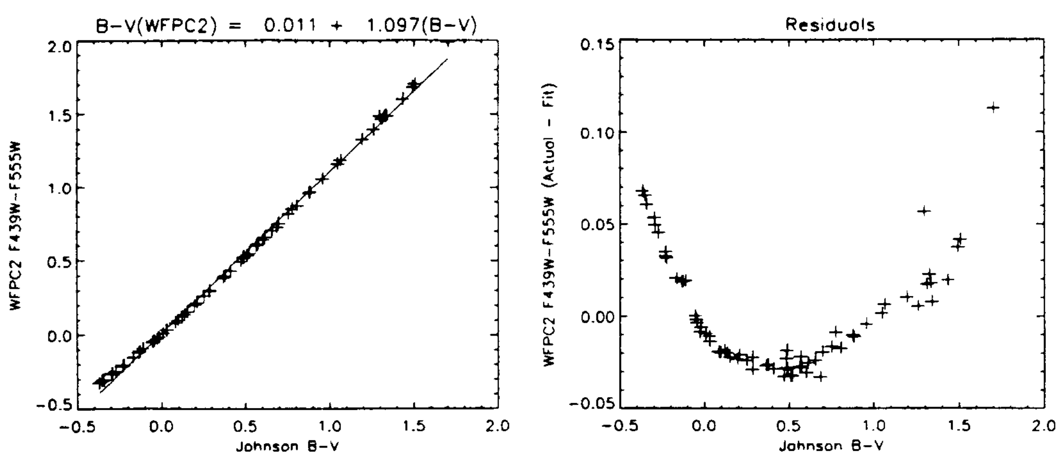


Figure 8.3: F555W-F814W against Johnson V-I_C. The residuals from the best linear fit are generally very small. This particular color combination is widely used.

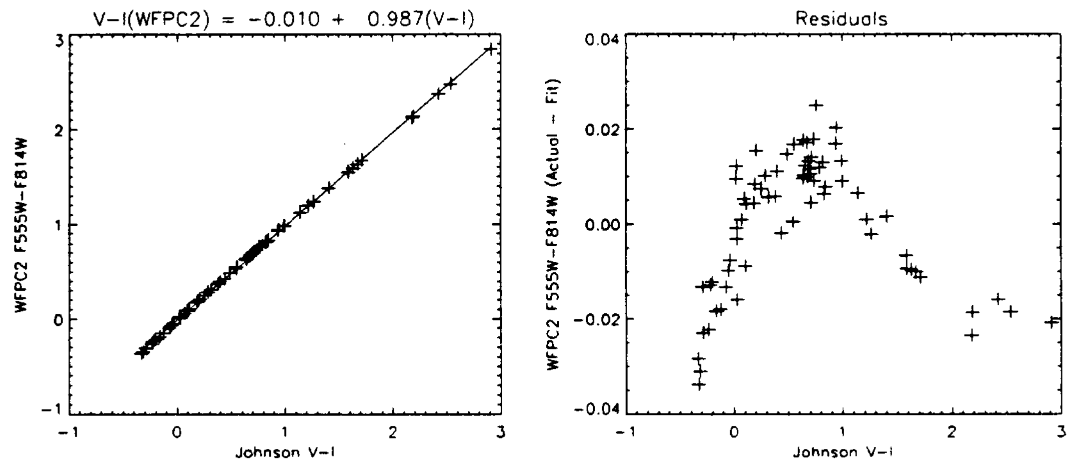
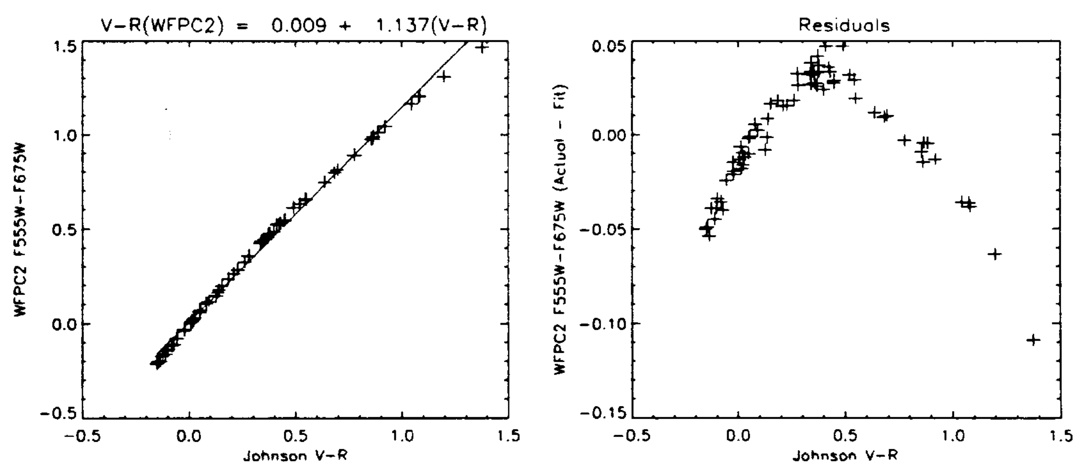
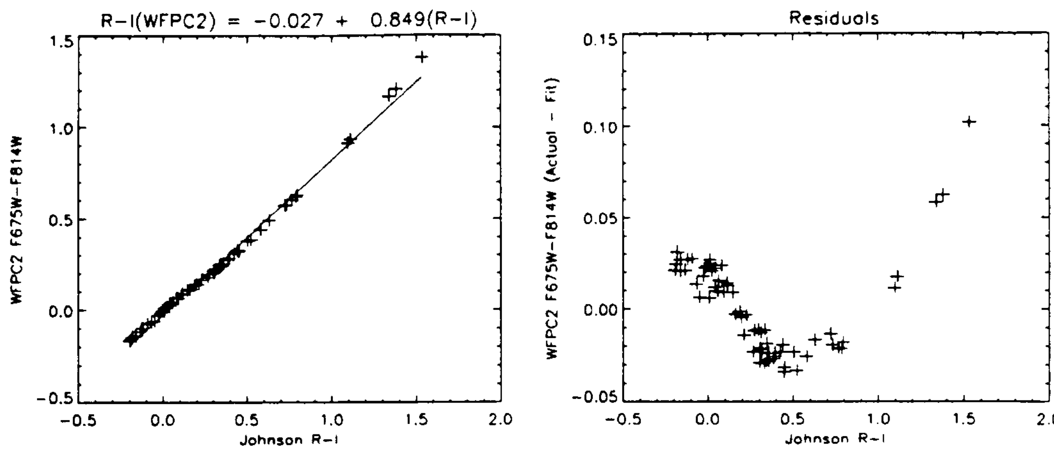


Figure 8.4: F555W-F675W against Johnson V-R_C. The residuals from the best linear fit are somewhat larger for blue stars than those that apply if F569W is chosen.



given in Holtzman et al. (P.A.S.P., 1995b), which also discusses the changes in the transformations that result from source spectrum variations (such as metallicity and gravity effects).

Figure 8.5: F675W-F814W against Cousins R_C-I_C. The residuals from the best linear fit are similar to those that apply if F791W is chosen for a WFPC2 I passband. For spectral type M8V and later (not shown) the transformation will not work as well.



8.9 Cycle 5 Calibration Plan

A summary of the Cycle 5 calibration plan follows as a general guide to the calibration and monitoring program in place for WFPC2. The full proposals are available through STScI's proposal status web page.

`http://presto.stsci.edu/public/propinfo.html`

The data that the calibration and monitoring program produces has no proprietary period and is available through the HST archive. In each case the proposal ID is given followed by its title, purpose, description, accuracy goals and products produced.

Calibration information obtained to date consists primarily of the System Level Thermal Vacuum (SLTV) tests, the initial on-orbit tests conducted in SMOV, and the Cycle 4 calibration. These tests have shown that the instrument is stable with some important exceptions and have provided an initial calibration sufficient for routine processing of most data.

The Cycle 5 calibration is designed to enable users to maximize the scientific usefulness of their data, while at the same time minimizing the use of spacecraft time. This is done by designing efficient proposals that:

- A) Improve the existing calibration - in particular towards the goal of 1% absolute photometric accuracy.
- B) Assess the accuracy of the existing and new calibrations.
- C) Recalibrate important known time variable features of the instrument.
- D) Calibrate some important instrumental effects that are not well understood.
- E) Monitor the instrument and telescope to ensure that no new problems or variability in their performance are missed.
- F) Maintain the instrument in a healthy state and ensure that in the event of partial instrumental failures, the calibration can be maintained when possible.

The calibration of the instrument must be seen in a larger context than simply preparing reference files for a pipeline reduction and assessing the errors in them. Several calibrations (such as geometric distortion, CTE correction, PSF calibration, chip-to-chip alignments, polarization calibration) are very important to some observers. Yet they are not included in the pipeline. Other things frequently need to be done to the data after it is ADC, bias, dark, and flat field corrected, with a photometric calibration included in the header. These other calibrations are made available to users through this Instrument Handbook, journal publications, instrument science reports, and postings linked to the Institute's WFPC2 WWW home page. The address is:

`http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_top.html`

A list of the most important calibrations consists of the following items:

1. Photometric zero-point. This involves converting DN values to flux units.
2. Photometric transformations. This involves converting DN values to magnitudes in standard systems. Two separate photometric calibrations can be used for this, a direct approach and a synthetic approach.
3. Photometric temporal variations. This is particularly important in the UV where significant variability is seen.
4. Photometric spatial variation (flat fields and CTE).
5. Dark current. This includes its time variability (hot pixels).
6. Bias.
7. Analog-to-Digital converter errors.
8. PSF. This is crucial for PSF fitting photometry, PSF subtraction, PSF modeling, and deconvolution efforts. Because PSF subtraction of very saturated sources is specialized to a few very diverse programs, PSF calibration in the image halo (beyond about 0.5 arcsecond) is not supported and must be requested with the program as a special calibration.
9. Polarization calibration.
10. Geometric calibration.

The program consists of 15 proposals which use a total of 63 orbits of spacecraft time (to be compared to a total of about 1550 orbits of approved GO time). The proposal summaries and their associated RPS2 files largely speak for themselves. Table 8.2 lists all of the proposal numbers, titles, the schedule for the calibration execution, an indication of whether the output forms part of the pipeline data reduction (CDBS) or provides other information, usually documented in Instrument Science Reports (ISR), the approximate calibration accuracy expected (see the summary forms for the interpretation of these numbers, because they are almost meaningless without a context), and the primary areas from the above 10 calibration types they address and in what ways (A-F from the above list). Therefore, if you are interested in a particular calibration, look for its number in the last column of the table, and then refer to the subsequent proposal summaries for more details.

Table 8.2: Summary of Cycle 5 Calibration Plans.

ID	Proposal Title	Schedule	Results	Accuracy	External Time (orbits)	Notes[a]
6179	Photomet. Zero.	Late 95	CDBS	1%	8	1ABE, 2AB
6182	Photomet. Trans.	9/95, 3/96	CDBS	2%	6	2ABE
6183	Decontamination	1x per 4 wks.	ISR	N/A	0	F
6184	Photometric Mon.	2x per 4 weeks	ISR	1%	24	3E
6186	UV Throughput	Early in Cyc. 5	CDBS	10%	6	1AB, 3C
6187	Earth Flats	Continuous	CDBS	1%	0	4ABE
6188	Darks	Weekly	CDBS	6%	0	5ABC
6189	Visflat Monitor	2x per 4 weeks	ISR	0.6%	0	4E
6190	Internal Flats	Early Cyc. 5	CDBS	0.6%	0	4F,7E
6191	UV flats	2x in Cyc. 5	ISR	2%	0	4ABE
6192	CTE Calibration	Early Cyc. 5	TIPS	<1%	4	4ABD
6193	PSF	CTE+2m	TIM	10%	5	8ABD
6194	Polarizers+Ramps	TBD	CDBS	3%+2%	8	9DE, 1AB
6195	Flat field Check	Late 95	CDBS	1%	2	4B
6250	Internal Monitor	2x per week	ISR	N/A	0	5,6,10F
	TOTALS				63	

a. Letters and numbers are keyed to lists in text.

6179: Photometric Zero-point

- **Purpose**: Set synthetic zero points of all WFPC2 filters.

- **Description**: GRW+70D5824 is observed through all filters not in the photometric calibration monitors and longward of F336W (inclusive). It is observed in both PC1 and WF3. This data-set is directly comparable to the corresponding results for Cycle 4 (program 5572). Because of possible errors in the spectrophotometry for this target, and in order to check synthetic color transformations over a reasonably wide range of colors, the observations are repeated with 3 red standards, and 2 other blue standards in WF3 only. This time, most of the 18 broad and medium bandpass filters longward of F336W are included (restricted to 1 orbit/target). If CTE calibration fails, this proposal may need to be run with preflash (and take more time or do less targets). This proposal is needed by all GO proposals that want to do quantitative photometry at the few percent level.
- **Accuracy**: Overall discrepancies between the synthetic photometric products and the results of this test should be reduced to 1% rms. Part of the point of the test is to measure this accuracy, which will largely depend on the accuracy of the spectrophotometric calibration sources.
- **Products**: After pipeline processing, each image will be reduced by aperture photometry to measure the throughput of each filter. These numbers can be directly compared to SYNPHOT predictions. Systematic differences will be corrected in the throughput database by tweaking the filter normalizations (already done for the primary target in Cycle 4), overall system response (which is quite uncertain particularly longward of 8000Å), and finally bandpass shapes. Residual differences will give an idea of the intrinsic accuracy of the calibration.

6182: Photometric Transformation

- **Purpose**: Update photometric transformations to Johnson-Cousins system.
- **Description**: A photometric standard star field in ω Cen is observed twice, once at the September 1994 orientation and once rotated by 180˚ degrees (to correct to first order for residual CTE effects). All broad and medium bandpass filters are used. Based on Cycle 4 program 5663, this proposal also gives a check on the long term full field photometric stability of the instrument.
- **Accuracy**: Independent of the synthetic photometry results this test gives direct transformations to the Johnson-Cousins system for a wide range of source colors (but excluding very blue stars). These transformations should be accurate to 2%. The stability of these transformations will be measured to the sub-percent level (because then errors in the ground based photometry do not enter significantly).
- **Products**: A comparison with the corresponding Cycle 4 monitor (which ran monthly) will verify the photometric stability of the camera. Direct transformations to the Johnson-Cousins photometry system can be derived for all filters. The observations also provide a check of the astrometric and PSF stability of the instrument over its full field of view.

6183: Decontamination

- **Purpose**: Remove UV blocking contaminants from CCD windows.
- **Description**: A sequence of observations is defined that is run twice - once before and once after a DECON when the CCDs are heated to +20˚C for 6 hours. The sequence consists of 2 bias frames at each gain setting, 5 1800 second darks, 2 INTFLATS through F555W at each gain, and two K-spot images. The observations are arranged so that the first sequence occurs about 33 hours before the DECON, and the second follows it by 12 hours. The proposal is run every 4 weeks. This is based on Cycle 4 program 5568 with bias frames added.
- **Accuracy**: This proposal is mainly designed to test aliveness, and monitor the instrument to ensure that no untoward effects from the DECON have occurred. It will identify all hot pixels that are annealed by the DECON.
- **Products**: The data is examined and checked for anomalies. The dark frames are processed to yield plots showing the growth and annealing of hot pixels.

6184: Photometric Monitor

- **Purpose**: Monthly external check of instrumental stability.
- **Description**: GRW+70D5824 is observed through F170W in all four chips. It is then observed in one chip for filters F160BW, F185W, F218W, F255W, F300W, F336W, F439W, F555W, F675W, F814W to fill out the orbit. The chip chosen is changed each month, so each chip is used three times during the year. One extra F555W exposure is taken through the PC to allow for focus monitoring. The proposal is run once before and once after each monthly decontamination, with the same chip selected. Based on Cycle 4 programs 5629 + 6143 + (5563) + 5564.
- **Accuracy**: Overall discrepancies between the results of this test should be less than 1% rms. The point of the test is to measure this variation.
- **Products**: After pipeline processing, each image will be reduced by aperture photometry to measure the throughput of the filters. These numbers can be directly compared to results for previous months. This will allow the long term performance of the instrument to be checked for changes, and verify that the decontaminations are satisfactory. This proposal will be run every 4 weeks in association with the DECON. Results reported in Baggett et al., WFPC2 ISR 96-02 and Whitmore, et al., WFPC2 ISR 96-04

6186: UV Throughput

- **Purpose**: Update SYNPHOT database for UV throughput.
- **Description**: GRW+70D5824 is observed shortly before and after a DECON through all of the UV filters in each chip and through F160BW crossed with F130LP, F185LP and F165LP (where applicable) to determine the wavelength dependence of the throughput across the bandpass (hence

color terms). Based on no particular Cycle 4 program, this program is designed to characterize better the spectral response curve in the UV, and the spectral shape introduced by the contamination.

- **Accuracy**: Overall discrepancies between the updated synthetic photometric products and the results of this test should be 1-2% rms. This does not mean that the UV throughput will be known to this accuracy, primarily because of uncertainties in the flux calibration of the standard used (5%), uncertainties in the UV flat fields (maybe 3% near the chip center), and time dependent contamination corrections (3% error), and uncertainties in the CTE correction (2%). The derived UV absolute photometric accuracy at the center of the chips should therefore be about 10%.
- **Products**: After pipeline processing, each image will be reduced by aperture photometry. The throughput curves and their normalizations can be updated by trial and error.

6187: Earth Flats

- **Purpose**: Generate flat fields.
- **Description**: 4 sets of 200 Earth streak-flats are taken to construct high quality narrow-band flat fields with the filters F375N, F502N, F656N, and F953N. Of these 200 perhaps 50 will be at a suitable exposure level for de-streaking. The resulting Earth superflats map the OTA illumination pattern, and will be combined with SLTV data (and calibration channel data in case of variation) for the WFPC2 filter set, to generate a set of superflats capable of removing both the OTA illumination and pixel-to-pixel variations in the flat field. In addition, more limited observations are made in F160BW and the broad bandpass photometric filters.

  The Cycle 4 plan is being largely repeated except: (1) UV filters are dropped because the measurement is generally only of the red leak. (2) F160BW is retained in order to check for developing pinholes. (3) Crossed filters used as neutral densities are eliminated (illumination pattern is wrong). (4) An attempt will be made to schedule some broad bandpass measurements on the dark Earth. This is based on Cycle 4 programs 5570 + 5571 + 6142.
- **Accuracy**: Overall accuracy of the flats derived from this test and the corresponding Cycle 4 observations should be below 1% RMS. Discrepancies between the results of this test and those from Cycle 4 should be 1% RMS. Differences between the two datasets analyzed separately will measure the flat field variability to this level. This data, together with the flat field check proposal should enable similar accuracy in the broad bandpass flats.
- **Products**: This proposal provides medium and narrow bandpass streak flats which can be combined with the high frequency information in the TV flats to yield accurate flat fields. The ratio of the TV and derived flats provides a correction that can also be applied to the TV broad bandpass data. We may also get broad band flat fields directly for comparison from the sky or from this proposal's exposures on the Earth's shadow.

6188: Darks

- **Purpose**: Provide dark frames for pipeline reduction, and hot pixel lists.
- **Description**: 5 dark frames are taken every week to provide ongoing calibration of the CCD dark current rate and to monitor the characteristics and the evolution of hot pixels. Over an extended period, these data provide a monitor of radiation damage to the CCDs. The dark frames will be obtained with the CLOCKS=OFF. In addition, 4 darks are taken per month with CLOCKS=ON (although there is no effect such as amplifier glow expected from running the serial register for these CCDs).

  Changes from the Cycle 4 program 5562 are that each group of 5 darks is constrained to be taken within a 2-day period, in order to simplify the data analysis (because fewer new hot pixels are involved), and the CLOCKS=ON exposures have been added.
- **Accuracy**: The accuracy of the super-dark computed from these data depends on the number of frames combined. The present practice is to combine them in groups of 10 frames for pipeline super-darks. This gives a median signal-to-noise of 16 and higher signal-to-noise on hotter pixels than the median (with the somewhat shaky assumption that the dark noise is Poisson). This means that the residual systematic error after super-dark subtraction on an 1800-second exposure is about 3 electrons - much less than the read noise. In principle, this residual can be further reduced to 0.4 electrons if a super-dark is generated from all of the dark frames, with suitable masking based on hot pixel lists.
- **Products**: The data is grouped into sets of 10 frames every two weeks. These are combined into super-darks for use in the pipeline. In addition, hot pixel lists can be generated with a time resolution of one week.

6189: VISFLAT Monitor

- **Purpose**: Monitor internal flat fields of instrument.
- **Description**: All use of the VISFLAT channel is concentrated in this proposal. It is based on Cycle 4 programs 5568 and 5655. The program takes one complete set of exposures using the visible calibration channel lamp (VISFLATS) at the start of the cycle through all visible filters. Monthly, VISFLATS will be obtained with the photometric filter set (F336W, F439W, F555W, F675W, and F814W) both before and after the DECON. A monthly VISFLAT exposure with the Wood's filter, F160BW, allows its visible transmission to be monitored. Two monthly VISFLAT exposures obtained through the LRF (FR533N), one at each gain, provide a monitor of the ADC's performance. The VISFLAT exposures should be packed together to optimize use of each lamp-on cycle.
- **Accuracy**: The internal flats, when well exposed, are each accurate to 0.6% in terms of the pixel-to-pixel (high frequency) variations in the CCDs. Thus, high frequency flat field stability can be verified to 1%. When the results from several filters are combined it will be possible to check that the CCDs are indeed relatively stable to much better than 1%.

- **Products**: The complete filter-set sweep will be compared to the corresponding Cycle 4 data-set primarily to verify that none of the filters are developing problems. Ratios of these flats will primarily indicate the stability of the channel itself, unless there are strong variations from filter to filter. Unless time dependence in the filters is seen, it is likely that flat fields for pipeline calibration will continue to be made by combining Earth-flat, SLTV-flats, and eventually sky-flats.

  The bi-monthly photometric filter-set observations will be used to monitor WFPC2's flat field response and to build a high S/N flat field database (primarily useful in tracking any changes in the pixel-to-pixel response of the instrument and any possible long term contamination induced changes). Histograms generated from the ramp filter flats will be used to trace the ADC transfer curve. F160BW can be checked monthly for pinholes. Results reported in Stiavelli and Baggett, WFPC2 ISR 96-01.

6190: Internal Flats

- **Purpose**: Provide backup database of INTFLATS, in case VISFLAT channel fails.
- **Description**: Based on Cycle 4 program 5568. A complete set of illuminated shutter blade flats (INTFLATS) is taken close to the complete set of VISFLATS. Each filter is exposed on each shutter blade (A or B) at each gain setting (7 or 15). Thus, there are 4 exposures per filter which should be uninterruptedly sequenced as (A7, A15, B15, B7). There is a possible concern on thermal control, where an out-of-limit condition was almost reached when 5568 was run. This will be avoided by spacing the exposures suitably.
- **Accuracy**: The signal-to-noise per pixel is similar to that obtained in the VISFLAT program (0.6%) but there are much larger spatial and wavelength variations in the illumination pattern. As a result, this data-set will not form any part of the pipeline calibration. This baseline is necessary in case the VISFLAT channel fails, and there are temporal variations in the camera flat fields at the 1% level. The test does give a good measurement of the gain ratios and their stability, which should be accurate to much better than 1%, when all of the data is analyzed.
- **Products**: INTFLAT/VISFLAT ratios can be generated if there is a failure in the calibration channel. Gain ratios and stability will be assessed. Results reported in Stiavelli and Baggett, WFPC2 ISR 96-01.

6191: UV Flats

- **Purpose**: Use UV calibration channel to monitor long term internal UV stability.
- **Description**: UV flat fields will be obtained with the calibration channel's ultraviolet lamp (UVFLAT) using the limited FUV filter set (F122M, F170W, F160BW, F185W, and F336W) twice in the cycle immediately after a DECON. The UV lamp is degrading with use, so its use must be minimized. The UV flats will be used to monitor the FUV flat field stability

and the stability of the Wood's filter, F160BW, by using F170W as a reference. The VISFLAT/UVFLAT ratio from the F336W filter will provide a diagnostic of the UV flat field stability, and tie the UVFLAT and VISFLAT flat field patterns together. This program represents the entire use of the UV lamp in Cycle 5. This proposal is based on the Cycle 4 program 5568, but with two extra filters (F122M and F185W).

- **Accuracy**: Should verify stability of the UV filters and flat field to 2%. The overall flatfield response is not measured because the lamp output is not uniform, and temporal variations in throughput are not measured because the lamp output varies.
- **Products**: Ratio images with the corresponding data-set from Cycle 4 and future cycles will verify the UV flat field stability.

6192: CTE Calibration

- **Purpose**: Calibrate CTE effect for a range of star brightness and background.
- **Description**: The crowded ω Cen field is observed for 40 seconds through F555W with gain 7 and preflashes of 0, 5, 10, 20, 40, 80 and 160 electrons. As a gain check and calibration, it is observed at the same orientation with gain 15 twice at preflash levels of 0 and 160 electrons. The whole sequence is repeated with filter F814W. Then a whole orbit is filled with 1 second exposures, in order to investigate the effect of CTE on low signal level stars (but with high accumulated signal-to-noise). This last orbit is repeated with a preflash of 40 electrons. This is based on Cycle 4 programs 5645 + 5646 + 5659.
- **Accuracy**: As this test is a differential measurement of the CTE slope, it should be very accurate (much better than 1%). As a large number of stars are involved, and the photon noise on each measurement is of order 1%, the slope derived should be much more accurate. The largest remaining uncertainty will be the absolute level of the slope, not differential effects caused by varying background.
- **Products**: After pipeline processing, each image will be reduced by aperture photometry to measure the stellar brightness and how it depends on the preflash level. This is a differential measurement and gives no direct information about the slope of the CTE effect at high background levels. The absolute CTE can be estimated from 5646 (already run once with a raster in this field).

6193: PSF Characterization

- **Purpose**: Provide a sub-sampled PSF over the full field to allow PSF fitting photometry.
- **Description**: This proposal measures the PSF over the full field in photometric filters in order to update the TIM and TinyTIM models and to allow accurate empirical PSFs to be derived for PSF fitting photometry. With one orbit per photometric filter, a spatial scan is performed over a 4x4 grid on the CCD. The step size is 0.025 arcseconds. This gives a critically sampled

PSF over most of the visible range. The crowded ω Cen field is used. 40 sec images are taken through each of the photometric filters (F336W, F439W, F555W, F675W, F814W). Data volume will be a problem, so special tape recorder management will be called for. This is based partially on Cycle 4 program 5575, which used the same field. The proposal also allows a check for sub-pixel phase effects on the integrated photometry.

- **Accuracy**: The chosen field will have hundreds of well exposed stars in each chip. Each star will be measured 16 times per filter at different pixel phases. In principle, the proposal therefore provides a high signal-to-noise critically sampled PSF. This would leave PSF fitting photometrists in a much better position than now where pixel undersampling clearly limits the results. The result will be largely limited by breathing variations in focus. It is hard to judge the PSF accuracy that will result. If breathing is less than 5 microns peak-to-peak, the resulting PSFs should be good to about 10% in each pixel. PSF fitting results using this calibration would, of course, be much more accurate. In addition, the test gives a direct measurement of sub-pixel phase effects on photometry, which should be measured to much better than 1%.
- **Products**: This program provides sub-sampled PSFs for photometry codes, data for comparison with PSF codes, and measurement of pixel phase effect on photometry (sub-pixel QE variations exist).

6194: Polarization and Ramps

- **Purpose**: Perform residual calibration and check for stability of polarizer and ramp filters.
- **Description**: This proposal does not duplicate the existing ramp wavelength calibration or polarization calibration (Cycle 4 programs 5574 and 6140). Instead, it provides a full polarization calibration for a filter that was not supported in Cycle 4 (F300W), a check for polarization stability, and a throughput calibration for the linear ramp filters, by scanning the spectrophotometric standard along the ramps.
- **Accuracy**: The proposal should support polarimetry at the 3% level and measure the ramp throughput at the 2% level.

6195: Flat field Check

- **Purpose**: Check quality of flat fields and estimate errors in them.
- **Description**: The crowded ω Cen field is positioned with a bright star at the center of each CCD in turn. 40 second images are taken through each of the photometric filters (F336W, F439W, F555W, F675W, F814W) and as many supplementary filters (from F450W, F606W, F702W and F547M) as can be fitted in. If data volume is a problem, single chip readout is acceptable, but should be avoided as much as possible. This is based on Cycle 4 programs 5659 and 5646.
- **Accuracy**: Overall discrepancies between the existing flat fields and the results of this test should be 1-2% rms. Part of the point of the test is to measure this accuracy.

- **Products**: After pipeline processing, each image will be reduced by aperture photometry to measure the RMS errors in the flat fields. The RMS error will be determined by the additional noise in the independent measurements over the expected variance of less than 1% from photon statistics. The single bright star at the center of each chip independently estimates the chip to chip normalization error.

6250: Internal Monitor

- **Purpose**: Check for short term stability of instrument.
- **Description**: The routine internal monitor, to be run twice weekly for WFPC2 during Cycle 5, obtains two bias frames at each gain, two INTFLATs with the F555W filter at each gain, and two Kelsall spot images with exposure times optimized for the WF and PC, respectively. It is identical to the Cycle 4 program 5560.
- **Accuracy**: This monitor is not involved in generating quantitative calibration information.
- **Products**: The test provides a biweekly monitor of the integrity of the CCD camera chain electronics both at gain 7 and 15, a test for quantum efficiency hysteresis in the CCDs, and an internal check on the alignment of the WFPC2 optical chain. Stiavelli and Baggett, WFPC2 ISR 96-01.

8.10 Cycle 6 Calibration Plan

The Cycle 6 calibration plan is similar to that for Cycle 5, and is summarized in Table 8.3. Important differences include the addition of programs to check the astrometric calibration (6941), more detailed checking of the camera electronics (6942), and measurements of narrow band filter throughputs (6943). Also, it is expected that there will be reduced usage of the calibration channel VISLAMP, so as to prolong the lamp lifetime. More detailed program descriptions are given below.

Table 8.3: Summary of Cycle 6 Calibration Plan.

ID	Proposal Title	Schedule	Results	Accuracy	External Time (orbits)	Notes
		Routine Monitoring Programs				
6902	Photometric Monitor	2x per 4 weeks	SYNPHOT	2%	26	
6903	Decontamination	1x per 4 weeks	CDBS	n/a	0	(darks, internals)
6904	Darks	Weekly	CDBS	1 e/hr	0	WWW hot pixel lists
6905	Internal Monitor	Weekly	CDBS	0.8 e	0	
6906	Visflat Monitor	2x per 4 weeks	ISR	0.3%	0	(monitor lamp health)
6907	Intflat Monitor	1x per 4 weeks	ISR	0.3%	0	
6908	UV Flat Field Monitor	2x in Cyc. 6	ISR	2-8%	0	
6909	Earth Flats	Continuous	CDBS	0.3%	0	
		Special Calibration Programs				
6934	Photometric Zeropoint	1x in Cyc. 6	SYNPHOT	2%	6	Add 2 new standards
6935	Photometric Trans.	2x in Cyc. 6	ISR	2-5%	9	Three targets
6936	UV Throughput & Ly α	2x in Cyc. 6	SYNPHOT	3-10%	12	Include BD+75D325
6937	CTE Calibration	1x in Cyc. 6	ISR	1%	2	
6938	PSF Characterization	1x in Cyc. 6	CDBS	10%	7	
6939	Linear Ramp Filters	1x in Cyc. 6	CDBS	3%	4	
6940	Polarizers	1x in Cyc. 6	CDBS	3%	4	
6941	Astrometry Verification	1x in Cyc. 6	STSDAS	0.01″	4	
6942	Camera Elect. Verification	1x in Cyc. 6	ISR	0.5%	1	
6943	Narrow Band Throughput	SNAP	SYNPHOT	3%	8	SNAP
	TOTALS				83	

6902: Photometric Monitor

- **Purpose:** Monthly external check of instrumental stability.
- **Description:** The standard star GRW+70D5824 is observed before and after each decontamination (thus twice in a four-week period). Each observation consists of three sequences: (1) F170W in all four chips to monitor contamination in the far UV; (2) F439W, F555W, F814W on the PC to monitor focus; and (3) F160W, F185W, F218W, F255W, F300W, F336W, F439W, F555W, F675W, F814W in a different chip each month. Some filters may be cut because of lack of time (F185W cut first, then F300W, then

F675W, then F218W). This proposal is based largely on Cycle 5 program 6184; focus monitoring in F439W and F814W is added at the expense of some UV filters.

- **Accuracy:** Overall discrepancies between the results of this test need to be measured to better than 2% and are expected to be less than 1% rms. The point of the test is to measure this variation.
- **Products:** Documents produced are Instrument Handbook, TIPS, WWW (sensitivity trends). Updates in UV sensitivity variation used in SYNPHOT are provided.

6903: Decontamination

- **Purpose:** UV blocking contaminants are removed by warming the CCDs.
- **Description:** The decon itself is implemented via use of the DECON mode, in which the TECs are turned off and the CCD and heatpipe heaters are turned on to warm the detectors and window surfaces. Keeping WFPC2 warm for ~6 hours has been shown in previous Cycles to be sufficient to remove the contaminants and anneal many hot pixels; continuation of 6-hour decons is anticipated for Cycle 6.

  The internal observations taken before and after each decontamination consist of: 4 biases (2 at each gain setting), 4 INTFLATs (2 at each gain setting), 2 kspots (both at gain 15, one short and one long exposure, optimized for PC and WF), and finally, 5 darks (gain 7, CLOCKS=NO). To minimize time-dependent effects, each set of internals will be grouped within 2 days and performed no more than 1 day before the DECON and no later than 12 hours after the DECON. To protect against residual images in the darks (which results in the irretrievable loss of the critical pre-DECON hotpixel status), the darks will be executed NON-INT and requested to be done at least 30 minutes after any WFPC2 activity.

  Special Requirements: This requires scheduling at 4 week intervals. It prevents WFPC2 from being used for several hours, although other instruments can be used most of that time. Dark frames taken before decontaminations need to be protected from possible residual images from overexposed sources.
- **Accuracy:** This proposal is mainly designed to maintain the health of the instrument. Biases, darks and other internals taken with this proposal are used in generating appropriate reference files.
- **Products:** They are obtained from use of darks, biases and other internals (see Proposals 6904 and 6905).

6904: Darks

- **Purpose:** Measure dark current on individual pixels and identify hot pixels at frequent intervals.
- **Description:** Every week, five 1800s exposures are taken with the shutter closed. The length of the exposures is chosen to fit nicely within an occultation period. The weekly frequency is required because of the high forma-

tion rate of new hot pixels (about 70/CCD/day). Five darks a week are required for cosmic ray rejection, to counterbalance losses due to residual images, and to improve the noise of individual measurements. Even with these measures, some weeks no usable darks will be available because of residual images. Normally this results only in a longer-than-usual gap in the hot pixel lists, but in a decontamination week, information on pixels that became hot and then annealed would be lost irretrievably. For this reason, pre-DECON darks are to be executed NON-INT and at least 30 minutes after any WFPC2 activity (see Proposal 6903). Normal darks do not need to be protected in this fashion.

- **Accuracy:** Superdarks should be accurate to better than 1 e/hour and are expected to reach errors of about 0.05 e/hour (single-pixel rms). Systematic errors due to dark glow (a spatially and temporally variable component of dark signal) and hot pixels may exceed these limits significantly.
- **Products:** Weekly dark frames are delivered to CDBS and monthly tables of hot pixels are posted on the Web.

6905: Internal Monitor

- **Purpose:** Verification of short-term instrument stability for both gain settings.
- **Description:** The internal observations will consist of 8 biases (4 at each gain, and 4 INTFLATs (2 at each gain). The entire set should be run once per week (except for DECON weeks) on a non-interference basis. This proposal is similar to the Cycle 5 Internal Monitor (6250), except that the K-spot images have been removed (these are being taken with the DECON Proposal). The execution frequency during Cycle 6 has also been reduced, from twice a week to once a week, although the total number of biases has been increased to continue to provide an adequate number of frames for pipeline reference file generation.
- **Accuracy:** Approximately 40 bias frames will be used for each pipeline reference file; accuracy is required to be better than 1.5 e/pixel, and is expected to be 0.8 e/pixel.
- **Products:** Superbiases are delivered every few months to CDBS. TIPS reports are made on possible buildup of contaminants on the CCD windows (worms) as well as gain ratio stability, based on INTFLATs. ISRs are prepared if significant changes occur.

6906: Visflat Monitor

- **Purpose:** Monitor the stability of the camera and filter responses via the VISFLAT channel.
- **Description:** Twice a month, internal flat fields (VISFLATs) will be obtained using the visible calibration channel lamp with the photometric filter set plus a couple of narrow-band filters. The images will be used to monitor WFPC2's flat field response as well as to build a high S/N flat field database, which will provide information on the pixel-to-pixel response in the cameras and any possible long-term contamination-induced changes.

The LRF (FR533N) exposures, one at each gain, taken after DECON will provide a monitor of the ADC's performance. Histograms generated from the ramp filter flats will be used to trace the ADC transfer curve. ON HOLD: In addition to the monitor observations, an initial filter-sweep is done to obtain VISFLATs in all visible filters. These will be compared to the Cycle 5 filter-sweep data to verify that none of the filters are developing any problems, and to provide a check of the calibration channel's long-term stability.

- **Special Requirements:** Uses the VISFLAT calibration channel, whose Welch-Allyn bulb is apparently wearing out. (A back-up exists for the Welch-Allyn bulb.) The Cycle 6 proposal has been redesigned to limit the number of ON/OFF cycles placed on this channel to a level believed safe over 10-15 years. The sweep part of the proposal, which puts the heaviest usage on the lamp, is on hold, pending verification of the lamp health from the short monthly executions. The INTFLAT Monitor (Proposal 6907) can obtain similar information if necessary.
- **Accuracy:** The VISFLAT response is stable to about 0.3%, both in overall level (lamp degradation aside) and in spatial variations. The point of this proposal is to verify this stability on a regular basis and to monitor the lamp degradation.
- **Products:** ISR and TIPS reports will be prepared.

6907: Intflat Monitor

- **Purpose:** Provide backup database of INTFLATS in case VISFLAT channel fails.
- **Description:** This proposal consists of two parts: 1) an INTFLAT filter sweep and, 2) a series of exposure to test the linearity of the camera. 1) The sweep is a complete set of internal flats cycling through both shutter blades and both gains. Signal-to-noise per pixel is estimated to be similar to the VISFLATs (0.6%) but the spatial and wavelength variations in the illumination pattern are much larger. However, the INTFLATs will provide a baseline comparison of INTFLAT vs. VISFLAT, in the event of a calibration channel system failure and temporal variations in the flat fields at the 1% level. In addition, these images will provide a good measurement (better than 1%) of the stability of the gain ratios. 2) The linearity test portion is aimed at obtaining a series of INTFLAT with both gains and both shutters. Since the INTFLATs have significant spatial structure, any non-linearity would appear as a non-uniform ratio of INTFLATs with different exposure times. A set of exposures is also taken with gain 7, shutter B, and CLOCKS=YES.
- **Accuracy:** The signal-to-noise per pixel is similar to that obtained in the VISFLAT program (0.6%) but there are much larger spatial and wavelength variations in the illumination pattern. As a result, this dataset will not form any part of the pipeline calibration. This baseline is necessary in case the VISFLAT channel fails and there are temporal variations in the camera flat-fields at the 1% level.

- **Products:** TIPS reports and ISRs will be prepared if any significant variations are observed.

6908: UV Flat Field Monitor

- **Purpose:** Monitor the stability of UV flat field.
- **Description:** UV flat fields will be obtained with the calibration channel's ultraviolet lamp (UVFLAT) using the UV filter set (F122M, F170W, F160BW, F185W, and F336W). The UV flats will be used to monitor UV flat field stability and the stability of the Woods filter (F160BW) by using F170W as the control. The F336W ratio of VISFLAT (Cycle 6 proposal 6906)/UVFLAT ratio will provide a diagnostic of the UV flat field degradation and tie the UVFLAT and VISFLAT flat field patterns together. Two supplemental dark frames must be obtained immediately after each use of the lamp, in order to check for possible afterimages.
- **Special Requirements:** This uses the limited life UV lamp. In order to prevent excessive degradation of the lamp, the SU duration for each UVFLAT visit should be kept the same as the durations used during Cycle 5 (proposal 6191); the lamp should not remain on for periods of time longer than those used in Cycle 5. To be executed once before and once after the refurbishment mission, shortly after a decontamination.
- **Accuracy:** About 2-8% pixel-to-pixel are expected (depending on filter).
- **Products:** New UV flat fields are made if any changes are detected.

6909: Earth Flats

- **Purpose:** Monitor flat field stability.
- **Description:** As in Cycle 5 program 6187, 4 sets of 200 Earth streak-flats are taken to construct high quality narrow-band flat fields with the filters F160BW, F375N, F502N, F656N and F953N. Of these 200 perhaps 50 will be at a suitable exposure level for de-streaking. The resulting Earth superflats map the OTA illumination pattern and will be combined with SLTV data (and calibration channel data in case of variation) for the WFPC2 filter set to generate a set of superflats capable of removing both the OTA illumination and pixel-to-pixel variations in flatfield. The Cycle 4 plan is being largely repeated except: (1) UV filters are dropped because measurement is generally only of the redleak; (2) F160BW is retained in order to check for developing pinholes; and (3) Crossed filters used as neutral densities are eliminated (illumination pattern is wrong). Specific observations for the Methane Quad filters will also be included.
- **Accuracy:** The single-pixel noise expected in the flat field is 0.3%.
- **Products:** New flat fields to CDBS if changes detected.

6934: Photometric Zeropoint

- **Purpose:** Verify synthetic zeropoint of WFPC2 filters.

- **Description:** Standard stars are observed through all filters longward of F336W (inclusive) with the limit of one orbit per target. Targets include: the spectrophotometric standard GRW+70D5824 in PC and WF3; two stars chosen as standards by other instruments on HST; and two standard star fields, containing 3-4 stars each, commonly used in ground-based photometry. Observations of GRW+70D5824 will be directly comparable to the corresponding observations for cycles 4 and 5 (programs 5572 and 6179) and will verify the stability of the filters as well as improve the accuracy of the calibration. The other standards are observed to provide cross-instrument calibration and in order to increase the range of colors used for photometric verification. This proposal will help all observers who want to do quantitative photometry at the 2% level.
- **Special Requirements:** Specific orientations will be required for the two fields of standards in order to fit the maximum number of stars. All observations should be executed within a week after decontamination.
- **Accuracy:** 2% required, 1% expected for our main spectrophotometric standard GRW+70D5824. Expected accuracy for the other standards is between 2% and 5%, depending on spectral type and filter; most of the error derives from limited knowledge of the transformations between ground-based and WFPC2 photometric systems.
- **Products:** TIPS reports, SYNPHOT updates if necessary, and ISRs will be prepared.

6935: Photometric Transformation

- **Purpose:** (1) Update photometric transformations to Johnson-Cousins system and Strömgren system; (2) Determine spatial dependence of contamination; (3) Check the astrometric solution using M67; (4) Spot check of gain=7 vs. gain=15 ratios; 5) Spot check short vs. long exposure zeropoints.
- **Description:** Three photometric standard star fields in NGC 5139 (ω Cen; metal rich), NGC 2682 (M67; metal poor), and NGC 2100 (young cluster) are observed before and after a decontamination. Four different filter sets are used: (1) The five filters generally used to match the Johnson-Cousins system (F336W, F439W, F555W, F675W, F814W); (2) The wide-band equivalents for the Johnson-Cousins system (F300W, F380W, F450W, F606W, F702W); (3) The Strömgren equivalents (F336W, F410M, F467M, F547M); and (4) Two filters farther toward the UV (F255W, F170W), so that contamination over the full field of view can be measured. F255W is not used for the reddest cluster (NGC 5139). F170W is only used for the bluest cluster (NGC 2100).

  For the brighter clusters (NGC 2682 and NGC 2100) long and short exposures are taken in the UBVRI equivalents both to extend the dynamic range and to check for differences in photometric zeropoints.

  A spot check is included to compare gain=7 and gain=15 is also included for NGC 5139 and NGC 2682.

- **Special Requirements:** The first visit for each target must be taken within 3 days after a decontamination. The second visit, including only the UV filters, must be taken more than 25 days after the first visit, but before the next decontamination.
- **Accuracy:** The photometric transformations should be accurate to 2-5%. The stability of these transformations will be measured to the 1% level. The astrometry should be good to 0.1″ (absolute) and 0.05″ (relative).
- **Products:** ISR and Instrument Handbook. It will also be part of a planned paper on the possibility to do 1% photometry.

6936: UV Throughput and Lyman-α Verification

- **Purpose:** Verify throughput for all UV filters, including Lyman-α test to monitor possible contamination on pick-off mirror.
- **Description:** Spectrophotometric standards are observed shortly before and after a DECON through all the UV filters in each chip and through F160BW crossed with F130LP, F185LP, and F165LP to determine the wavelength dependence of the throughput across the bandpass (for color terms). This proposal is based on the Cycle 5 UV Throughput proposal (6186) but includes also the standard BD+75D325 used in Cycle 4 (proposal 5778) to establish the Lyman-α throughput calibration.
- **Special Requirements:** Timing requirements with respect to decontaminations.
- **Accuracy:** The UV throughput will be measured to better than 3%. Accuracy in Lyman-α throughput is expected to be between 5 and 10%, because of the residual uncertainty of the red leak correction after observations with crossed F122M and F130LP.
- **Products:** TIPS reports, SYNPHOT updates, and ISRs will be prepared if necessary.

6937: CTE Calibration

- **Purpose:** (1) Test whether the exposure-time dependence of the photometric calibration is due to CTE (long vs. short exposure problem); (2) refine flux and background-level dependent aperture corrections.
- **Description:** The globular cluster NGC 2419 will be observed through F555W with a combination of exposure times (between 5 and 1400 s) and preflash levels (0 to 500 e^-). Analysis of cycle 5 CTE calibration (proposal 6192) suggests that magnitude errors due to charge transfer effects are greatly reduced (if not entirely eliminated) at background levels of 160 e^- or greater. CTE effects have been proposed as the solution to reported differences in the magnitudes of stars measured on frames with short exposures vs. long exposures. If CTE is the cause, then the differences should disappear with preflash. We will re-observe the cluster NGC 2419 with and without preflash to test this hypothesis. This dataset will also provide a large

number of stars with which to refine existing measurements of the effects of CTE on the wings of the PSF. A range of preflash levels will be explored at the 60 sec exposure time.

- **Special Requirements:** Observations should be made at the same position and roll angle as the previous NGC 2419 LONG exposures (proposal GO-5481).
- **Accuracy:** The reported short vs. long effect is ~0.05 mag. We wish to reduce this to less than 0.01 mag.
- **Products:** An ISR will be prepared. If appropriate, a special task to correct the CTE effect will be generated.

6938: PSF Characterization

- **Purpose:** Provide a sub-sampled PSF over the full field to allow PSF fitting photometry, test PSF subtraction as well as dithering techniques (c.f. effects of the OTA breathing and CCD gain).
- **Description:** Measure PSF over full field in photometric filters in order to update the TIM and TINYTIM models and to allow accurate empirical PSFs to be derived for PSF fitting photometry. These observations will also be useful in order to test PSF subtraction and dithering techniques at various locations on the CCD chips. With one orbit per photometric filter, a spatial scan is performed over a 4X4 grid on the CCD. The step size is 0.025 arcseconds; this gives a critically sampled PSF over most of the visible range. This program uses the same specially chosen field in ω Cen as the Cycle 5 proposal 6193, but with a few arcsec shift in order to map the PSF variation better. The standard 'photometric' filters are used. Two additional orbits are used to explore the effects of OTA breathing and CCD gain onto dithering and PSF subtraction techniques. Data volume will be a problem, so special tape recorder management will be called for. The proposal also allows a check for sub-pixel phase effects on the integrated photometry.
- **Special Requirements:** This needs the same pointing and orientation as Cycle 5 observations for proposal 6193, thus should be scheduled within a similar time frame.
- **Accuracy:** It provides measurement of pixel phase effect on photometry (sub pixel QE variations exist). The chosen field will have tens of well exposed stars in each chip. Each star will be measured 16 times per filter at different pixel phases. The proposal therefore provides, in principle, a high signal-to-noise, critically sampled PSF. This would leave PSF fitting photometrists in a much better position than now, where pixel undersampling clearly limits the results. The result will be largely limited by breathing variations in focus. It is hard to judge the PSF accuracy that will result. If breathing is less than 5 microns peak-to-peak, the resulting PSFs should be good to about 10% in each pixel. Breathing effects will be investigated (1 additional orbit) as well as the gain dependence (1 additional orbit). PSF fitting results using this calibration would of course be much more accurate. In addition, the test gives a direct measurement of sub-pixel phase effects on photometry, which should be measured to better than 1%.

- **Products:** A PSF library (CDBS) will be assembled, and an ISR will be issued as needed.

6939: Linear Ramp Filters

- **Purpose:** Verify throughput calibration for Linear Ramp Filters at selected wavelengths.
- **Description:** Throughput calibration is obtained by observing the spectrophotometric standard GRW+70D5824 at several filter rotations and wavelengths. This completes the program carried out in Cycle 5, in which some wavelength ranges and rotations could not be covered.
- **Accuracy:** Throughput accuracy should be verified to better than 3%; 1-2% can be achieved.
- **Products:** SYNPHOT throughput tables will be updated if necessary.

6940: Polarizers

- **Purpose:** Verify stability of polarization calibration.
- **Description:** The goal of this proposal is to check for any changes in the polarization calibration since Cycle 5. Observations are made in F555W+POLQ of both polarized and unpolarized stars, in addition to VISFLATs. Data are taken in all four quads of the polarizer, as well as in three rotated positions of the POLQ.
- **Special Requirements:** Requires specific orientations.
- **Accuracy:** 3%.
- **Products:** Update throughput tables if necessary

6941: Astrometry Verification

- **Purpose:** Verify accuracy and stability of geometric transformation and relative astrometry solution.
- **Description:** A very rich star field in ω Cen will be observed in five different positions with relative shifts of 40″ in each coordinate. Positions of more than 2000 stars per chip will be compared between pointings using the three different astrometric solutions provided by Gilmozzi, Holtzman and Trauger, in order to verify and refine their accuracy. (Differences of up to 1 PC pixel exist in some regions of the field of view.) A very densely populated field is chosen in order to achieve better coverage of the field of view, even if at the expense of the accuracy of individual position measurements. Observations will be carried out in three filters, F555W, F300W, and F814W, to provide a verification and/or correction of the wavelength dependence of the solution. The F555W observation is repeated with smaller shifts of 15″ to ensure a better coverage of the PC.
- **Accuracy:** We expect better than 0.01″ and require better than 0.05″ (full field of view).
- **Products:** Improvements will be noted in METRIC and in the aperture reference file if required. An ISR will be issued as needed.

6942: Camera Electronics Verification

- **Purpose:** Verify several aspects of the WFPC2 camera electronics: linearity, gain ratios, effect of CLOCKS, and effect of CTE on extended sources.
- **Description:** Observing a very extended non-uniform target represented by the giant elliptical galaxy NGC 4472. The linearity test is carried out by taking exposures of NGC 4472, centered in WFALL, with a variety of exposure times. Since the galaxy is non-uniform, the ratio of these exposures is directly related to the camera linearity. The exposures will be taken with GAIN=7. However, one exposure will also be taken with GAIN=15. Additional exposures will be taken with CLOCKS=YES and with a preflash. These observations complement those of the internal calibration proposal 6907. The two major advantages of these observations compared to the 6907 ones are the possibility of studying the effect of preflash (since the light distribution of the preflash is different from that of NGC 4472) and the possibility of measuring an absolute response curve, since NGC 4472, unlike the INTFLAT lamp, does not have variations in luminosity. NGC 4472 has been chosen as target galaxy because it is large enough to produce significant signal in all chips and bright enough to allow us to explore the highest counts without excessive integration times.
- **Accuracy:** We expect 0.5% for linearity and CTE, 0.1-0.2% for gain ratios and CLOCKS. We require less than 1% on each item.
- **Products:** ISRs and TIPS reports will be prepared as needed.

6943: Throughput Verification for Narrow Band Filters

- **Purpose:** Direct verification of throughput of narrow band filters through observations of emission line objects.
- **Description:** The current throughput calibration of narrow-band filters is based on filter profiles from data obtained before launch and on observations of continuum sources. This program will verify the accuracy of the calibration, and indirectly the stability of the filters, by observing eight planetary nebulae with strong lines and well-established ground-based spectra. The observations can be executed in SNAPSHOT mode since they will be short and none is specifically required. Some planetary nebulae with existing Cycle 4 and 5 observations will be included for stability verification.
- **Accuracy:** We expect 2% and require 3%.
- **Products:** SYNPHOT tables will be updated and an ISR issued if required.