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Wide Field Camera 3: Design, Status, and Calibration Plans

John W. MacKenty

Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

Abstract. The mission of Wide Field Camera 3 (WFC3) is to assure the continuance of *HST*s superb imaging capability until 2010 while adhering to a cost capped development approach. It will provide *HST* with a UVIS channel from 200 to 1000 nm and an infrared channel from 850 to 1700 nm with a rich set of filters. WFC3 is based on the heritage of the existing *HST* instruments and follows a philosophy of extensive re-use of designs, components, and procedures. Its calibrations and data products are based on the approaches used by the ACS and NICMOS instruments.

1. Introduction

WFC3 will be the first "panchromatic" camera on *HST* with two channels covering from the near-ultraviolet into the near-infrared. The WFC3 UVIS channel uses a CCD detector. This channel backs up ACS WFC capability while providing in addition a vastly improved near-ultraviolet wide field science capability for *HST*. The WFC3 IR channel extends the infrared capabilities on *HST* beyond the NICMOS instrument with a seven times larger field of view, improved sensitivity where *HST* is most advantageous compared to ground-based observatories, and a design compatible with operation until the end of the *HST* mission.

WFC3 is a facility instrument being developed on behalf of the *HST* user community. It will replace the Wide Field Planetary Camera 2 (WFPC2) in *Hubble*'s radial science instrument slot during Servicing Mission 4. The primary purpose of WFC3 is to assure continued world class *HST* imaging science to the end of mission (now expected around 2010). To this end, NASA decided to develop WFC3 as a facility instrument without the GTO team associated with prior *HST* instruments. The scientific goals and oversight of WFC3 are provided by a NASA appointed Scientific Oversight Committee (SOC) chaired by Dr. Robert O'Connell of the University of Virginia. Day to day development of the instrument is conducted by an Integrated Product Team (IPT) formed by teams experienced in the development of prior *HST* instruments. Led by NASA's Goddard Space Flight Center (GSFC), the IPT includes the Space Telescope Science Institute (STScI), Ball Aerospace Corporation, Swales Aerospace Corporation, the Jet Propulsion Laboratory (JPL), and many industrial suppliers. The IPT is led by Dr. Randy Kimble (GSFC) as Instrument Scientist [who replaced Dr. Ed Cheng (GSFC) in September 2002], Dr. John MacKenty (STScI) as Deputy Instrument Scientist, and Thai Pham (GSFC) as Instrument Manager.

2. UVIS Channel

2.1. CCD Detector

The UVIS channel has a Focal Plane Array consisting of two 2048 × 4096 pixel backside illuminated CCDs. These were manufactured by E2V (then Marconi) Corporation in the United Kingdom. They will provide a field of view of 162 × 160 arcsecond with 0.039 arcsecond projected pixel size. This is comparable to the existing WFPC2 Planetary Camera

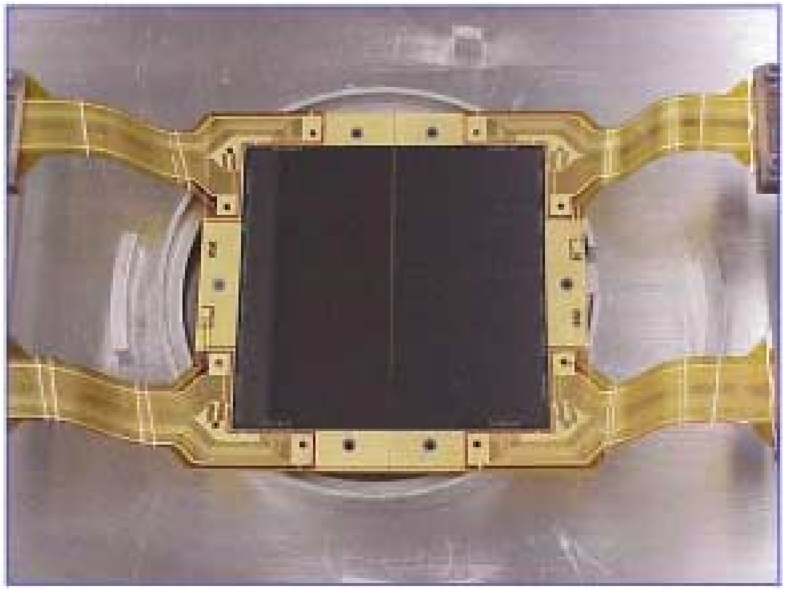

Figure 1. CCD Focal Plane Array.

channel and somewhat better than the ACS/WFC (0.050 arcsecond) sampling. These CCDs have blue/near-UV optimized anti-reflection coatings that extend their sensitivity down to 200 nm. These coatings extend the wide field imaging into the near-UV at the expense of sensitivity in the green-red region (where ACS is optimized). Further, WFC3 uses Aluminum reflective optics rather than protected silver (as employed by ACS/WFC) resulting in a further red light performance advantage for ACS.

At this time, E2V/Marconi has completed all the WFC3 program CCD detector deliveries. These are exceptional devices, with extremely uniform behavior from device to device, ultraviolet (250 nm) quantum efficiencies of 50 to 60 percent, readout noise of 2 to 2.5 e− rms (approximately 3 e− rms including the flight electronics), and excellent CTE. These CCD detectors were extensively characterized at the GSFC Detector Characterization Laboratory by the WFC3 team. At the present time, Ball Aerospace has bonded two pairs of these CCDs into 4K ×4K focal plane substrates and is nearing completion of their assembly into flight units.

2.2. UVIS Filter Elements

The complement of filters was selected by the WFC3 SOC after extensive input from the astronomical community. It represents a carefully considered balance between continuing the presence of heavily used WFPC2 and ACS filters and offering new capabilities. WFC3 also benefits from recent improvements in filter technology that reduce pinholes, improve out of band rejection, and in-band throughput and bandpass shape.

The UVIS channel has a 48 element selectable, optical filter assembly (SOFA) that is the actual unit flown in the WF/PC-1 instrument from 1990–1993. This refurbished unit has been populated with new filters designed and manufactured for WFC3 by Barr Associates and Omega Optical (two filters were obtained from the stock of WFPC2 spares). There are 42 full field of view filters and 5 quad-filters which provide different passbands in each quadrant of the image. There is also an ultraviolet grism to provide slitless spectroscopy that was originally developed for the WF/PC-1 instrument. These filters represent the state of the art in astronomical filters with especially excellent broad-band near-UV filters. Combined with the enhanced UV detector sensitivity, WFC3 is several magnitudes more sensitive than WFPC2 in the UV.

Figure 2. SOFA Mechanism.

2.3. UVIS Calibration Considerations

The UVIS channel is nearly identical to the ACS Wide Field Channel (WFC). It uses the same detector format, electronics, flight and ground software. The data sent to observers has the same format and is processed by nearly identical pipeline calibration software. There are two significant new features of its operation: (1) we have added support for 2×2 and 3×3 pixel on-chip binning, and (2) we will replace post-flash with charge-injection for mitigation of the decline in charge transfer efficiency with on-orbit radiation damage.

We have obtained a full characterization of the detectors including monochrometer flat fields in the red to provide the basis of a fringing correction with narrow emission line sources. We are placing a high priority in obtaining extensive calibration in the ultraviolet during the system level ground testing. WFC3 will be equipped with internal deuterium and tungsten lamps for differential calibration.

An important consideration for calibration of WFC3 (also present to nearly as large an extent in the ACS) is the significant geometric distortion in the field of view. We anticipate that WFC3 will fully re-use the CALACS (drizzle) pipeline and that the majority of observations will be reconstructed using dithered observations.

3. IR Channel

3.1. HgCdTe Detector

The Infrared Channel has a focal plan array consisting of a single 1024×1024 pixel HgCdTe detector array. This array is a Rockwell Scientific Hawaii-1R device with a custom WFC3 mounting. The array provides a 1014×1014 pixel imaging area with 5 non-light-sensitive reference pixels along each edge. This array provides a 139×123 arcsecond field of view

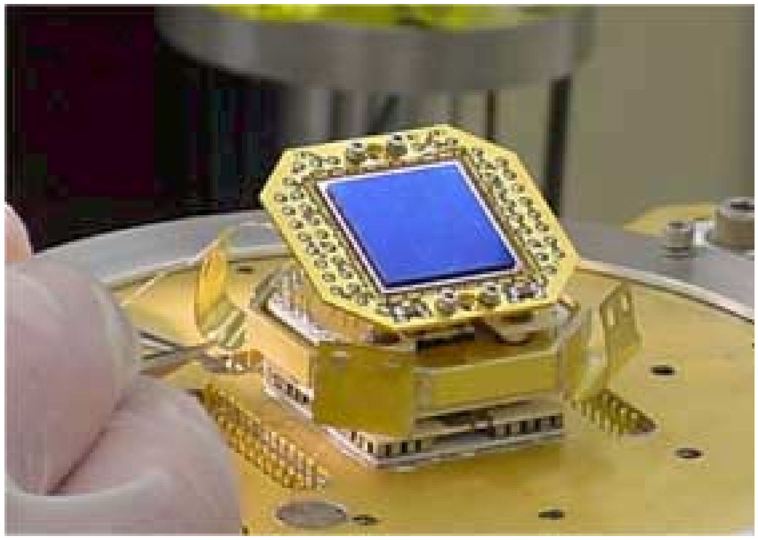

Figure 3. Infrared Focal Plane Array mounted on 6 stage TEC.

(0.130×0.120 arcsecond projected pixel size). While not fully Nyquist sampled, the IR sample represents a balance between maximizing the field of view and sampling the point spread function. With dithered observations, it is expected that the full diffraction limited resolution of *HST* will be preserved at wavelengths longwards of 1 micron.

The HgCdTe detector has a short wavelength cutoff at 0.82 to 0.85 microns determined by its CdZn substrate and a long wavelength cutoff turned to 1700 nm. The long wavelength cutoff was selected to provide acceptable dark current for operation at 150 K. This temperature is the minimum practical with the use of a solid state thermal electric cooler(TEC). Compared to NICMOS's original limited lifetime stored cryogen or current power-hungry mechanical power cooler, the TEC cooling permits low power and long lifetime operation and has strong design inheritance from the TECs that have cooled CCD detectors in STIS, ACS, and the WFC3 UVIS channel.

The IR detector program was less mature at its inception than the CCD detectors and required the production of multiple lots of devices. At this time, recent detectors approach the desired specification and are in evaluation. The WFC3 IR channel is expected to have somewhat better point source sensitivity than the NICMOS. In the broad J and H filters, the detector dark current and noise, plus the instrument and telescope background, is comparable to the zodiacal dust emission. Combined with its larger field of view (and improved sampling over the large field), it should greatly increase *HST*'s infrared survey capability. The NICMOS instrument will remain the only *HST* instrument with infrared coronographic and polarization capability, and with response beyond 1.7 microns.

3.2. IR Filter Elements

The IR channel has a single 18 element filter wheel located in a cold enclosure near the cold stop (and *HST*'s pupil). This provides 15 bandpass filters and two grisms that offer coverage from 850 to 1700 nm at broad, medium, and narrow bands (mapped to astronomically interesting features).

3.3. IR Calibration Considerations

The IR Channel is closely patterned on the NICMOS instrument. While NICMOS supported five detector operation modes, WFC3 only supports MULTI-ACCUM since this was used for essentially all NICMOS observations. Also known as sample-up-the-ramp,

Figure 4. Infrared Filter Wheel.

MULTI-ACCUM obtains a sequence of readouts while signal accumulates in the detector. The observer selects from a menu of stored exposure Sample Sequences (for which dark calibrations will be maintained) and obtains a selected number of readouts from that sequence. WFC3 is capable of obtaining up to 16 readouts during a single exposure; this is limited by onboard data storage.

The data format follows the NICMOS model with provision for cosmic ray removal from individual datasets and the combination of datasets. The addition of the reference pixels may help track drifts in the baseline (pedestal) signal. As with the UVIS channel, we expect these datasets will be compatible with the ACS second stage (drizzle) imaging combination pipeline software. This has several benefits: combination of multiple samples to reduce noise and artifacts, improved spatial resolution, and correction for the geometric distortion of the field of view.

We have equipped the IR Channel with the capability to read subarrays of 256×256, 128×128, and 64×64 pixels. This capability helps with data volume but, perhaps more importantly, enables shorter exposures. Since the IR Channel does not have a mechanical shutter (the detector reset serves to start an exposure), the minimum exposure time is the 3 to 4 second detector readout time when the entire detector is read out. Subarrays reduce this time approximately proportionally to their area.

4. Optical and Mechanical Design

The WFC3 instrument started from the foundation of the returned hardware of the original WF/PC-1 instrument. Early on it was decided to design and fabricate a new optical bench rather than attempt to re-use the WF/PC-1 bench. However, the external enclosure and radiator were retained and reworked for WFC3. The physical layout captures the center of the *HST* field of view with a pickoff mirror (essentially identical to WF/PC-1 and WFPC2), passes the light past a Channel Select Mechanism (CSM) that either reflects the beam into the IR Channel or lets it pass unhindered into the UVIS channel. The UVIS channel has

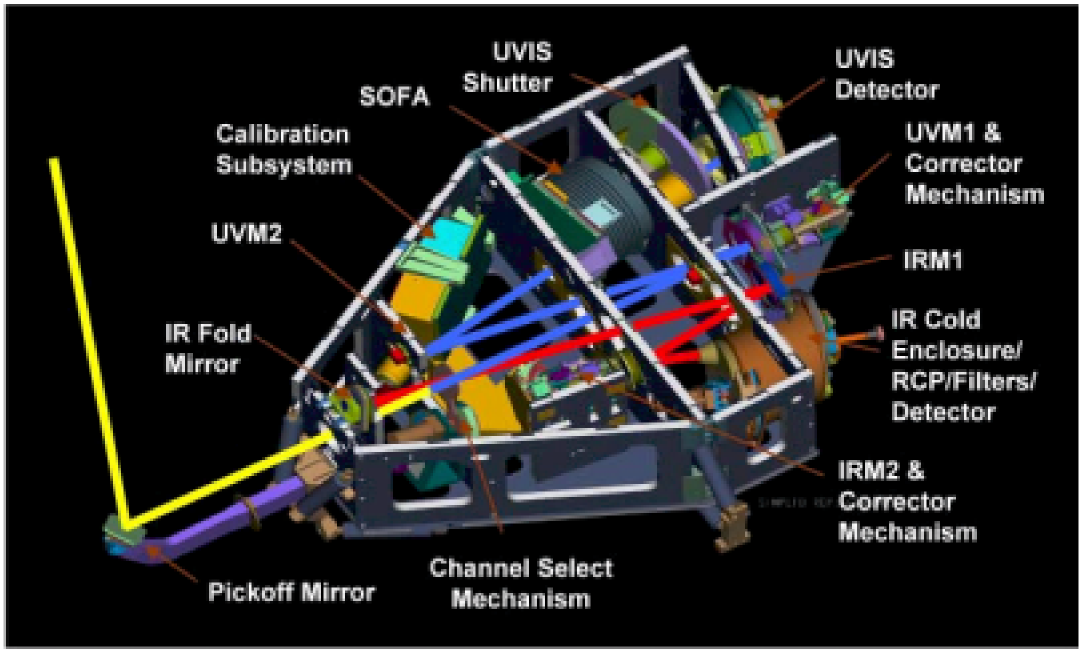

Figure 5. WFC3 Optical Assembly showing UVIS and IR light paths.

the light fall onto an adjustable mirror (in tip, tilt, and piston) that steers the beam onto a mirror containing the correction for the *HST* spherical aberration. This design, and the actual corrector mechanism, are a close copy of the ACS WFC. The beam then transits the SOFA, shutter mechanism (copied from the ACS WFC shutter), and then enters the CCD detector enclosure (also copied from the ACS WFC design).

With the CSM in the IR Channel position the beam is directed onto a fold mirror, then re-imaged using a pair of optics (one positioned on an identical tip-tilt-piston correction mechanism as used in the IR channel). The beam then enters a cold enclosure (−35C) that reduces both the cooling requirements of the IR detector and the internal background at infrared wavelengths. Within this enclosure it passes through a refractive corrector element (to remove the *HST* spherical aberration), a cold mask (for the *HST* pupil), and the infrared filter element. The detector is housed in a enclosure with heritage from the STIS and ACS detector enclosures. The use of a transmission correction for the spherical aberration has the decided advantage of making a clean pupil available for the cold mask. This design is both physically compact and minimizes oversizing of the cold mask (and thereby minimizes the resulting throughput loss).

WFC3 makes considerable use of its attached dedicated thermal radiator. This is divided into two zones. The hot zone dumps heat from the electronics and reduces WFC3's thermal load into the aft shroud of *HST* where the other science instruments are located. The cold zone provides the first stage of cooling for both the UVIS and IR detectors plus the IR cold enclosure. This is accomplished via a bank of 18 single-stage TEC units.

5. Instrument Status and Plans

WFC3 is presently in the Integration and Test phase. The optical bench assembly and testing has been completed by Ball Aerospace and delivered to GSFC in early December 2002. The team is presently concentrating on getting the electronics and bench integrated into the enclosure at GSFC. Final selection of IR detectors, detector packaging and installation, system level thermal vacuum testing, and science calibration will be accomplished

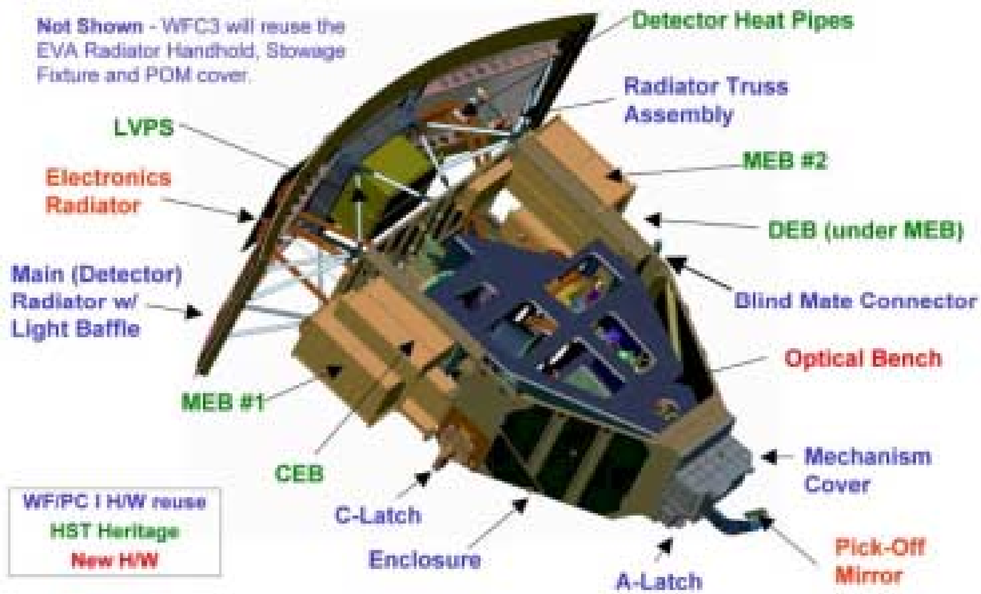

Figure 6. Solid Model of WFC3 showing re-use of components.

during the coming year. While at the time of the Calibration Workshop the SM4 mission was expected in April 2004, it is now rescheduled for early 2005.

Acknowledgments. The WFC3 instrument is an ongoing effort of a large and talented team of people. Additional information may be obtained from the World Wide Web sites at GSFC (http://wfc3.gsfc.nasa.gov) and at STScI (http://www.stsci.edu/instruments/wfc3/). A more detailed discussion of WFC3 (and its anticipated performance as of August 2002) is available in the *WFC3 Mini-Handbook* (http://www.stsci.edu/instruments/wfc3/wfc3-docs.html).