WIDE FIELD AND PLANETARY CAMERA-2

RECOVERING THE PROMISE OF HUBBLE SPACE TELESCOPE

HUBBLE ABERRATION

Spherical aberration in the HST was discovered soon after launch. It was quickly realized that if the aberration could be well characterized and was stable over time, an optical fix could be made to the aberrated beam. Significant work on image analysis by several groups provided a highly accurate on-orbit characterization of the aberration. In addition, the ground equipment used to polish the HST mirrors was investigated, and the cause of the aberration was discovered: an error in the placement of one of the optical elements in the reflective null corrector for the primary mirror. The ground data was used to determine the expected amount of spherical aberration in the HST. Both the ground data and the on-orbit data agree closely on the amount of aberration present. Uncertainties in the error determination are small enough so that they will not seriously affect image quality in the corrected instruments.

The HST project decided to pursue two separate courses for optical correction. The WFPC-2 incorporates optics which will internally correct the HST beam, as discussed below. The beams to the other instruments will be corrected before their apertures by adjustable optics to be placed in their beams by the COSTAR (Corrective Optics Space Telescope Axial Replacement).

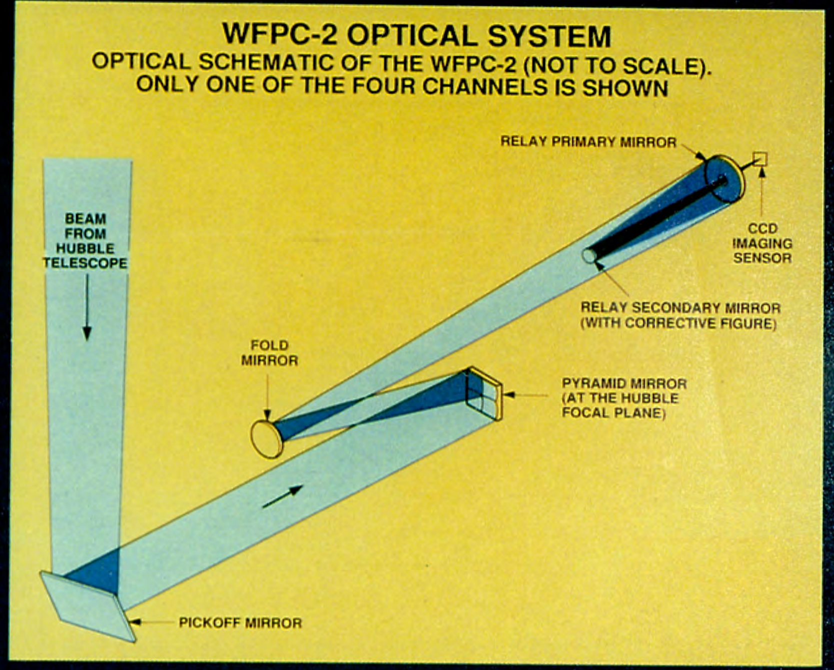
WFPC-2 OPTICAL CORRECTION

The incoming aberrated beam is sent to WFPC-2 using a tip-tilt actuated pickoff mirror. The beam is split into four facets by the pyramid mirror. Three of the beams are sent to Wide Field (f/13.6) cameras; the fourth goes to a Planetary Camera (f/32.5). Fold mirrors send each beam back into individual relay cameras. The fold mirrors are figured to place an image of the HST pupil on the relay secondary mirrors.

Secondary mirrors in each relay camera are figured with compensating spherical aberration to cancel that coming from the HST. Provision is made to accurately center the HST pupil image on each corrective secondary mirror. The pickoff actuator is used to center one of the WF cameras. Fold mirrors are actuated in the remaining three cameras to provide precise alignment. Corrected images are formed on the WFPC-2 CCDs.

WFPC-2 OPTICAL SYSTEM

OPTICAL SCHEMATIC OF THE WFPC-2 OPTICAL (NOT TO SCALE). ONLY ONE OF THE FOUR CHANNELS IS SHOWN



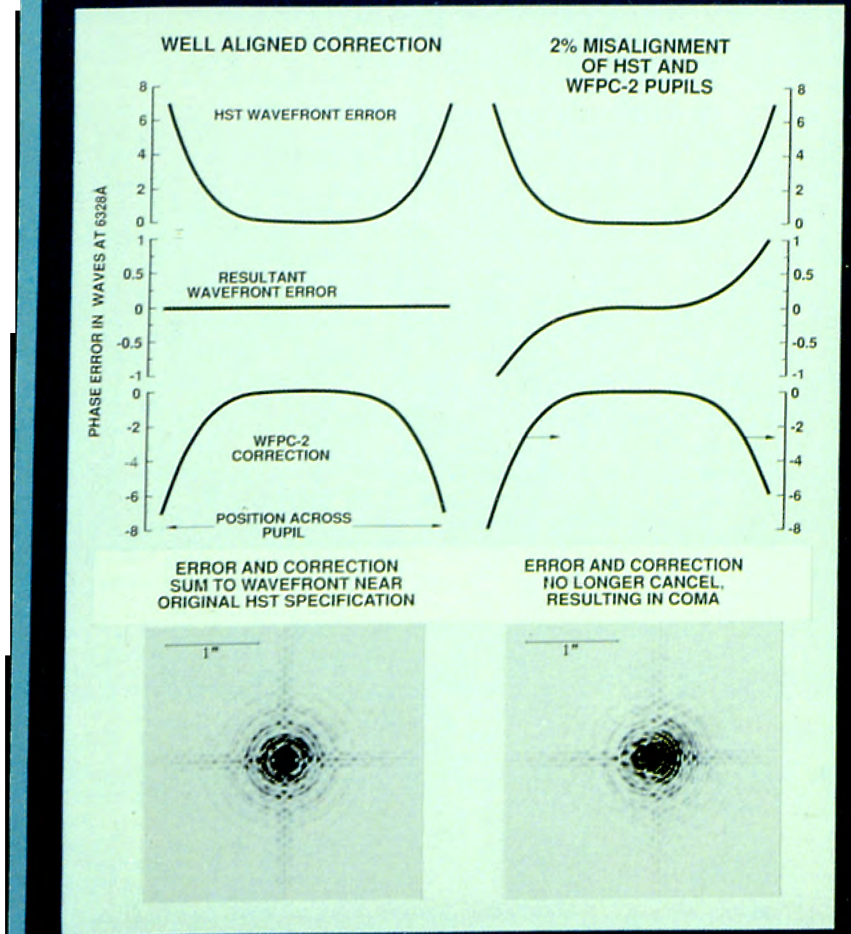
ALIGNMENT IS CRUCIAL

The convergence of fossil and on-orbit data on a value for the Hubble aberration provides confidence that the optical prescription for the correction is well understood. Because of the nature and severity of the aberration, the single most critical and challenging technical aspect of applying a correction is assuring exact alignment of the WFPC-2 pupils with the pupil of the HST.

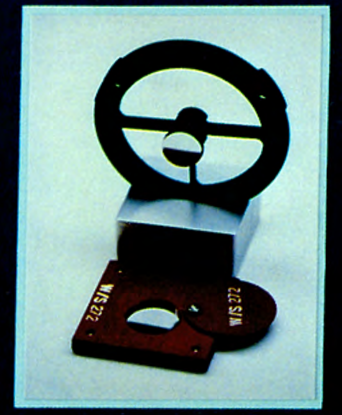
The drawing at lower left shows how the aberrated HST wavefront is corrected by introducing an equal but opposite error at the secondary of each of four Cassegrain "relays." The point spread function in this case is close to the original as-designed HST+WFPC.

The drawing at the lower left shows what happens if the image of the HST pupil does not align exactly with the relay secondary. The aberrations no longer cancel, leading to a R^3 wavefront error and comatic images. For example, an error of only 2% of the pupil diameter produces the PSF degradation shown, leading to degraded spatial resolution and a loss of sensitivity to faint point sources. This error corresponds to mechanical tolerances of only a few microns in the tip/tilt motion of the pickoff mirror, the pyramid, and the fold mirrors.

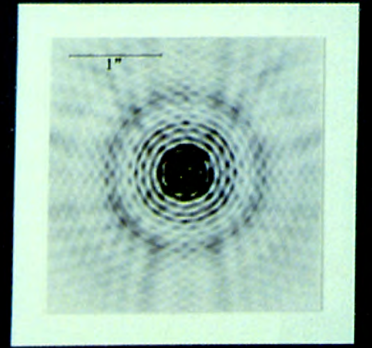
The mechanical tolerances required to passively maintain WFPC-2 alignment far exceed the original requirements for WFPC-1. Actuated optics are being incorporated into WFPC-2 to assure that accurate alignment, and hence good images, can be achieved and maintained on orbit.



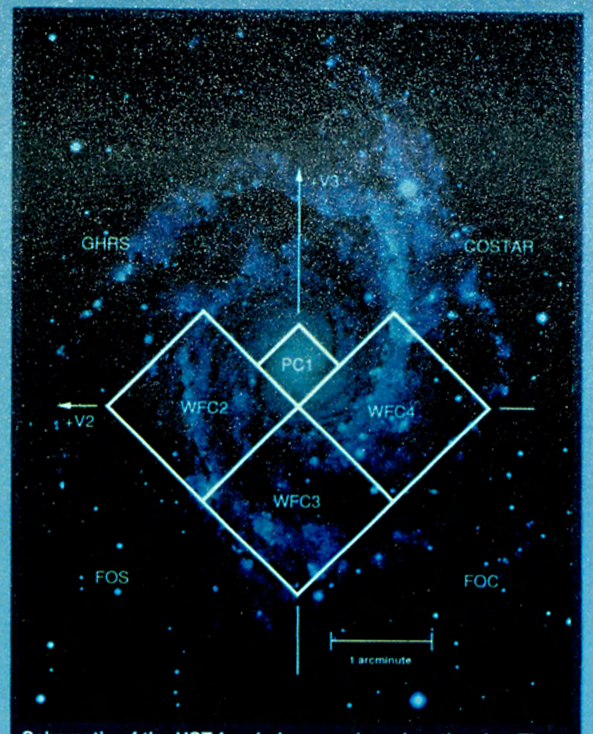
Assembly of a flight fold mirror invar flexure and bezel. Electrostrictive ceramic actuators within this structure provide tip/tilt adjustments up to ±1 milliradian in each axis.



One of three flight WFC Cassegrain relay secondary mirrors, mounted on its support spider. An image of the aberrated Hubble primary mirror is projected onto the surface of these relay secondaries, which are figured to cancel the Hubble aberration.



A simulation of the current HST point spread function with spherical aberration. The scale is the same as the two simulations to the left. All PSFs are displayed with a logarithmic contrast stretch.



Schematic of the HST focal plane as viewed on the sky. The rescoped WFPC-2 will have four camera channels: three Wide Field (WFC) channels and one Planetary Camera (PC) channel. The relative locations of the other HST instruments in the focal plane are also shown.

WFPC-2 FILTER SET

The set of 48 filters has been revised for WFPC-2, with the following features:

Accurate replication of the WFPC-1 "UBVRI" photometry set and "wideband" series,

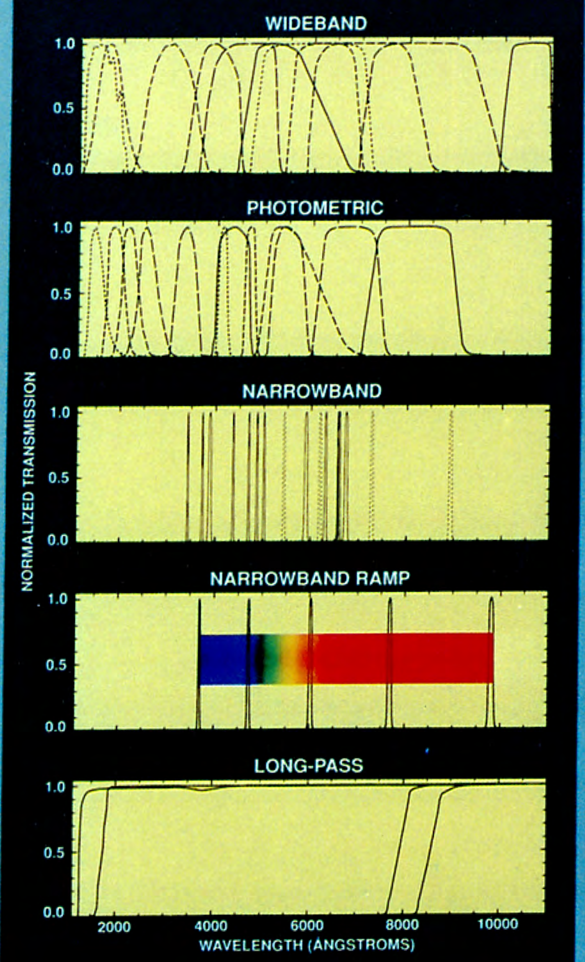
Extension of wideband filter series into the far–UV,

Addition of a Strömgren set,

"Woods" filter for far–UV imaging without a red-leak,

Linearly variable 1% bandpass filter series covering 3700-9800Å,

More uniform and better calibrated narrowband filters.



The complete set of 48 WFPC-2 filters. All filter profiles have been normalized to a peak transmission of unity.

WFPC-2 OBJECTIVES

RECOVER HST WIDE FIELD IMAGING CAPABILITIES IN TIME FOR THE FIRST HUBBLE SERVICING MISSION IN LATE 1993

BUILD ON THE WFPC-1 EXPERIENCE TO PROVIDE IMPROVED SCIENCE CAPABILITY AND OPERATIONAL EFFICIENCY

PROVIDE THE LARGEST FIELD OF VIEW, WELL-CORRECTED FOR SPHERICAL ABERRATION, CONSISTENT WITH SCHEDULE AND BUDGET CONSTRAINTS

PLAN

EMPLOY THE FLIGHT PROVEN WFPC-1 DESIGN

INCORPORATE A COMPENSATING OPTICAL ABERRATION INTO THE RELAY OPTICS TO CORRECT FOR SPHERICAL ABERRATION IN THE HUBBLE PRIMARY MIRROR

UTILIZE AN ADJUSTABLE PICKOFF MIRROR AND ACTUATED FOLD MIRRORS TO GUARANTEE ACCURATE ALIGNMENT OF CORRECTIVE OPTICS ON-ORBIT

RESPOND TO PROJECT, BUDGET, AND SCHEDULE CONSTRAINTS WITH A RESCOPE TO 3 WIDE FIELD CAMERAS AND 1 PLANETARY CAMERA, PROVIDING BOTH HIGH SPATIAL RESOLUTION AND WIDE-FIELD MODES IN A SINGLE POINTING

IMPROVE EFFICIENCY OF INSTRUMENT OPERATION WITH STABLE CCD SENSORS, PROVISION FOR INTERNAL FLAT-FIELD CALIBRATIONS, IMPROVED FILTER SET, AND STABLE FUV PERFORMANCE

SCIENCE PERSPECTIVE

The technical aspects of WFPC-2 are of no real consequence unless they translate into an improved capability to do exciting state of the art science. The areas highlighted in this presentation all have a direct bearing on both existing science programs and programs being planned by the WFPC-2 Investigation Definition Team.

Recovery of the point spread function is essential to all science programs to be conducted with the WFPC-2, because it is recovery of the PSF that allows HST to both go deeper than ground-based imagery and to resolve smaller scale structure with higher reliability and dynamic range. In addition, accomplishing the scientific goals which originally justified the HST requires that good quality images be obtained across as wide a field of view as possible. The Cepheid distance scale program, for example, cannot be accomplished without a relatively wide field of view.

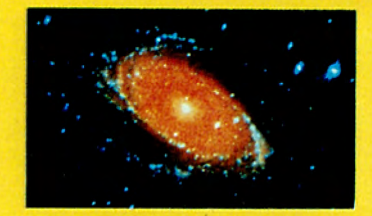
Providing a sustained, high resolution, wide field imaging capability in the vacuum ultraviolet is a unique capability of the WFPC-2. Considerable effort has been expended to assure that this capability is maintained.

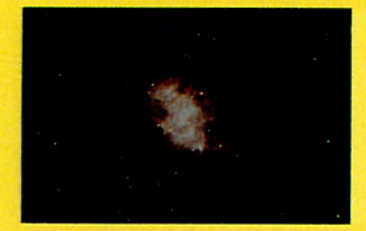
While the WFPC-2 CCDs have somewhat lower quantum efficiency than the WFPC-1 chips, for most applications this is more than made up for by the lower noise, improved charge transfer, and better cosmetics. These characteristics are expected to greatly improve the accuracy of stellar photometry, where uncertainty in the flat field is a major contributor to the uncertainties in photometry with WFPC-1. They will also greatly enhance the quality of low light level exposures where read noise and deferred charge limit sensitivity with WFPC-1 devices. This will be especially important for narrow band imaging.

A carefully thought out filter set will also add to the scientific capabilities of the WFPC-2. Highlights include new filter technology developed for WFPC-2 which should overcome the "red leak" problem that has hampered UV imaging with HST. In addition, a set of linearly variable filters will provide a 1% FWHM passband over a 13" field at any visible wavelength, allowing narrow band imaging of distant objects in a variety of emission lines.

A FEW NEW & RECOVERED WFPC-2 PROGRAMS

Examples of scientific programs utilizing some of the features of the WFPC-2 include the following:





PSF RECOVERY

Wide Field Mode:

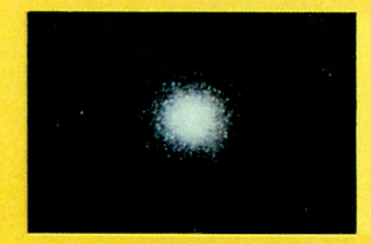
- Distance Scale Key Project
- Stellar Populations
- Medium Deep Survey Key Project
- Distant Clusters of Galaxies
- Star Cluster H-R Diagrams
- Morphology of Faint Galaxies

Planetary Mode:

- Planetary Atmosphere Structure
- Environments of QSOs and AGNs
- Structure of Galactic Nuclei
- Gravitationally Lensed Objects
- Disks around Young Stars
- Properties of Dense Star Clusters

FAR ULTRAVIOLET

- Hot Stellar Populations in Galaxies
- Reflection Nebulae
- Structure of AGNs and Jets
- Planetary Aurorae
- White Dwarfs in Star Clusters
- Faint UV Survey



NARROW BAND

- H II Region Structure
- Planetary Nebulae
- Supernova Remnants
- Planetary Nebulae in Galaxies
- Starburst Galaxy H II Structures
- Cluster Cooling Flows
- Io Nebula
- Cometary Comae
- Circumstellar Shells
- Environments of Protostars

BETTER FUV PERFORMANCE

WFPC-2 has several features which should greatly improve UV performance:

CONTAMINATION
Contamination rates will be reduced by two to three orders of magnitude by material selection, processing, and improved bakeout.

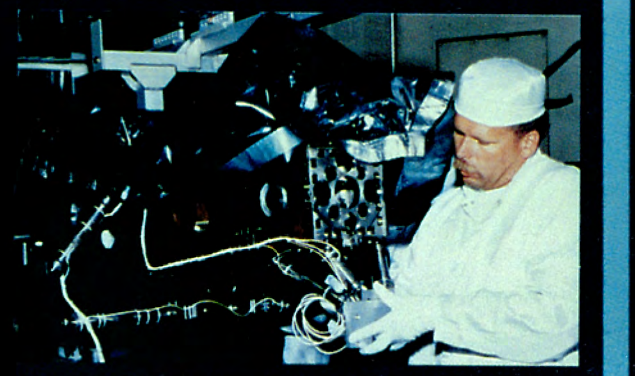
ADSORBER
Adsorbent material is being placed within the camera to reduce the contamination rate an additional order of magnitude.

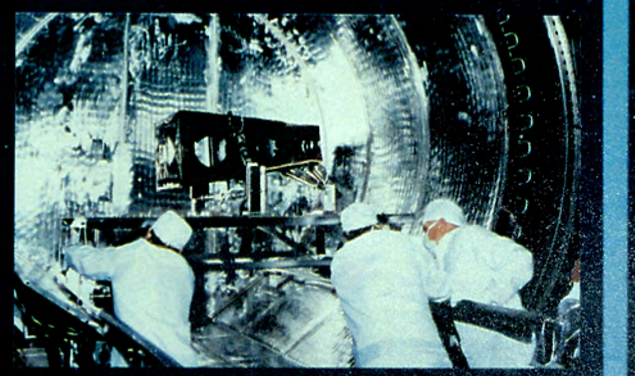
CCD TEMPERATURE
The Loral CCDs can be operated at a higher temperature than the old TI devices. At a higher temperature, the rate of contamination is expected to be decreased by a factor of 3-10.

PHOTOMETRIC STABILITY
The new CCDs have stable quantum efficiencies. No UV flood is required, so it will be possible to warm up the detectors to flush contaminants without significantly affecting the photometric performance of the detectors.

FUV PHOSPHOR
The WFPC-2 CCDs use a lumogen coating which is more efficient at detecting UV light than the coronene used in WFPC-1.

FILTERS
Broad passband far–UV filters, including a Sodium Woods' filter, will be included in the filter set. The Woods' filter has superb red-blocking characteristics.





Preparation for vacuum bakeout of the optical bench. In WFPC-2, all components are being baked out to reduce contamination in the UV

IMPROVED CCD TECHNOLOGY

WFPC-2 will use new Loral CCDs in place of the TI devices used in WFPC-1. These devices maintain the WFPC-1 format (800 x 800, 15 micron pixels) and offer a number of advantages:

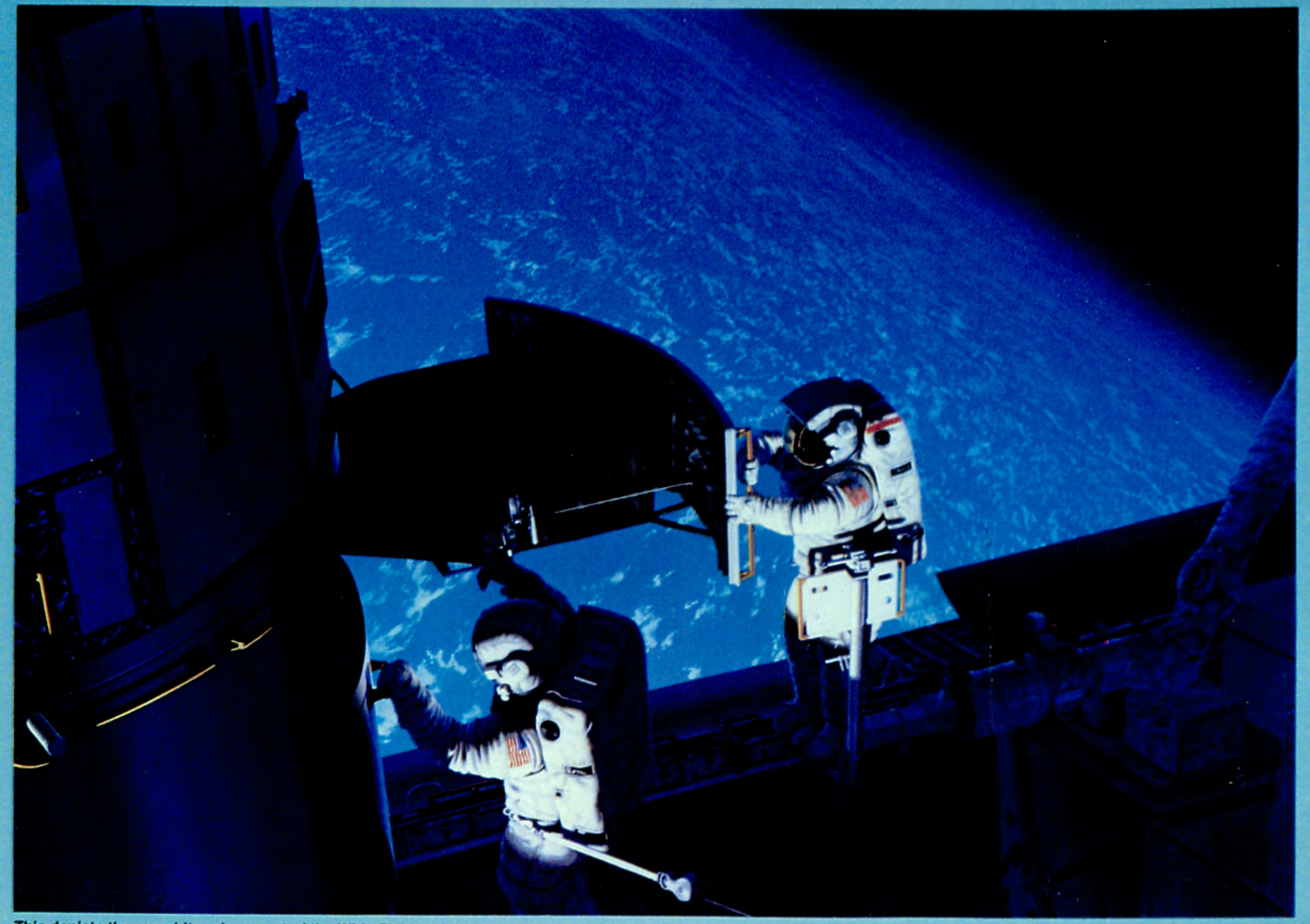
LOWER READ NOISE
The total CCD + WFPC electronics signal chain have a read noise of 7 e⁻, allowing superior performance for read-noise limited low surface brightness applications.

NO DEFERRED CHARGE/RESIDUAL IMAGES
The Loral CCDs do not suffer from "deferred charge," and so do not need to be preflashed. This further reduces the effective noise in low light level exposures. A fix for residual images has also been incorporated in the WFPC-2 electronics.

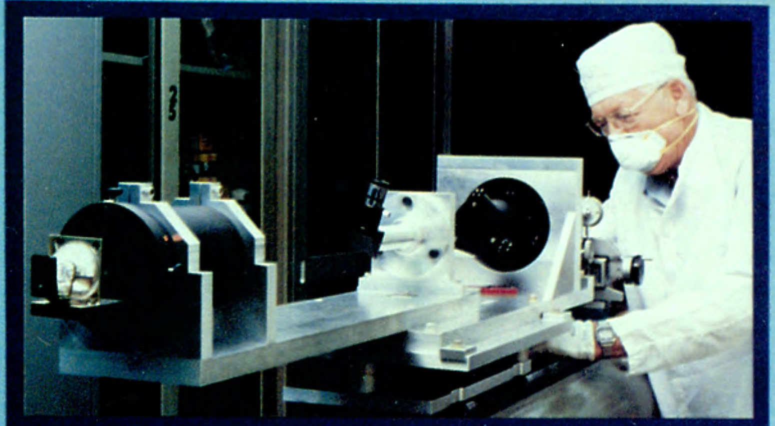
A/D CONVERSION
The timing problem which lead to errors in A/D conversion especially prominent in the low order bits of WFPC-1 has been fixed in WFPC-2.

NO UV FLOOD
The Loral CCDs do not demonstrate the "Quantum Efficiency Hysteresis" behavior seen in WFPC-1, and so do not need to be subjected to a UV flood. Apart from the obvious operations advantages, this makes the calibration of the devices insensitive to thermal cycling. This leads to a better calibrated instrument, and will enable decontamination of the chips by warming them (to maintain UV capability) without loss of calibration.

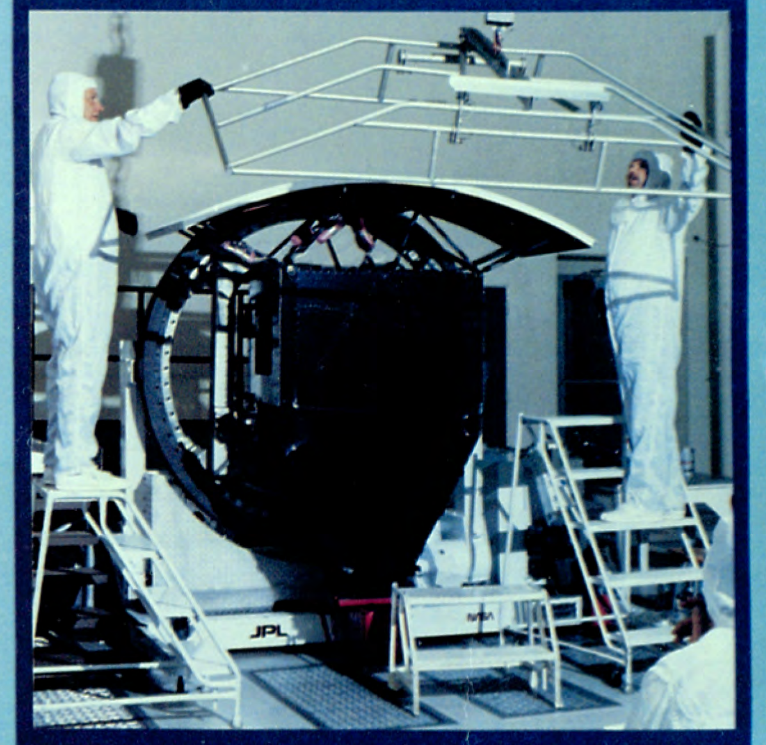
COSMETICALLY SUPERIOR
The figures at right compare flat fields with WFPC-1 and WFPC-2 devices. The WFPC-2 devices typically show <5% sensitivity variations across the chip, and show very little color sensitive structure. The improved cosmetics make the devices far easier to calibrate than WFPC-1 and will greatly improve photometric accuracy.



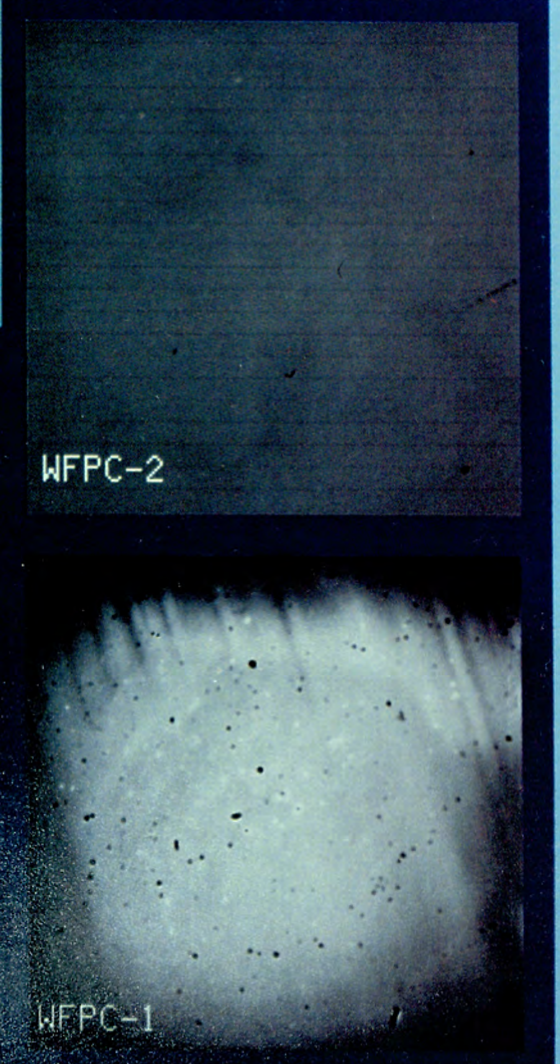
This depicts the on-orbit replacement of the Wide Field and Planetary Camera (WFPC-1) with WFPC-2, a Shuttle activity now scheduled for November 1993. WFPC-2 is in construction at Jet Propulsion Laboratory.



Initial alignment of relay optics



Fit check of WFPC-2 housing, radiator, and optical bench.



Sample flat-fields from a WFPC-1 Texas Instruments CCD (lower) and a WFPC-2 Loral CCD (upper). The new CCDs are significantly flatter and cosmetically superior. This allows much better calibration for WFPC-2.

Inspection of radiator hardware

NASA
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California