The following terms and acronyms are used in this handbook.

**A-D**: Analog to digital.

**CCD**: Charge-coupled device. Solid-state, light detecting device.

**CDBS**: Calibration Data Base. System for maintaining reference files and tables used to calibrate HST observational datasets.

**CIT**: California Institute of Technology.

**COBE**: Cosmic Background Explorer.

**COSTAR**: Corrective Optics Space Telescope Axial Replacement.

**CP**: Call for Proposals.

**CR**: Cosmic ray.

**CVZ**: Continuous viewing zone.

**DQ**: Data quality.

**DQE**: Detector quantum efficiency.

**DN**: Data number.

**ETC**: Exposure Time Calculator.

**FAQ**: Frequently asked questions.

**FGS**: Fine Guidance Sensors.

**FITS**: Flexible Image Transport System. A generic IEEE- and NASA-defined standard used for storing image data.

**FOC**: Faint Object Camera.

**FOM**: Field Offset Mirror (or mechanism)

**FOS**: Faint Object Spectrograph.

**FOV**: Field of view.

**FPA**: Focal plane array.

**FSW**: Flight software.

**FTP**: File Transfer Protocol. Basic tool used to retrieve files from a remote system. Ask your system manager for information about using FTP.

**FUV**: Far ultraviolet.
**FWHM**: Full width at half maximum.

**GASP**: Guide Star Astrometric Support Program.

**GEIS**: Generic Edited Information Set. The multigroup format used by STSDAS for storing some HST image data.

**GHRS**: Goddard High-Resolution Spectrograph.

**GO**: General Observer.

**GTO**: Guaranteed Time Observer.

**HSP**: High-Speed Photometer.

**HST**: Hubble Space Telescope.

**ICD**: Interface control document. Defines data structures used between software or systems to ensure compatibility.

**IDT**: Instrument Development Team.

**IR**: Infrared.

**IRAF**: Image Reduction and Analysis System. The system on which STSDAS is built.

**IUE**: International Ultraviolet Explorer.

**K**: Degree Kelvin.

**LSF**: Line spread function.

**MOS**: Multi-object spectroscopy.

**ND**: Neutral density.

**NICMOS**: Near-Infrared Camera and Multi-Object Spectrograph.

**NUV**: Near ultraviolet.

**OPUS**: OSS and PODPS Unified Systems.

**OSS**: Observation Support System.

**OTA**: Optical Telescope Assembly.

**PAM**: Pupil Alignment Mirror (or mechanism).

**PI**: Principal investigator.

**PODPS**: Post-Observation Data Processing System.

**PSF**: Point spread function.

**QE**: Quantum efficiency.

**RA**: Right ascension.

**rms**: Root mean square.

**SAM**: Small angle motion.

**SLTV**: System level thermal vacuum (testing phase).

**SMOV**: Servicing Mission Orbital Verification.

**S/N**: Signal-to-noise ratio.

**SSR**: Solid state recorder.
**ST-ECF**: Space Telescope European Coordinating Facility.

**STEIS**: Space Telescope Electronic Information System. The World Wide Web host from which information, software, documentation, and other resources pertaining to the HST can be obtained.

**STIS**: Space Telescope Imaging Spectrograph.

**STScI**: Space Telescope Science Institute.

**STSDAS**: Space Telescope Science Data Analysis System. The complete suite of data analysis and calibration routines used to process HST data.

**SV**: Science verification. Process of taking observations that can be used for HST instrument calibration.

**TAC**: Telescope Allocation Committee.

**TEC**: Thermal electrically cooled.

**URL**: Uniform resource locator. Address for WWW.

**UV**: Ultraviolet.

**VCS**: Vapor cooled shield.

**WF/PC**: Wide Field/Planetary Camera.


**WWW**: World Wide Web. Hypertext-oriented method for finding and retrieving information over the Internet.

**YSO**: Young stellar object.
Glossary
Appendix

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Bright Object Mode

The time taken to read through a quadrant on the array sets a fundamental limit on the fastest electron collection rate which can be achieved by resetting all the pixels. An inherent consequence of the methods of operating the NICMOS array detectors in the ACCUM, MULTIACCUM, and RAMP modes is therefore that there is a minimum possible exposure time, ~ 0.6 seconds (0.302 for MULTIACCUM), set by the time required to read the array. For a very bright object, such as the disk of Jupiter, the time between the reset of a pixel, and its final read is sufficiently long that the pixel saturates. Although the detector arrays are multiplexed by division into four quadrants, each pixel in a 128 x 128 pixel quadrant must be sampled in some order (note that there is no transfer of charge as is done in a CCD).

The solution adopted to this problem for NICMOS is the provision of a bright object mode which enables targets to be observed which are ~600 times brighter than is possible in the other modes without saturating. In BRIGHTOBJ mode, an ACCUM sequence of operations is performed on one pixel in each quadrant at a time. That is, the pixel is reset, read, integrated, and read again with the difference between the final and initial readouts being stored as the measured signal and the interval between the reads being the exposure time. This process is repeated sequentially for all pixels in each quadrant. Users can think of this as integrating on a single pixel at a time. The smallest integration time which can be used is 1.024 milliseconds. Figure 15.1 illustrates the operation of bright object mode. Initially the detector is reset and the first pixel (solid shading) in each quadrant is read. A reset is then made and the second pixel in each quadrant is read. The process continues until all 16,384 pixels in each quadrant have been read.
The time required to take a BRIGHTOBJ mode exposure can be rather long. Since photons are only collected in one pixel per quadrant at a time, the time associated with obtaining the frame is \(0.206 + (EXPTIME \times 16384)\) where \(EXPTIME\) is the integration time per pixel (i.e. the observation time is approximately \((128^2)\) x the exposure time). For example, if an integration time of 0.1 seconds is used to observe a bright target then the actual time required to complete the observation would be around 27 minutes! This means that allowing for acquisition time only two such exposures could be obtained in a single target visibility period. However, it is not always so serious. In the case of Jupiter for example the integration times required per pixel are only of the order of milliseconds and so the total integration time will only be around 20 seconds.

The longest exposure time which is possible in BRIGHTOBJ mode is 0.261 seconds, requiring 4278 seconds in total. Thus it is possible, in the worst case, for a single BRIGHTOBJ mode exposure to use more than an orbit. In general observers are strongly advised to consider the trade-off between relatively long BRIGHTOBJ mode exposures (which take the longest time) and short ACCUM
Ramp Mode exposures (perhaps using a filter and camera combination with lower throughput).

One of the obvious uses of BRIGHTOBJ mode is for solar system targets. Due to the limitations of the Track 51 capability (linear tracking with orbital or planetary parallax correction) HST can only follow a moving target for 2048 seconds, of which 1980 seconds is available for an exposure. This therefore sets the longest integration time that is possible for a moving target in BRIGHTOBJ mode. Proposers will need to judge the real integration time and signal to noise ratio required for the observation time and adjust accordingly.

The advantage of this mode of operation is the ability to observe objects significantly brighter than the normal saturation limit of the detector.

The disadvantages are several:

- Due to the extremely large time penalties involved in this mode operation, it cannot be used to accomplish time resolved observations on shorter time intervals than ACCUM mode.
- Some observations will take a long time. BRIGHTOBJ mode exposures are therefore very sensitive to the quality of the pointing of HST. They should not be obtained using GYRO guiding mode. In addition, if the object changes (planetary rotation) or if the telescope pointing changes it will affect different parts of the image differently.
- The D.C. offset of the detector output is not removed in this mode of operation. In general, the signal is very high and the offset does not matter. In some cases it will and this can be a detriment to the signal accuracy.
- There is also no cosmic ray correction or saturation detection in this mode of operation. Although they are still susceptible to cosmic rays, events should be very rare as the integration time per pixel is very short.

Ramp Mode

The RAMP mode is an intrinsically different way of obtaining an image which can be thought of as an on-board hybrid between ACCUM and MULTIACCUM, providing a limited version of the advantages we described for MULTIACCUM with the simplicity of ACCUM, producing a single output image at the end of the exposure. RAMP mode is appropriate when high dynamic range or cosmic ray cleaned observations are required but the data volume is constrained. The basic ideas behind the RAMP mode are illustrated in Figure 7.4.

RAMP mode has not been tested on-orbit, and no plans exist for its validation. Given the proven capability of MULTIACCUM and the solid state recorder which effectively alleviates data rate concerns, RAMP is not believed to be useful.
As in the case of the MULTIACCUM mode, in RAMP mode the initial detector readout, which obtains the initial pixel values, is followed by a number, NSAMP, of non-destructive readouts, up to a maximum of 254. Both the integration time $T$ and the number of passes NSAMP are set by the observer in the proposal. Unlike the readouts of MULTIACCUM the intermediate readouts in RAMP mode must be at equal intervals during the exposure and are not individually downlinked to the ground. The integration time is the time between the initial non-destructive read of the first pixel and the last non-destructive read of the first pixel. If $T$ is the total integration time the sub-reads occur at intervals of $T/\text{NSAMP}$. As illustrated in Figure 7.5, each of the ramp samples are formed by taking the difference between the cumulative signal recorded after the current read and that obtained at the previous read.
Figure A.3: The On-Board Ramp Mode Calculations

Each readout is differenced ONBOARD with the previous readout and used to compute a running mean of the # of counts per sample interval, t, and an associated variance for each pixel.

\[ \bar{y} = \frac{1}{6} \sum_{i=1}^{6} y_i \]

Mean countrate image

+ variance image

+ # valid samples image

Integration time = t

The time taken to perform the ramp calculation is ~7 seconds per camera and this sets the minimum time between successive ramp samples. Thus if 3 cameras are in use in ramp mode this restriction expands to > 21 seconds (there are other overheads involved). Ramp mode produces three data arrays; the image which contains the mean values of the slope or ramp of each pixel derived from the
difference images; the number of samples which were used to determine the slope, and the variance over all the samples used in the calculation of the image.¹

The aware reader will have realized that if all the difference images are used to form this final mean the output of RAMP mode will be identical to that of an ACCUM for a time T/NSAMP. However, the great power of RAMP mode is that during the calculation of the slope it is also possible to detect pixel saturation and optionally cosmic rays, but not without penalties as we will explain shortly. A variety of ways of using this saturation and cosmic ray hit information are available to the user. The samples array becomes meaningful when one of these options is chosen.

**Using Ramp Mode to Reject Cosmic Rays and Detect Saturation**

Ramp mode provides processing mechanisms for the detection, and elimination of cosmic rays (CR) and for saturation detection. The optional parameter CR-ELIMINATION (see the proposal instructions) selects from four available processing modes for handling cosmic ray events. We have already described the first of these in which no action is taken, and the data returned is equivalent to a simple ACCUM exposure. Since the ramp mode computes a progressively updated variance at each sample cosmic ray events are detected by changes in slope which are more than 3 σ away from the slope determined by the previous reads. The basic principles behind cosmic ray rejection are illustrated in Figure A.4 and Figure A.5.

In the CONTINUE method, which is the default setting, when a cosmic ray is detected at a given pixel the value from that ramp sample for that pixel is eliminated from the image and variance arrays. Other pixels are unaffected by the detection. The ramp sampling then continues until the end of the exposure, removing any subsequent suspect samples in the same way on a pixel-by-pixel basis.

In the RETAIN method when a cosmic ray is detected at a given pixel, processing for that pixel is suspended and the mean pixel and variance values obtained up to the sample in which the CR hit occurred are recorded and the number of valid samples is set to that before the hit occurred. As before, other pixels are unaffected by the detection. The ramp sampling continues processing these until either they also receive a CR hit, and are themselves suspended, or the end of the exposure is reached.

In The MARK method any pixel which receives a detected CR hit is flagged as bad (set = 0) in the data quality array, but the sample in which this occurred, and all subsequent samples, are still used in the variance and pixel value calculations.

¹ The term *ramp* came from the original concept of performing an updating linear least-squares fit to the data, which was not implemented due to the limited computer power of the NICMOS computer. Over 20 seconds would be required to compute the LSQ-fit at each ramp step.
The user then has the responsibility for deciding what to do with suspect pixels during analysis.

Figure A.4 shows the ramp mode operation for an uncontaminated signal. In the top panel we see the cumulative counts with time. Marked is the time interval between ramp samples, \( t \), and the signal associated with each ramp sample. The middle panel shows a plot of the signals measured in each of the ramp samples. Since there is no cosmic ray contamination, this is essentially a constant except for statistical fluctuations. The bottom panel shows how the data quality flag would have been evaluated for each ramp sample by the flight software. In this case all samples are good.
Figure A.5 shows ramp mode operation for a signal contaminated with cosmic rays. In the top panel we again see the cumulative counts with time. Two cosmic ray events are marked. The middle panel again shows a plot of the signals measured in each of the ramp samples. Notice that the samples effected by the cosmic rays are outliers from the trend we saw in Figure A.4. The bottom panel shows how the quality flag would have been evaluated for each ramp sample by the flight software. The two samples with cosmic ray hits have been identified as bad and are not used in the final calculation of the mean signal.
**Figure A.5: Ramp Mode Operation for Signal Contaminated by Cosmic Rays**

RAMP mode also discontinues the processing on a pixel once the signal in the pixel reaches a level in which the deviation from linearity is > 2%. As shown in Figure A.6, the result up to that time, and the number of samples which had been collected are stored and downlinked. This can be very useful in images where the expected flux levels are not well known and in serendipitous or survey observations. Figure A.6 shows ramp mode operation for a signal which reaches the saturation or nonlinear limit prior to the end of the exposure. In the top panel we again see the cumulative counts with time. The horizontal line marks the saturation or nonlinear threshold. The bottom panel shows how the quality flag would have been evaluated for each ramp sample by the flight software. All the samples which occur after the saturation limit have been identified as bad and are not used in the final calculation of the mean signal.
**Limitations of Ramp Mode**

**Dark Current Removal**

The real science data sits on a plateau of dark current which is a varying function of time since reset (the shading effect—see Chapter 7). As this dark current varies significantly, at least in the first minute, in order to update the mean and variance without bias its contribution has to be removed. Moreover, with either or both the saturation and rejection actions turned on, each pixel can essentially have a different integration time (number of valid samples). Since the ramp mode will return an output array without the dark current removed this has to be accounted for in the subsequent data reduction, either using an empirical correction or a model. How this model is implemented is therefore crucial to the functioning of the mode as a failure to treat it properly will invalidate ramp mode data for faint sources. At present it is not clear how well this can be done. One must ensure that sufficient ramp samples are obtained in order for the ramp calculations to be reliable. Ideally this should be a number > 30, but numbers as low as 16 or so might well suffice, if the frequency of cosmic ray hits on orbit is...
not too high. Because the start of the ramp calculation has to be delayed for ~30 seconds to avoid the effects of shading ramp mode will not be useful for bright sources.

**Cosmic Ray ADU Distribution Function**

In an automatic sigma clipping procedure a crucial parameter is the threshold at which the rejection occurs. If this is set too high then there can be many low level cosmic rays which are not removed. With the ramp mode data it will not be possible to remove them without interpolating over them. Even detected CR hits will potentially have *halos* of distributed charge around them which might still contaminate the data if the CR hits turn out to not be confined to single pixels. This is a significant disadvantage compared to **MULTI-ACCUM** mode. More seriously if it is set too low then the underlying statistical distribution of the real events is censored invalidating the basic assumptions implicit in standard error analysis. This difficulty has led statisticians to develop robust iterative techniques for such problems. However these are computationally expensive, and require all the data to be kept in memory, so that a dynamic adjustment of the rejection criteria can take place. On board HST, the timing restriction created by the limited computing power of the flight computers eliminate this as a practical possibility.

**Cosmic Rays that Won’t be Detected**

Detection of cosmic rays (CR) in RAMP mode relies on discontinuities in the detected count rate for a pixel. However, three readouts are needed in order to make an estimate of the count rate. Cosmic ray hits before the fourth readout are therefore not detected. The first readout cannot occur earlier than 30 seconds into the integration, and the minimum time between readouts in RAMP mode is about 7 seconds. Therefore, the fourth readout cannot occur any sooner than 51 seconds into the integration. There is a significant probability that cosmic ray hits will occur during the first minute of an integration. These hits will not be detected or removed in RAMP mode (in **MULTI-ACCUM**, on the other hand, since all the readouts are accessible to the pipeline calibration software, cosmic rays can be detected at any stage during the integration).
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