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Restoration of HST WFPC2 Images in Gyro-Hold Mode

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Abstract. In gyro-hold tracking mode, *HST* is stabilized only with its gyros, and the Fine Guidance Sensors are not used to maintain pointing. With gyro drift rates of order $0\farcs002$ per second of time, a WFPC 2 Planetary Camera image with a typical exposure time of 100 s can be blurred by as much as five pixels. Image restoration techniques developed for use on aberrated *HST* images have been adapted for use to remove this motion blur. Experiments have been done on WFPC 2 images of NGC 330 and NGC 422 (having exposure times of 80 and 100 s in gyro-hold mode) with complete success.

1. Introduction

Since the first servicing mission in 1993 December, *HST*'s optical performance has been corrected to nearly the original design specifications. As a result, however, spacecraft stability and the guiding mode used by the Fine Guidance Sensors (FGSs) have become much more significant factors in determining overall image quality. The FGSs now have only two guiding modes: fine lock and gyro-hold. In order to utilize gaps in the *HST* observing program that would otherwise be unused, about 200–300 "snapshot" observations are placed on the program in each observing cycle. In order to minimize spacecraft overhead, snapshot observations are taken without guiding, using gyro pointing control only (e.g., Bond 1994). Gyro-hold pointing drifts at a rate ah high as 1.4 ± 0.7 mas s^{-1}. This motion causes a significant blur in WFPC 2 images, even for exposures as short as 100 s. Given our experience in restoring the aberrated images from WFPC 1, we decided to explore the possibilities of removing the motion blur from images taken in gyro-hold pointing mode with WFPC 2.

Two WFPC 2 snapshot observations of NGC 422 and NGC 330 (kindly provided by M. Shara) have been restored successfully using the image restoration techniques which have been implemented in the STSDAS package.

2. Motion Blurred WFPC 2 Images

An NGC 422 WFPC 2 WC2 image and an NGC 330 WFPC 2 PC1 image were taken in mode `FSGLOCK = GYROS` in 1994 January. A synopsis of these images

[1] Operated by AURA, Inc., for NASA

is given in Table 1. In the table, the column "Image Section" indicates the pixel coordinates of the detector in the sequence ($x_{\rm min} : x_{\rm max}, y_{\rm min} : y_{\rm max}$). The restorations have each been done on a 256×256 pixel subimage.

Table 1. WFPC 2 Images

Object	Camera	Filter	Exp Time	Date	Image Section
NGC 422	WF2	F450W	100 s	25/01/94	(103:358,494:749)
NGC 330	PC1	F450W	80 s	27/01/94	(499:754,99:354)

3. Image Restoration

The restoration of the motion blurred images is carried out in three stages: (1) standard restoration using a model PSF, (2) determination of the motion-blur function, and (3) final restoration. The initial model PSFs were computed using Tiny TIM Version 4.0. For each observation, the PSF position coincides with the peak position of a bright star.

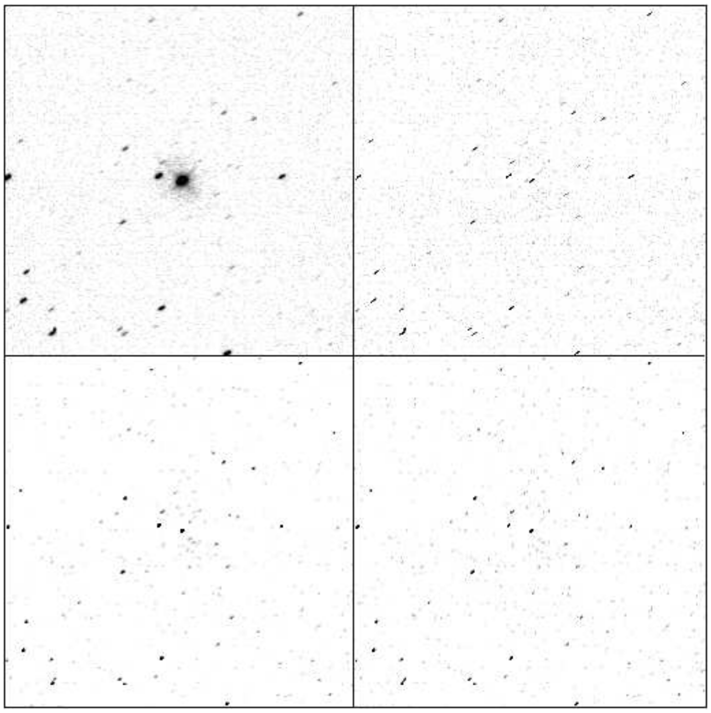

Figure 1. WFPC 2 image of NGC 422 (WF2, exposure = 100 s). Top left: original observation. Top right: standard Tiny TIM deconvolution. Bottom left: MEM restoration (final). Bottom right: Lucy restoration (final).

In order to generate the motion-blur function, a standard Tiny TIM PSF restoration is made for each observation. The blurring function is determined by averaging the images of several bright stars in the initial restored frame. The final PSF is constructed by convolving the motion blur function with the Tiny TIM PSFs.

The restorations were done using the maximum entropy method (MEM) (Wu 1992, 1994) as implemented in STSDAS. The restored image adopted is the ME solution after approximately 100 iterations. The Richardson-Lucy method has also been tested in this experiment using the task *lucy* implemented in STSDAS (White 1993; Stobie et al. 1994). The motion-blurred images of NGC 422 and NGC 330, and their restorations are illustrated in Figs. 1 and 2, respectively.

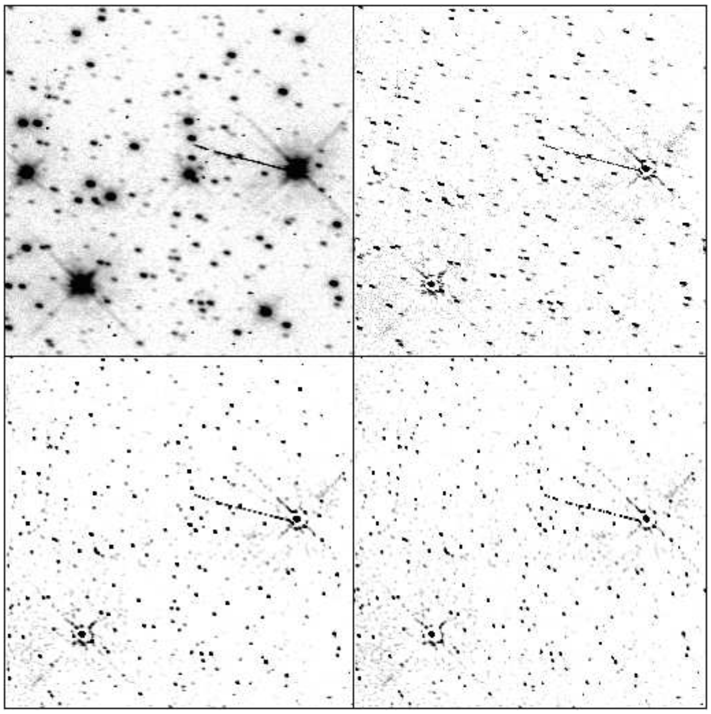

Figure 2. NGC 330 WFPC 2 (PC1, exposure = 80 s). Top left: original observation. Top right: standard Tiny TIM deconvolution. Bottom left: MEM restoration (final). Bottom right: Lucy restoration (final).

4. Discussion and Conclusions

The point spread function for data taken in gyro-hold mode is the convolution of the normal PSF with the motion blurring function. Because our PSF models are now quite accurate, deconvolution of a motion-blurred image with a model PSF yields an image in which the remaining shapes, and features associated with point sources, define the motion-blur component. This residual also encompasses

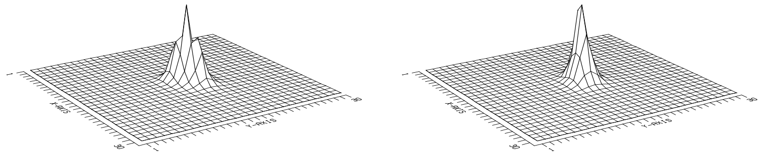

Figure 3. Motion-blurred PSF. Left: PSF of NGC 422 WFPC 2 (WF2, exposure = 100 s). Right: NGC 330 WFPC 2 (PC1, exposure = 80 s).

any additional mismatches between the model PSF and the observed PSF in the absence of motion blur.

WFPC 2 is undersampled, especially in the UV in WF mode. In order to obtain a better representation of the motion blurring function, several (partially) restored star images are averaged together. The success of the method relies upon having several bright but unsaturated star images in the field of view.

Our experiments indicate that gyro drift is not uniform linear motion, but rather must be described by a two-dimensional function. Indeed, the final PSF obtained for the NGC 422 image shows a multiply-peaked structure, indicating that within the exposure time the telescope dwelled longer at certain locations than in others. A surface plot of this PSF and the final PSF of the NGC 330 image are shown in Figure 3. Both the MEM and Richardson-Lucy algorithms implemented in STSDAS were successful in restoring the image with a multiply-peaked PSF, and gave virtually indistinguishable results.

The standard image restoration techniques developed for use on aberrated *HST* images can be adapted for removing the motion blur from snapshot images taken under gyro-hold pointing mode. This should allow observers to obtain optimal spatial resolution and dynamic range on many of these data sets.

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