CHAPTER 3: THE SATELLITE

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3.1 General Description
3.2 The Mirror
3.3 Pointing and Visibility
3.4 Aspect
3.5 Recovery of IPC and HRI data which were rejected in the automatic processing.

3.1 General Description

The HEAO-B X-ray telescope consists of a high resolution mirror assembly, a focal plane transport assembly capable of positioning one of four X-ray instruments at the telescope focus, a monitor proportional counter aligned with the telescope,. broad band filter and objective grating spectrometers which can be used in conjunction with focal plane instruments and an aspect system. Each of the focal plane instruments operating along with auxiliary systems stresses one or more of the measurement capabilities of the Observatory: precise location, angular size and structure, energy spectra, and time variability. Figure 3.1 shows the configuration of the HEAO-B Observatory.

A more detailed description of the EO can be found in Giacconi et al. 1979 (Ap. J. 230, p540).

3.2 The High Resolution Mirror

The telescope design chosen for HEAO-B is the Wolter type I geometry shown in Figure 3.2/1 in which the first element is a paraboloid and the second element is a confocal, coaxial hyperboloid. Axial rays are reflected towards the common focus by the paraboloid and then reflected by the hyperboloid towards its other focus.

The grazing angle required for efficient X-ray reflection is < one degree, and the optical elements have the appearance of shallow cones with relatively small ratios of collecting to polished area. The area cannot be increased indefinitely by increasing the length without a loss of resolution for off-axis rays, since the size of the image is approximately proportional to the length of the telescope. The area can be increased by nesting surfaces which have the same focal plane; this results in increased area and acceptable resolution since the individual mirror lengths do not become excessive.

The HEAO-B mirror design consists of four nested surfaces with diameters varying between 12.8 and 22 inches. The separation between the paraboloid-hyperboloid intersection plane and the focal plane is 135 inches, which results in a focal plane scale of 1 mm/arcmin, or 16.6 microns/arcsec. The 21-inch segment lengths theoretically result in one arcsecond blur circle radii for sources within three arcminutes of the telescope axis. The accuracies

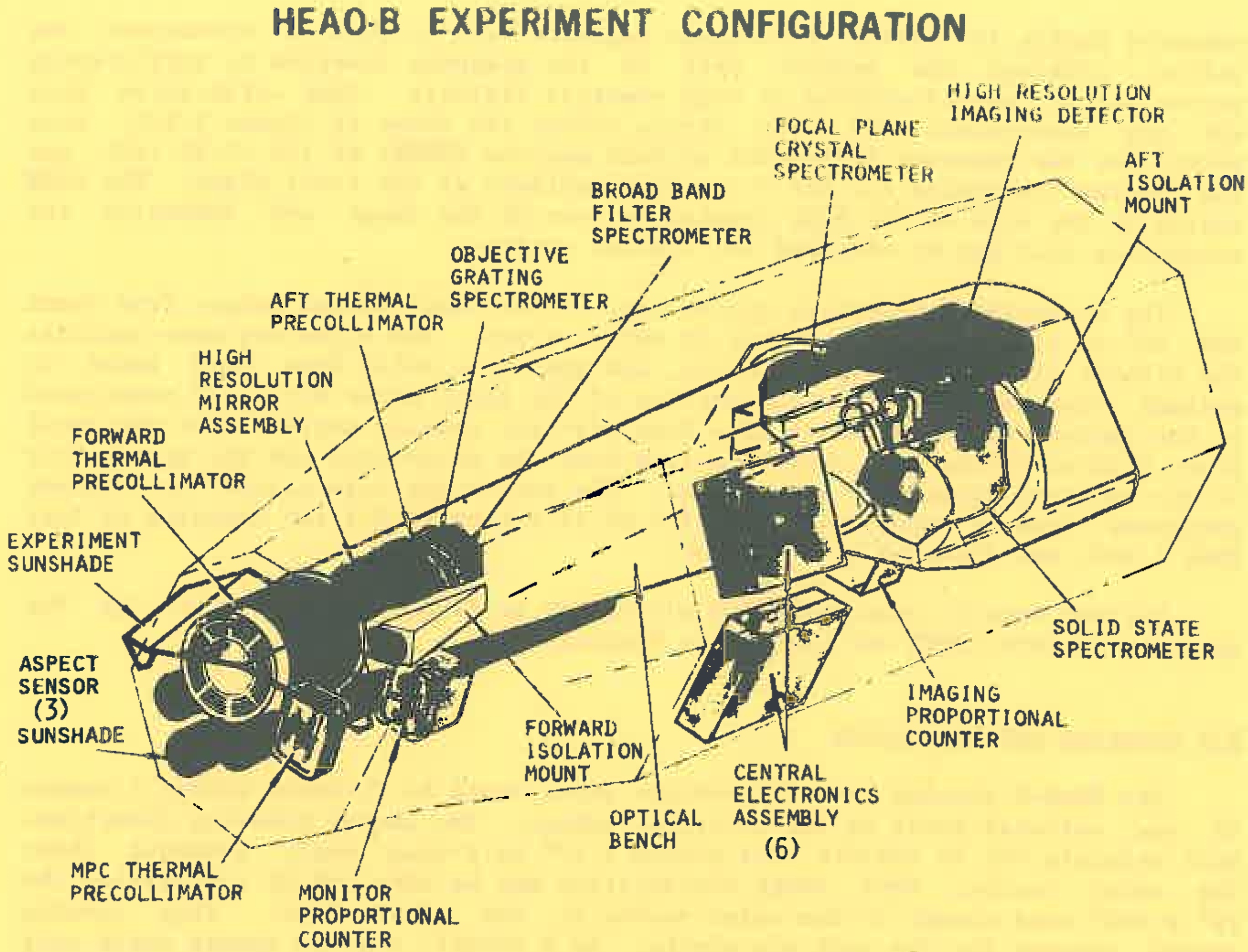

Figure 3.1

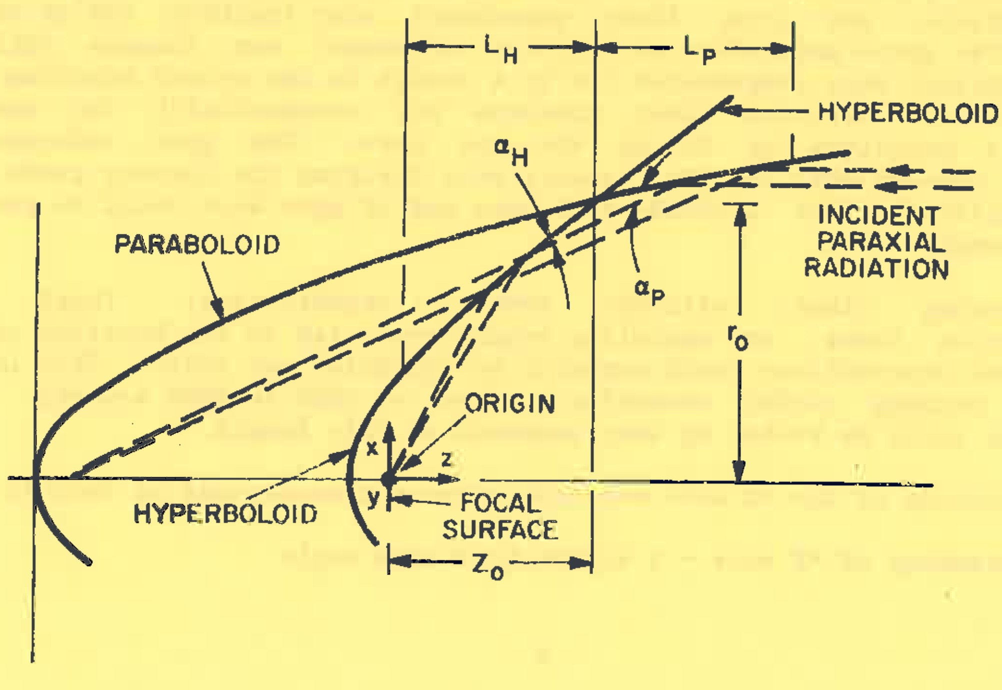

Figure 3.2.1

achieved during the mirror fabrication degraded this to about 2 arcseconds rms radius, although the central peak of the response function is sufficiently narrow for arc second studies of high contrast features. Some calibration data and the theoretical rms blur circle radius are shown in figure 3.2/2. Data points are the measured half-width at half maximum (HWHM) at 44A (0.28 keV) and the radius containing 1/2 the X-ray flux incident at the focal plane. The HWHM radius is the size of the high resolution core of the image and indicates the resolution that can be obtained for typical sources.

The theoretical effective mirror area of the final design ranges from about 400 cm^2 at 0.25 keV down to about 30 cm^2 at 4 keV. The effective area includes the effects of the telescope geometry, and apertures which have been added to exclude unwanted rays from the portion of the focal plane within 20 arcminutes of the optical axis. Unwanted rays from off-axis sources could strike the focal plane without having been reflected from both the paraboloid and the hyperboloid if the aperture stops were not present. The scattering loss caused by surface roughness from a circle with diameter of 12 arcsec is 0.4 for energies of less than 1 keV, and rises to 0.7 at 4 keV.

Further details concerning the mirror may be found in an article by Van Speybroeck, 1979 (SPIE vol.184, Space Optics).

3.3 Pointing and Visibility

The HEAO-B viewing axis (+X vehicle axis) could be directed within 1 arcmin of any selected point on the celestial sphere. The normal pointing directions must maintain the +Z vehicle axis within a 15° half-cone angle centered about the solar vector. Thus, rough visibilities may be obtained by considering the 30° x 360° band normal to the solar vector at any given date: this viewing swarth covered the sky each six months. As a result, a given source could only be observed twice a year for periods of duration of 1 month.

The observatory had an active attitude control system consisting of gyros, reaction wheels, gas jets, three experiment star trackers, and an on-board computer. The gyros maintained an inertial reference; any torques (primarily gravity gradient) were compensated for by a change in the stored momentum of the reaction wheels. Reaction wheel momentum was automatically (or manually) unloaded as necessary by firing the gas jets. The gyro reference was continually updated when the star sensors were tracking the correct guide stars. Manual updates of the attitude reference and of gyro bias could be performed from the ground.

Maneuvering times, attitude control capabilities, focal plane reconfiguration times, and operating requirements led to the baseline that not more than two observations would normally be scheduled per orbit. This in turn implied a minimum useful observing interval of 1000 to 2000 seconds. Longer observations could be broken up into segments of this length.

The pointing of the +X axis was controlled and maintained as follows:

1. Accuracy of +X axis - 1 arcmin half cone angle

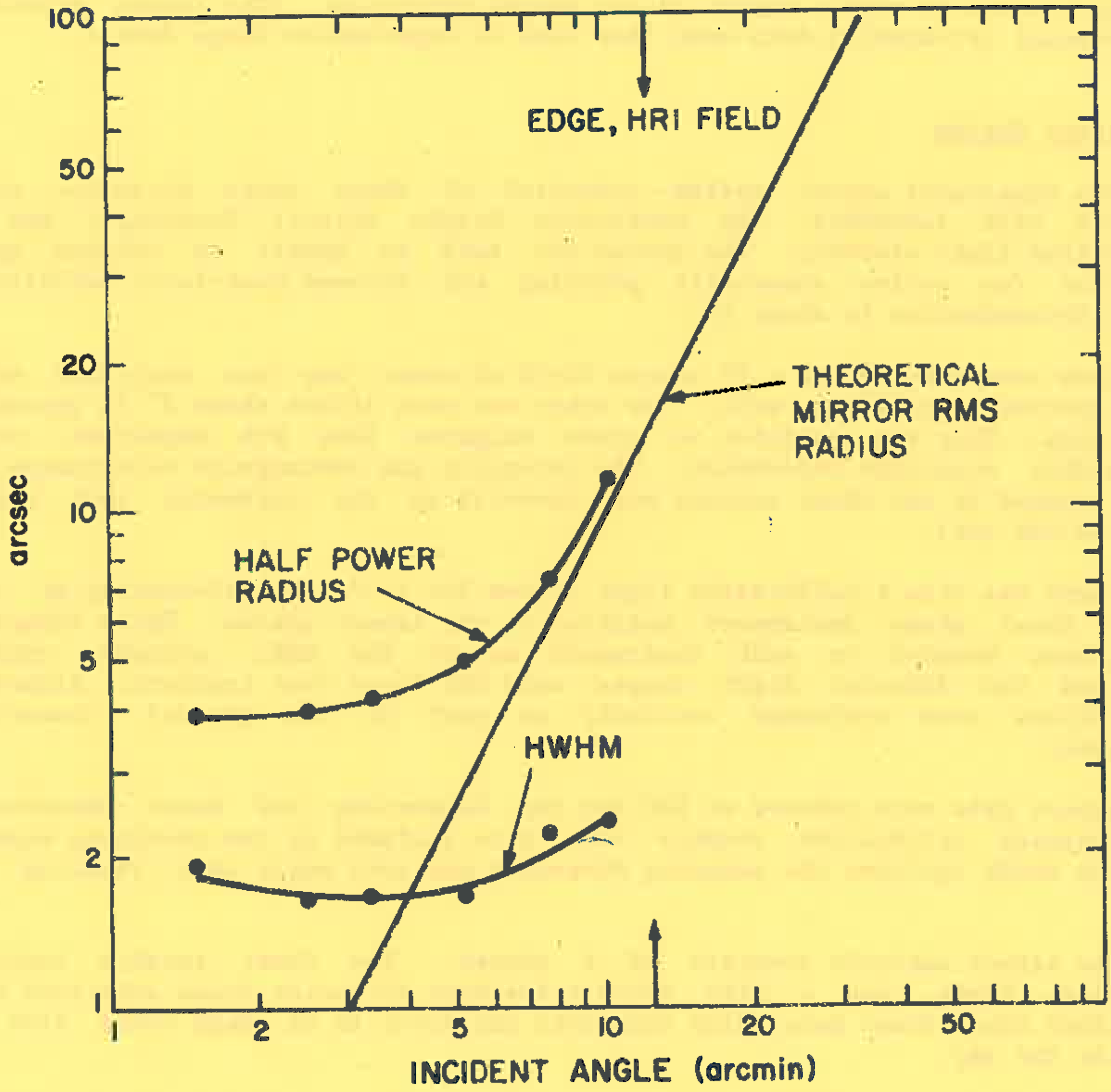

Figure 3.2.2 Measured HEAO-B mirror/HRI system response at 44Å.

(1 sigma).
2. Stability of +X axis - 30 arcsec in 1 hour (1 sigma).
3. Jitter of +X axis - 1 arcsec in 1 sec (1 sigma).
4. Jitter about +X axis (roll) - 20 arcsec in one sec (1 sigma).

Final attitude determination was performed at SAO. The star tracker data (along with gyro data as necessary) were compared with the known positions of the guide stars to obtain aspect to arc second precision. (The aspect solution and fiducial calibration data were then used to superimpose image data.)

3.4 Aspect System

The experiment aspect system consisted of three image dissector star trackers with sunshades, two protective bright objects detectors, and a calibration light assembly. The system was used to update an onboard gyro reference for active spacecraft pointing and allowed post-facto definitive aspect determination to about 1".

Each star tracker had a 2° square field of view; one was coaligned with the experiment pointing axis, the other two were offset about 2° in opposite directions. They are sensitive to stars brighter than 9th magnitude, with commandable magnitude thresholds. The intensity and rectangular coordinates of stars tracked by the three sensors were inserted in the telemetry each minor frame (0.320 sec).

There was also a calibration light system for in-flight referencing of the active focal plane instrument position to the aspect system. Three fiducial lights were mounted on each instrument except the SSS; suitable optics projected the fiducial light images onto the three star trackers. Fiducial calibrations were performed routinely as part of the planned observing sequences.

Aspect data were reduced at SAO for the Consortium and Guest Observers. The fiducial calibration results were also included in the resulting aspect solution which includes the pointing direction and roll angle as a function of time.

The aspect analysis consists of 4 phases. The final results include printouts, plots, and a file which gives best fit major frame solutions and individual minor frame data which corelates any point in an image field with a point on the sky.

ASPECT1 reads the ACDS file on a minor frame (time sequential) basis and performs:

- star tracker (STA) data temperature correction
- aspect solution for each minor frame based solely on tracked stars (one in each of two trackers)
- generation of fiducial calibration parameters

-transformation of gyro data to orthogonal coordinates
-generation of files for later phases
-(optional) gyro interpolation to fill in TM gaps (ASPECT1A)

ASPECT2 produces the final aspect solution for the nominal pointing situation by folding the individual minor frame STA solutions with gyro data to obtain a best fit for a specified interval. Gaps of bad STA data are automatically interpolated via gyros. Options exist to rely solely on gyro or STA data for specified intervals.

ASPECT3 allows for manual or automatic star identification and can put STA data on the graphics display, overlaying a star catalogue. This is used to augment ASPECT2, or replace it when the star trackers have not locked on the proper stars ("mapping mode").

ASPECT4 uses the star identification results of ASPECT3 to produce an aspect solution similar to ASPECT2.

Detailed results of the aspect analysis for each observation are now archived on microfiche at the CFA. Summary results are given in each production run: see section 4.9 for the HRI and 5.13, 5.14, and 5.15 for the IPC.

3.5 Recovery of IPC and HRI data which were rejected in the automatic processing.

The Einstein IPC and HRI processing systems have been designed to give optimum images for the 'typical' user. There are special circumstances in which a different set of photons can be selected which gives a better image for your purposes. The most common examples are listed here. A combination of these different criteria can also be made.

3.5.1 No aspect.

In a typical observation, a significant percentage of time intervals does not generate an aspect solution form the star trackers. Photons are still recorded in these intervals but are normally excluded from the image. If you are not interested in accurate positions or structure, but rather in source detection, variability, or possibly spectra, you may do well to include these data intervals.

3.5.2 No High Background. For bright sources it is possible to do useful science even in those time intervals with enhanced background (from charged particles, Earth's limb fluorescence, etc.). These intervals are normally rejected but can be included.

3.5.3 No Earthblock. The Earth size used for this filtering of the data is

significantly larger than the physical size of the planet as viewed from the satellite (75° instead of 67°). This was done to reduce the background. Thus, again for bright sources, including Earthblocked data can give extra photons and time coverage; but caution is advised: source attenuation by the atmosphere as the source nears occultation will occur. A successful recovery of useful data was demonstrated by S. Kahler et al. in a simultaneous optical/x-ray flare from YZ Canis Maj. which took place during "Earthblock", (Ap.J. 252, 239, 1982).

<u>3.5.4</u> <u>No Masking.</u> Both the HRI and the IPC have the edges of their fields of view "masked out" by the standard software to remove regions of high background. In the HRI this region is small (about 1 arcmin wide) and is not useful since the mirror blur circle has become large (see figure 3.2/2) so source positions are inaccurate, the Mg coating does not cover this area so fluxes are unreliable, and the detector effective area is not known. In the IPC however, the region is quite large (about 7' wide, see figure 3.5.4) so that fairly bright sources near the edge of the field of view can quite often be found here. The above options can be implemented at CFA by requests for "Special Processing". One should first be convinced that there is a reasonable probability of obtaining useful data of course. This can be ascertained by a careful examination of the strip charts and data logs or by consultation with knowledgeable staff.

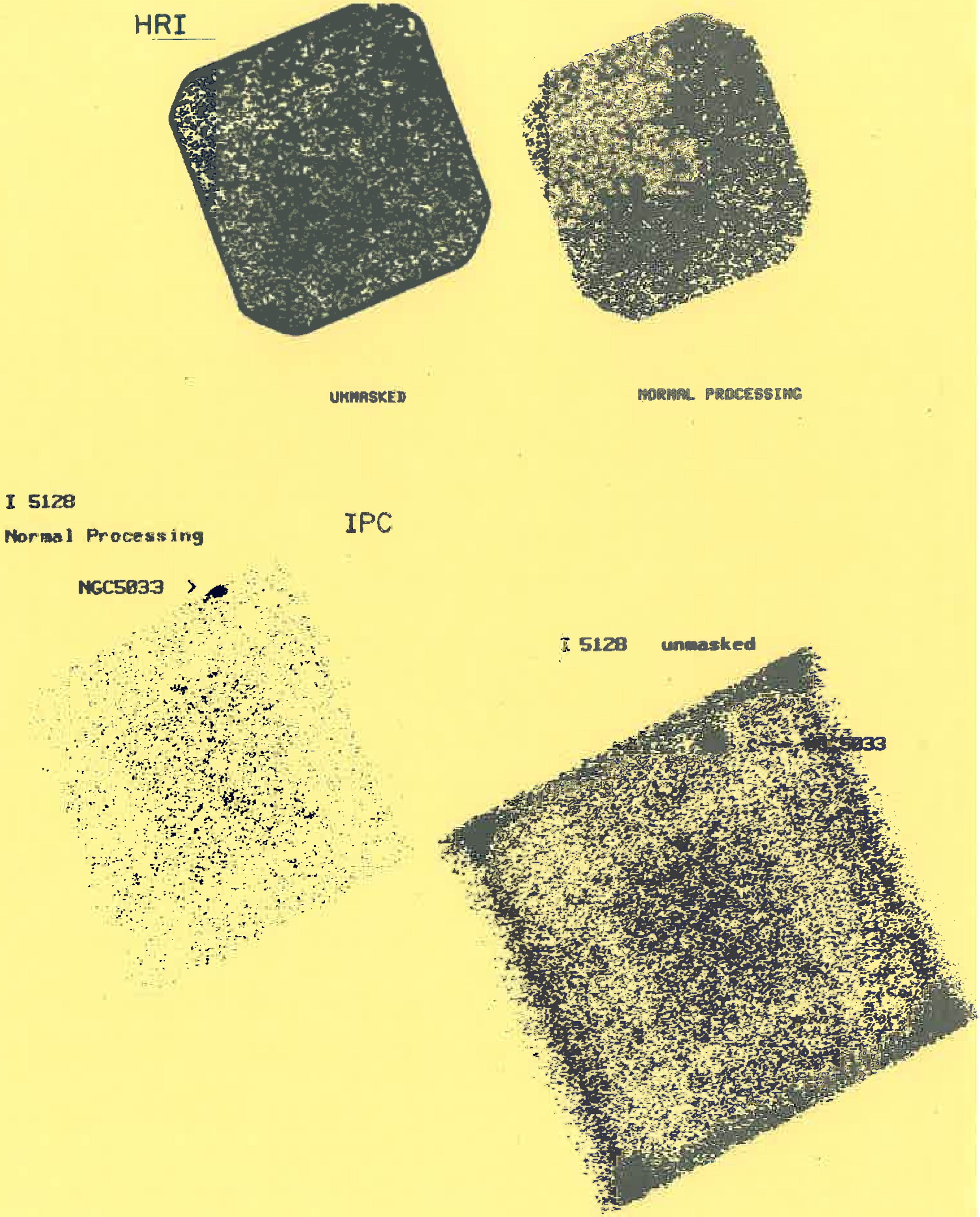

Figure 3.5.4 Normal processing compared to unmasked processing.