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The preparation of the Halley Multicolour Camera encounter night data set for submission to the International Halley Watch.

by

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SUMMARY

Data obtained by the Halley Multicolour Camera (HMC) from on board the European Space Agency's (ESA) spacecraft, Giotto, on the night of the 13th March 1986 have been prepared for submission to the archive of the International Halley Watch (IHW). This document briefly describes the calibration status of the submitted data, the form in which the data have been submitted and the FITS header entries accompanying the data themselves. Some data acquired on encounter night have been omitted from the set submitted to IHW. A brief explanation and a description of these data are included.

INTRODUCTION

Purpose

The European Space Agency's (ESA) Giotto spacecraft made its closest approach to comet P/Halley at 00:03:01.84 (+/-0.20) UT on March 14th 1986 (Curdt et al., 1988). On board, the Halley Multicolour Camera (HMC) was the only remote sensing experiment studying the nucleus and its environment. HMC operated for more than three hours prior to closest approach (CA) taking 2304 images before a malfunction occurred 9 seconds before CA. It had previously been agreed that the data obtained by the Giotto spacecraft during the fly-by would be made available to the International Halley Watch (IHW) for inclusion in its Halley archive. The objectives and structure of IHW have been described by the IHW staff (1985) and by Edberg et al. (1987). This document describes the HMC experimentors' contribution to the archive.

Instrumentation

The design of HMC has been described in depth by Schmidt et al. (1986) and Keller et al. (1987) and only details necessary for the evaluation and accurate description of the data are presented here. HMC was a modified Ritchey-Chretien type telescope with 2 584x390 Texas Instruments charge-coupled devices (CCDs) located in the focal plane. Each CCD was divided into 2 sections. CCD1 contained detectors B and C while CCD2 contained detectors D and E. HMC operated in a line scan mode from on board the spinning spacecraft and could take an image every spin (approx. every 4s). For the vast majority of the encounter, HMC operated in single detector mode (SDM) during which all transmitted images originated from detector C. For the last 5 minutes before closest approach, HMC operated in multi-detector mode (MDM) during which time four images were made (one from each detector) every spin and subsequently transmitted to ground. Hence, for MDM the image identifier (image id) which was incremented every spin does not provide a unique identification of the image. For images made during this period (from image id 3436 to 3503), the detector must also be specified.

The analogue to digital (A/D) converter in HMC provided images with 4096 levels. Three data compression techniques were adopted to bring the total data transmission to within acceptable levels. Firstly, all images were "square-root encoded" which, in combination with a two level gain switch, provided a dynamic range of 14 bits in 8 transmitted bits. Secondly, specific sections of each image could be selected by the onboard software for transmission to ground resulting in image formats such as 98 x 98 or 74 x 74 (the latter in MDM for example). Finally, images could be taken in various "superpixel" formats. In this case a group of pixels were summed on the CCD to form one superpixel for subsequent transmission to ground. Improved signal to noise is achieved in this technique at the cost of inferior spatial resolution. Information is included in the FITS header which specifies the data compression technique adopted for each individual image.

THE DATA SET

In total 2304 images were returned on encounter night between 20:50 and 00:03 UT. Of these images, a total of 2017 are present in the data set submitted to IHW.

Omitted data

Images taken in "photometer" mode have not been submitted. These data were obtained by using the spin of the spacecraft to scan the sky while the CCD remained unclocked. They therefore have one dimensional spatial information but each pixel contains the integrated intensity from some portion (depending upon the exposure time) of an annulus on the sky. These data would be useful for this purpose (particularly when taken through the narrow-band filters because of the significantly higher exposure time) were it not for the straylight entering the optics of the camera when HMC was on the sunward side of the spacecraft. No effort has been made to reduce this data and its scientific usefulness is assumed to be negligible.

The last three image sets returned in multi-detector mode (MDM) immediately prior to the power disturbance which terminated operations before closest approach are also excluded. Image set 3504 does contain useful data but is corrupted and requires manual reduction. This task has not been completed at this time. Image sets 3505 and 3506 are also corrupted and probably do not contain useful image data.

Seven images taken at the beginning of the encounter sequence (image ids 674 to 680) were not correctly converted by the telemetry conversion routine. These images are not currently in the HMC database system and are therefore not included in the IHW data set. The similarity between these data and the subsequent data probably ensures that, for scientific evaluation of HMC data, their omission is of little or no importance.

One image (3142) has been omitted because it does not have an associated header.

Available data

The total numbers of images taken in each superpixel format (SPF) in the IHW data set are shown in Table I together with the size of each superpixel and the size of the output image in superpixels. For the encounter night data set, images taken in SPFs 2, 3, 4, and 5 showed the complete CCD at all times. SPF1 images were only used in MDM and provided a 37 x 37 superpixel image. For the MDM set, one image (usually detector C image) was in SPF0 while the other 3 were in SPF1. In SPF0, the image format varied as shown in Table II.

Red, blue and clear fixed filters covered detectors B, D, and E respectively. Detector C was exposed through a filter wheel with 11 filters and polarizers. The total numbers of images taken through each filter are shown in Table III together with the effective wavelengths and bandwidths of the configurations for single detector mode (from Thomas and Keller, 1989).

Table I

Superpixel format	Superpixel size in original pixels	Number of available images	Image size in superpixels
0	1 x 1	882	see Table II
1	2 x 2	204	37 x 37
2	4 x 4	38	98 x 73
3	8 x 8	171	49 x 36
4	16 x 16	394	25 x 18
5	4 x 3	328	98 x 97

Table II

Image format in SPF 0	Number of images
74 x 74	68
392 x 292	131
368 x 26	210
34 x 276	209
36 x 36	132
98 x 98	93
196 x 196	39

Table III

Filter	Number of images	Effective wavelength [nm]	Effective bandwidth [nm]	Multiplication factor for FITS conversion
clear	893	652.9	372.6	10
red	177	813.0	165.0	10
orange	109	645.4	94.0	10
blue	175	440.0	101.1	10
cont.1	172	457.4	20.30	100
cont.2	174	738.1	37.42	100
p-	42	-	-	10
pII	43	-	-	10
oh	83	314.8	12.25	100
c-2	74	408.4	16.63	100
c-3	75	509.5	20.90	100

REDUCTION

The method used to reduce the data will be fully described in an ESA special publication (ESA SP-1127) by Keller et al. (1990). The expansion from square-root encoding has been completed for all images. Subsequently, all images were corrected for dark current and corrected for varying responsivity across the CCD (flat-fielded). Removal of energetic particle events has been performed. Coherent noise subtraction has been completed in detail for SPFs 0, 1, and 5. Other images (particularly low signal SPF 2 data) do show interference effects. The scientific content of many of these images is relatively low and as such, coherent noise removal from these images was assigned a low priority. All images have been converted into absolute units of [mW m**(-2) sr**(-1)].

The geometrical correction of the data (necessary because of the spin of the spacecraft) is a complex and computationally time consuming operation. For submission of data to IHW, several decisions were taken to facilitate interpretation of the data. Firstly, all SPF images have been expanded and geometrically corrected. The expansion was performed using bilinear interpolation. Strictly speaking, the data should have been decompressed by simple expansion of each individual superpixel, a process which would not interpret the information content of each superpixel. However, the geometrical correction of the data (which itself involves a bilinear interpolation) was considered a necessary part of the reduction for submission to IHW. The bilinear interpolation for the geometry combined with a simple expansion of the SPF data would have resulted in non-physical rhomboid structures (corresponding to each superpixel in the original CCD data) with rounded edges in the images. Consequently, bilinear interpolation for all processing steps was selected.

Due to the geometrical correction, images are not rectangular but "pie-shaped". Some pixels in the rectangular arrays are therefore not image pixels. All non-image pixels have been set to -32768. Similarly, image pixels corresponding to areas on the CCD which contain erroneous data (e.g. the unmasked area) have also been set to -32768.

The orientation of the images was the subject of considerable debate and several conventions were proposed. It was decided to leave the images in the orientation generated by the geometrical correction procedure and to specify the phase of the observation in the accompanying FITS header. The spin phase of the spacecraft at the time of image taking varied considerably through the encounter and care should be taken during the interpretation process.

FITS FORMAT CONVERSION

Conversion in FITS format was performed by a batch program. Data were written onto 5 magnetic tapes at 6250 bpi. A test was performed by reading the data tapes using the Munich Image Data Analysis System (MIDAS) software (November 88 version). In all cases the first file is a null file. Remaining records appear to be correct.

INTENSITY SCALING

For the reduction and analysis of data at Lindau, all HMC data is maintained in single precision floating point format. For FITS format however, data should be in integers. To maintain the correct degree of precision, the broad-band images have been multiplied by scaling factors before conversion to integer format. For broad-band filter images, the background level has been estimated to be accurate to better than 0.2 mW m**(-2) sr**(-1) (the statistical noise is several fold higher, of course). Thus, these images have been multiplied by 10 before conversion into FITS.

For the narrow band filter images, which contain little or no signal, multiplication factors ensuring the required accuracy have been assumed. The multiplication factors adopted, which are filter dependent, are summarized in Table III.

IMAGE ORIENTATION

In order to display the data in the correct orientation, the first record in any FITS file should be at the bottom of the image display. The projected direction of the Sun in the image plane can be calculated from the PHASE keyword in the FITS header as described below. As a guide, the direction of maximum emission at distances greater than about 100 km from the nucleus was directed between 35 and 55 degrees south of the projected direction to the Sun.

HEADER INFORMATION

There are 43 header entries in the FITS header accompanying each image. The contents of the header has been designed to define unambigiously the viewing geometry, resolution, and orientation of the images. Each header entry is described in detail in Table IV.

Table IV

	Header entry name	Description
1	SIMPLE	
2	BITPIX	Number of bits per pixel.
3	NAXIS	Number of dimensions of image.
4	NAXIS1	Number of columns.
5	NAXIS2	Number of lines.
6	IMAGE-ID	The original image identifier number.
7	TIME-ENC	The time to encounter in seconds. The distance to the target plane and the spacecraft-comet distance can be calculated from this using the relative velocity (68.373 km s**(-1)) and the spacecraft-comet distance at closest approach (596+/-2 km) (see Curdt et al., 1988).
8	SCALE	The scale of the image in [km px**(-1)].
9	SENSOR	The detector used to acquire the image. This together with IMAGE-ID uniquely identifies each image.
10	FILTER	The filter used.
11	SUPERPIX	The superpixel format used for this image (see Table I). This taken with SCALE defines the spatial resolution of the image.
12	TDI	The clocking rate for the CCD (TDI = time delay and integration). The TDI time [microsec.] combined with the number of exposed CCD lines in the line scan operation defines the exposure time for an extended source. The number of exposed lines for each detector section is shown in Table V.
13	PHASE	Because of the spin of the spacecraft and the method of image taking, the projection of the sun vector in the image plane depends upon the precise timing of the clocking of the CCDs. The timing of HMC image was expressed in terms of a phase which represents the spin phase of the spacecraft at the time of image.

		This, in turn, can be related to the projection of the sun vector on the image by the formula AZIMUTH = PHASE - 103.14 [deg] where AZIMUTH is the angle between the horizontal axis of the image and the direction of the sun vector. The angle is measured clockwise from the left.
14	RIGHTAS	The right ascension of the observation as seen from the spacecraft in the 1950.0 co-ordinate system. This refers to the central pixel (column 200, line 147) of detector C. Entries 14 and 15 are based on the attitude and fly-by geometry determined from HMC data.
15	DECLIN	The declination of the observation as seen from the spacecraft in the 1950.0 co-ordinate system. This refers to the central pixel (column 200, line 147) of detector C.
16	POS-HAL1	The x component of the position of the centre of the nucleus of comet Halley in barycentric equatorial 1950 co-ordinates (EME50) (Hechler and Jappe, 1986). From this and the following components for the Earth, Sun, Giotto, and comet Halley one can compute the viewing directions. Note that the values RIGHTAS and DECLIN refer to the centre of the CCD, not to the comet. The position of the central pixel on the CCD can be estimated on full-frame images by knowing that the central line (or row) is 375 pixels in length (after removal of invalid pixels) and that the first valid pixel is in column number 16. Entries 16 to 39 are original data sets provided by ESA. The approach geometry according to this data set differs slightly from the HMC model.
17	POS-HAL2	The y component of the position of the centre of the nucleus of comet Halley in barycentric equatorial 1950 co-ordinates (EME50).
18	POS-HAL3	The z component of the position of the centre of the nucleus of comet Halley in barycentric equatorial 1950 co-ordinates (EME50).
19	VEL-HAL1	The x component of the velocity of the centre of the nucleus of comet Halley in barycentric equatorial 1950 co-ordinates (EME50).
20	VEL-HAL2	The y component of the velocity of the centre of the nucleus of comet Halley in barycentric equatorial 1950 co-ordinates (EME50).
21	VEL-HAL3	The z component of the velocity of the centre of the nucleus of comet Halley in barycentric equatorial 1950 co-ordinates (EME50).
22	POS-GIO1	The x component of the position of the Giotto spacecraft in barycentric equatorial 1950 co-ordinates (EME50).
23	POS-GIO2	The y component of the position of the Giotto spacecraft in barycentric equatorial 1950 co-ordinates (EME50).
24	POS-GIO3	The z component of the position of the Giotto spacecraft in barycentric equatorial 1950 co-ordinates (EME50).
25	VEL-GIO1	The x component of the velocity of the Giotto spacecraft in barycentric equatorial 1950 co-ordinates (EME50).

26	VEL-GIO2	The y component of the velocity of the Giotto spacecraft in barycentric equatorial 1950 co-ordinates (EME50).
27	VEL-GIO3	The z component of the velocity of the Giotto spacecraft in barycentric equatorial 1950 co-ordinates (EME50).
28	POS-SUN1	The x component of the position of the Sun in barycentric equatorial 1950 co-ordinates (EME50).
29	POS-SUN2	The y component of the position of the Sun in barycentric equatorial 1950 co-ordinates (EME50).
30	POS-SUN3	The z component of the position of the Sun in barycentric equatorial 1950 co-ordinates (EME50).
31	VEL-SUN1	The x component of the velocity of the Sun in barycentric equatorial 1950 co-ordinates (EME50).
32	VEL-SUN2	The y component of the velocity of the Sun in barycentric equatorial 1950 co-ordinates (EME50).
33	VEL-SUN3	The z component of the velocity of the Sun in barycentric equatorial 1950 co-ordinates (EME50).
34	POS-EAR1	The x component of the position of the Earth in barycentric equatorial 1950 co-ordinates (EME50).
35	POS-EAR2	The y component of the position of the Earth in barycentric equatorial 1950 co-ordinates (EME50).
36	POS-EAR3	The z component of the position of the Earth in barycentric equatorial 1950 co-ordinates (EME50).
37	VEL-EAR1	The x component of the velocity of the Earth in barycentric equatorial 1950 co-ordinates (EME50).
38	VEL-EAR2	The y component of the velocity of the Earth in barycentric equatorial 1950 co-ordinates (EME50).
39	VEL-EAR3	The z component of the velocity of the Earth in barycentric equatorial 1950 co-ordinates (EME50).
40	FI-COL	First image column on detector. This and the following three entries identify the position of the image relative to the reference system based on column 200 line 147 of the CCD.
41	LA-COL	Last image column on detector.
42	FI-LINE	First image line on detector.
43	LA-LINE	Last image line on detector.

Table V

Detector section	Filter	Number of exposed CCD lines
B	red (fixed)	6
C	variable	6
D	blue (fixed)	8
E	clear (fixed)	4

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