

#### 4. Data and Image Processing

Because of the high sensitivity and high angular, energy and time resolution of the three MIMI sensors, continuous transmission of the raw data would require impossibly large bit rates. So, extensive onboard data processing and data compression is a fundamental aspect of the MIMI experiment. The MIMI flight software has been designed to meet the scientific requirements of the mission even in limited data transmission allocation conditions. A variety of data products have been defined, each corresponding to a virtual instrument, and a combination of them is transmitted to the telemetry.

All MIMI data acquisition and processing is synchronized to an internally generated “sector clock,” which when the spacecraft is in spinning mode is synchronized to the spacecraft rotation. One spacecraft rotation is divided into 16 sectors, each sector thus corresponding to  $22.5^\circ$  of spacecraft rotation. Each sector is then subdivided into 16 subsectors, and each subsector into 16 microsectors. For the nominal spacecraft spin period, which is  $\sim 23$  min, a sector corresponds to  $\sim 86.2$  s, a subsector to  $\sim 5.4$  s, and a microsector to  $\sim 0.34$  s. These values are updated at the beginning of each sector, by taking into account the most recent spin rate information transmitted by the spacecraft AACS. This allows the MIMI sectoring scheme to adapt to spacecraft spin-ups and spin-downs. When the spacecraft is in a staring mode, the same MIMI sectoring scheme is still applied, but now the sector duration is a fixed parameter value, that mimics spacecraft rotation. Transition between the two modes, i.e. staring or spinning, is performed automatically, by monitoring the spacecraft spin rate data transmitted by the AACS.

The MIMI instrument incorporates two 16-bit RTX 2010 processors; the Control Processing Unit (CPU) handles all instrument command, telemetry, and control tasks, as well as the LEMMS data collection. The Event Processing Unit (EPU) is dedicated to collecting and processing the raw INCA and CHEMS data.

INCA image data are organized in three different image groups, simultaneously generated: high spatial resolution images, acquired over four sectors; high time resolution images, acquired each sector; and high time-of-flight and mass resolution images, acquired over four sectors (Figure 4.1).

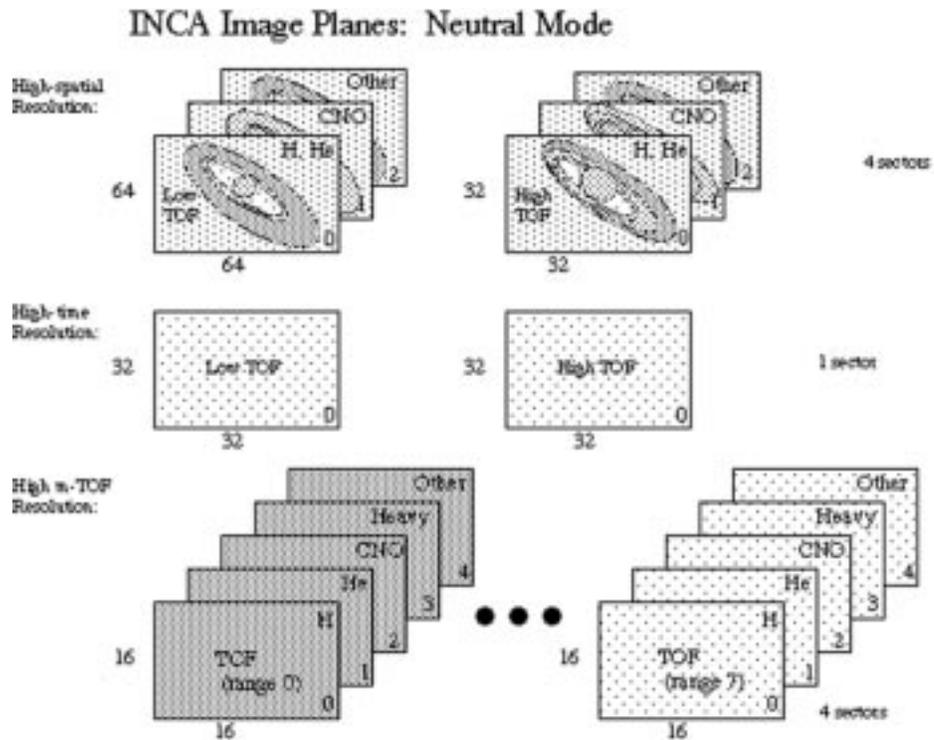


Figure 4.1. INCA images.

The EPU collects data from the INCA instrument, generates the images, performs image motion compensation (by taking into account the spacecraft attitude data, correcting thus for spacecraft mosaic-like attitude motion), and sends the images to the CPU. The images are then compressed by the CPU and sent to the telemetry. A double buffering process is used in order to acquire an image set in the EPU in parallel with the processing of the previous instrument cycle image set in the CPU. The INCA image types generated in neutral (ENA) mode are also shown in Table 4.1.

The INCA images must be compressed in order to fit into the available telemetry allocation. The data compression is a four-step process: event binning, selection of the “useful” part of the image, logarithmic compression, and “real” image compression.

Event binning, and organization of the image data into the scheme shown in Table 4.1, results in a preliminary data compression by a factor of ~20. As shown

TABLE 4.1  
INCA image types generated in neutral (ENA) mode

	Number of Images	Image accumulation period	Pixels/Image	Memory Pixels/Image
High Spat. Resolution Low TOF	3	4 sectors	$64 \times 64$	$128 \times 96$
High Spat. Resolution High TOF	3	4 sectors	$32 \times 32$	$64 \times 48$
High Time Resolution Low TOF	1	1 sector	$32 \times 32$	$64 \times 48$
High Time Resolution High TOF	1	1 sector	$32 \times 32$	$64 \times 48$
High m-TOF Resolution: (Neutral Mode)	$5 \times 8$	4 sectors	$16 \times 16$	$32 \times 24$

in the table, every four sectors INCA generates three  $64 \times 64$  pixel images (high spatial resolution), eleven  $32 \times 32$  pixel images (eight high time resolution and three high spatial resolution images) and forty  $16 \times 16$  pixel images (high TOF/mass resolution). This corresponds to an average of  $\sim 98$  pixels/s. Without the implementation of such a binning scheme, a single set of images would be generated, providing the full spatial, time and m-TOF resolution, i.e.  $5 \times 8$  images,  $64 \times 64$  pixels each, generated every 1 sector. This would have required an average of  $\sim 1900$  pixels/s.

Selection of the “useful” part of the image results in the reduction of the initial  $180^\circ \times 180^\circ$  equivalent FOV, allocated in the DPU memory, to the  $90^\circ \times 120^\circ$  image sent to the telemetry. At the start of image integration each  $180^\circ \times 180^\circ$  image buffer is centered with INCA’s FOV (Figure 4.2). As the spacecraft moves, the FOV can move and rotate within the image buffer, image motion compensation taking into account for that. Nevertheless, at the end of the image accumulation, only the  $90^\circ \times 120^\circ$  part of the image, i.e. equal to the INCA instantaneous field of view (corresponding to the most exposed part of the  $180^\circ \times 180^\circ$  image) is sent to the telemetry. This corresponds to a data reduction factor of 3.

Logarithmic compression of the accumulated counts is then performed by the CPU on each pixel (except during the very high bit rate), and results in a 16 to 8 bit compression. This is lossless only for the first 32 values, but the maximum relative error does not exceed 3.1%.

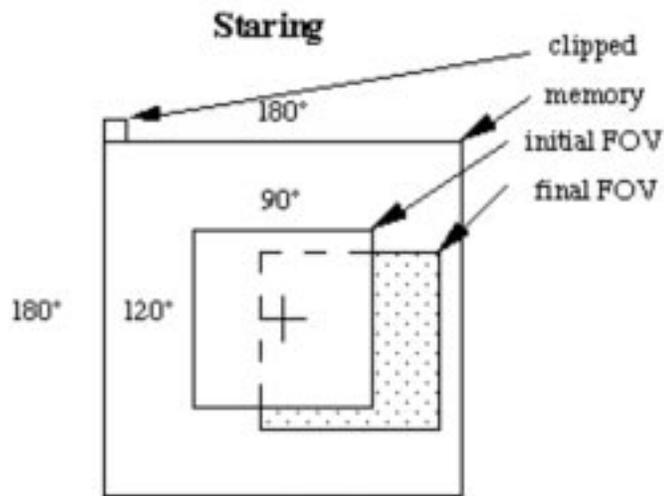


Figure 4.2. INCA image integration in stare mode.

“Real” image compression is then performed by the CPU, and it is a lossless Rice or Fast compression. The compression algorithm is selected via uplink command, and its use is flagged in the downlink data stream as a header variable. The Fast algorithm is an encoding scheme that examines a block of  $J$  pixels and finds the maximum pixel value in the block. It then calculates the minimum number of bits required to code this maximum value. Each pixel of the block is then represented using only this smaller number of bits. A block header is required for each block, that contains the value used for encoding the pixels in the block. The Rice algorithm is based on using a Comma code. The Comma code for any positive integer,  $k$ , is simply  $k$  leading zeroes followed by an ending “1.” As in the Fast encoder, the data are processed in a  $4 \times 4$  pixel block at a time. The Rice algorithm considers the block values as containing a certain number,  $m$ , of incompressible least significant bits (lsb’s). These lsb’s are stripped off of each block value and saved. The Rice algorithm must determine the best value for  $m$ , and the number of lsb’s to strip off for each block of data, so that the overall code length of the encoded block is minimized. The remaining most significant bit values (msb’s) are then Comma encoded. Both Rice and Fast algorithms have been tested on a test image set, generated from simulated INCA images, as the one shown in Figure 2.11, in which instrument noise was then introduced in order to examine the noise effects on the image entropy and the compression factor.

Compressed images are then organized in telemetry subpackets, each subpacket corresponding to a self-contained part of the parent image, including the necessary header information. It should be noted that image compression is performed within the image part corresponding to each subpacket. This allows decompression of each subpacket independently, so as to allow reconstruction of correct partial images in case of loss of some subpackets. INCA image subpackets (and all other MIMI science data product subpackets) are inserted into the fixed-length MIMI science packets, and are transmitted to the spacecraft solid-state recorder (SSR).

Other MIMI data products include:

- INCA and CHEMS accumulator rates, which are periodic readouts of the hardware accumulators in these instruments (9 INCA accumulators and 17 CHEMS accumulators). These are subject to a 24 to 10 bits logarithmic compression.
- INCA and CHEMS PHA events, which correspond to the complete information on the subset of the particles detected by these two instruments. For INCA this includes: TOF, pulse-height of the signal output from the front and rear MCPs, MCP identification (coincidence, start/stop), calculated azimuth and elevation, and mass range. For CHEMS it includes: TOF, pulse-height of the signal output from the SSD, MCP, and SSD identification, deflection voltage (DPPS) step, and calculated range (one of seven basic rates, each one being a subdivision of the  $m - m/q$  space).
- CHEMS basic rates and science rates, i.e., total number of detected ions corresponding to each of the 7 basic rates and 34 science rates, measured for each DPPS step. These are subject to a 16 to 8 bits logarithmic compression.
- LEMMS accumulator rates, which are periodic readouts of the 57 normal counters and the 4 priority counters, each corresponding to a different particle, energy, or species range. These are subject to a 24 to 10 bits logarithmic compression.
- LEMMS PHA data, corresponding to the periodic readout of 64 energy channels  $\times$  3 detectors and are subject to a 16 to 8 bits logarithmic compression.

Table 4.2 gives an overview of the MIMI science data products and of the periodicity of their transmission to the telemetry stream. Note that during spinning

TABLE 4.2  
Overview of MIMI science data products

		Staring		Spinning	
		Neutral	Ion	Neutral	Ion
INCA	High Spatial Resolution Images	4 sectors	-	16 sectors*	-
	High Time Resolution Images	1 sector	1 sector	1 sector	1 sector
	High m-TOF Resolution Images	4 sectors	1 sector	16 sectors*	1 sector
	PHA Events	4 subsectors			
	Accumulator Rates	1 subsector (# of events varies with telemetry mode)			
CHEMS	Science Rates	1 subsector (2 subsectors in <i>Very Low Bit Rate</i> )			
	Accumulator Rates	1 subsector			
	Basic Rates	1 subsector (2 subsectors in <i>Very Low Bit Rate</i> )			
	PHA Events	1 sector (# of events varies with telemetry mode)			
LEMMS	Accumulator Rates	4 "priority" counters : 2 microsectors 60 remaining counters : 16 microsectors (32 in <i>Very Low Bit Rate</i> )			
	PHA Events	1 subsector in <i>Very High Bit Rate</i> and <i>High Bit Rate</i> 2 subsectors in <i>Medium Bit Rate</i> 4 subsectors in <i>Low Bit Rate</i> 8 subsectors in <i>Very Low Bit Rate</i>			

mode, INCA 16-sector images, corresponding to a 360° azimuthal FOV, are transmitted to the telemetry as four separate 90° azimuthal FOV images, each one accumulated over a 4-sector period.

In addition to the above INCA, CHEMS and LEMMS sensor data products, the MIMI science telemetry stream also includes some auxiliary data, such as LEMMS turntable rotation data, spacecraft attitude data, MIMI instrument status data etc.

The MIMI science packet and subpacket headers have been designed to include all the necessary information for data and mode identification, decompression, and time tagging, while minimizing the overhead to the telemetry bit rate. This overhead is about 2.4%, including the standard CCSDS and Cassini project packet headers.

A flexible scheme has been implemented in order to optimally match the limited SSR allocation and the variable compression rates, while transmitting the maximum amount of information possible. Five telemetry rates have been defined for each of the three MIMI sensors: *Very High Bit Rate*, *High Bit Rate*, *Medium Bit Rate*, *Low Bit Rate*, and *Very Low Bit Rate* (cf. also Table 4.2). Each 24 hour period, corresponding to an SSR allocation, has been divided into a series of "observation periods," and a default telemetry rate is programmed by uplink command for each

of the three sensors and for each observation period. The higher telemetry rates can thus be programmed for the orbit sections corresponding to satellite flybys, flux tube crossings etc. The MIMI DPU monitors the science packet data volume sent to the spacecraft SSR during each observation period. If this volume exceeds a pre-defined threshold, the sensors automatically switch to a lower than the default programmed bit rate for the next observation period, so as to avoid an early saturation of the SSR partition allocated to MIMI. But if the monitored data volume is lower than anticipated, then for the next observation period the sensors switch to a higher than the default programmed bit rate, thus making optimum use of the SSR partition.