The Medium Energy Experiment MECS on board the BeppoSAX Observatory: Data Analysis and First Results

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The Medium Energy Concentrator Spectrometer MECS, operating in the 1.3–10 keV X-ray energy band, is one of the Narrow Field Instruments on board BeppoSAX. The main scientific objectives of the MECS are: spectroscopy with $E/\Delta E_{FWHM}$ in the range 6–16; imaging with angular resolution at the arcmin level; timing variability on time scales down to the millisecond. A dedicated software, based on the XAS data system, was developed for the MECS scientific data reduction. After a brief description of the instrument, we present here the first results obtained from the analysis of the Science Verification Phase observations, with emphasis on the MECS data reduction topics.

1 Introduction

The Medium Energy Concentrator Spectrometer MECS, one of the four narrow field instruments on board the BeppoSAX[1] observatory, is operating in the medium X-ray energy band. Main scientific objectives of the MECS are: spectroscopy from 1.3 to 10 keV ($E/\Delta E_{FWHM}$ in the range 6–16); imaging with angular resolution at the arcmin level; timing variability on time scale down to the millisecond.

Design, calibration and data analysis software of the MECS have been carried out by the MECS team at the IFCAI-Palermo and IFCTR-Milano Institutes in Italy. On-ground calibration was mainly performed at the X-ray PANTER facility of the Max Planck Institute, Germany.

A detailed description of the instrument, its performance, and results from the on-ground calibrations can be found elsewhere[2,3]. Here we briefly illustrate the MECS instrument, mainly for what concerns those components that play a fundamental role in the data reduction and in the definition of the MECS response matrix.

1.1 *The Medium Energy Concentrator Spectrometer MECS*

The MECS consists of three units, each composed of a grazing incidence Mirror Unit MU, and of a position sensitive Gas Scintillation Proportional Counter GSPC located at the focal plane. MUs and GSPCs are connected by a Carbon fiber tube, about 2 m long. At 6.4 keV the total effective area of the MECS instrument is 150 cm^2 and the angular resolution, at 80% of the signal, is 150 arcsec.

Each MU (focal length of 1850 mm) is composed of 30 coaxial and confocal mirrors, nested using two front-end spiders with eight arms. The mirrors have a double cone geometry to approximate the Wolter I configuration [4]; their design was optimized to have the best response at 6 keV [5].

The focal plane detectors are Xenon filled GSPC, working in the range 1.3−10 keV with an energy resolution of ~8% at 5.9 keV, a position resolution of ~0.5 mm (corresponding to 1 arcmin, approximately) at the same energy, and a circular Field of View FOV of 28 arcmin radius. The gas cell is composed by a cylindrical ceramic body closed, at the top, by an entrance Beryllium window surrounded by a NiCo ring and, on the bottom, by an UV exit window made of Suprasil quartz. The entrance window is reinforced by a Beryllium strongback structure, consisting of a ring connected to the window border by four ribs. Two grids inside the cell separate the absorption/drift region from the scintillation region.

An X-ray photon absorbed in the gas cell liberates a cloud of electrons. A uniform electrical field across the cell drifts the cloud up to the scintillation region, with an higher electric field, where UV light is produced through the interaction of the accelerated electrons with the Xenon ions. The amplitude of the UV signal, detected by a position sensitive Hamamatsu photomultiplier, is proportional to the energy of the incident X-ray. The duration of the signal, or Burst Length BL, depends on the interaction point and it is used to discriminate genuine X-rays against induced background events. BL rejection may be carried out on board and/or on ground, during the data reduction phase.

In order to avoid that the plasma particles crossing the MU can accelerate towards the GSPC entrance window, a plasma protection grid is mounted below the optics system. Furthermore, to be sure that any high velocity plasma component overcoming the grid shielding does not impinge on the entrance window, plasma filters have been placed in front of it; these filters (LEXAN for two MECS units and KAPTON for the third one) stop also UV light photons that could extract electrons from the entrance Beryllium window which produce a background increase.

Each GSPC detector unit is completed by two ^{55}Fe collimated calibration sources (nuclear line at 5.9 keV) with emission rate of ~1 count per second, located diametrically opposed near the edge of the Beryllium window. These inner calibration sources, continuosly visible at the edge of the FOV, allow the monitoring of the detector gain.

The MECS instrument can operate in two basic modes[6]: direct mode, in which basic scientific information (time, position, energy, BL) is telemetred for each detected event; indirect mode, in which BL and energy spectra are accumulated on board. Each mode has a set of submodes specified by the number of bits (or channels), time resolution and integration time. When running in direct modes (those supported for observers), the instrument also produces ratemeters data. Scientific data, ratemeters, and a set of engineering housekeeping (as for example HV and temperature that allow to monitor the MECS health and its performance) are then transmitted to ground.

2 The MECS Scientific Software

The BeppoSAX science data are distributed to the observer in form of Final Observation Tapes (FOT). Apart from a set of spacecraft housekeeping and ancillary information common to all the instruments on board BeppoSAX, the structure of the scientific and engineering data in a FOT is strictly dependent on each single instrument and a specific software is required to decode them.

The scientific software is specifically designed to the BeppoSAX data reduction; it allows the reading of FOT and calibration data and includes specific reduction and processing tasks such as the accumulation of photon lists, spectra, images and time profiles, and the creation of instrument response matrices.

The MECS reduction software is primary developed in the framework of the XAS data analysis system[7]. Scientific software related to MECS data has also been developed as part of the SAXDAS system at the BeppoSAX Scientific Data Centre[9] for uniformity with the data analysis system developed for the Low Energy Concentrator Spectrometer LECS[10]; in this paper we refer only to the MECS software developed in XAS environment.

MECS data reduced with the XAS software will be available in the specific XAS format[7] as well as in FITS format (by using appropriate XAS format converter programs whenever necessary) so to be analysed with the major of the existing software packages widely used in the astronomical community for spatial, spectral, and timing analysis (e.g. XIMAGE, XSPEC, XRONOS, IDL, MIDAS/EXSAS, IRAF/PROS).

The main steps of the MECS data reduction system can be summarized as follows:

- <u>FOT filing</u>. BeppoSAX observational data in a FOT are structured as observations in a given observing period; the *fotfile* program recreates from FOT on disk the original packet files with appropriate record length and produces telemetry files per observation and per data type, plus an observation directory file.

- Accumulation decodes observation directories and accumulates photon lists, images, pseudo-images, spectra, time or housekeeping profiles from the telemetry files, by using the description of the MECS telemetry format stored in specific files. During the accumulation, all the possible MECS selections are performed. The *accumulate* front-end program applied on MECS data allows the selection of time windows, spatial regions, energy range, and BL limits. When enabled by properly setting the XAS *correction* variable, a number of MECS specific corrections are applied to raw events in order to normalize their position and energy information. These corrections take into account the geometric distortions (image linearization), the positional dependency of gain with respect the detector centre, and the time dependency of gain.

- Response matrix generation. The *mecsmaccum* program, part of the XAS software, allows to generate the response matrix of the MECS experiment for a given observation.

As a general procedure of MECS data reduction, after FOT data have been filed on disk, the observer should inspect the MECS configuration (program *check_expconf*) during the given observing period and then choose those observations that can be chained (program *concatenate*) to obtain correct final products. Along with such an inspection, time windows files can be produced to select data according to some acceptance criterion (for example, to exclude data coming from a dark Earth exposure). Then the accumulation program can be started to obtain the desired reduced product (photon list, image, spectrum, time or housekeeping profile) in XAS format. Other particular corrections, as dead-time correction or background subtraction, can be performed on these XAS products. If necessary, MECS reduced data in XAS format can be easily converted in OGIP or FITS format (programs *toogip*, *tofits*) to be analysed with the data analysis packages widely used in the astronomical community and anyhow according to the final user's choice.

3 Response Matrix

The response matrix for each MECS unit is composed by two files: the Ancillary Response File ARF, and the Redistribution Matrix File RMF.

An ARF file is logically a one-dimensional array, indexed on input photon energy, which contains the total effective area. The total effective area for each MECS unit, $A_e(E,\theta)$, is function of the energy E and of the off-axis angle $/theta$, and it can be expressed as[3]:

$$A_e(E,\theta) = A_{MU,\infty}(E,\theta) \cdot T_{f1} \cdot T_{f2}(E) \cdot T_w(E,\theta) \cdot P_a(E) \cdot BL_s(E) \cdot IPSF_\rho(E)$$

where the MU effective area (A_{MU},∞) is reduced by various coefficients due to the different components of the MECS instrument. In particular:

- $A_{MU,\infty}(E,\theta)$ represents the Mirror Unit effective area.
- T_{f1} represents the transmission coefficient of the plasma protection grid mounted below the optics system.
- $T_{f2}(E)$ represents the energy dependent transmission coefficient of the plasma/UV filter (LEXAN or KAPTON) placed in front of the entrance Beryllium window.
- $T_w(E,\theta)$ indicates the Beryllium window transmission efficiency (analytically computed) and it depends also on the off-axis angle, due to the presence of the strongback structure.
- $P_a(E)$ is the detector efficiency due to the gas cell absorption.
- $BL_s(E)$ is a reduction coefficient due to the Burst Length selection that rejects both double events (long BL) that could present incorrect positions, and events that convert in the scintillation region (short BL) resulting in an incorrect energy channel.
- $IPSF_\rho(E)$ is a further reduction coefficient that considers the effects due to the selection of events within a radius ρ of the instrumental point spread function (a detailed description is given in Boella et al., 1997).

An RMF file is logically a bi-dimensional array which gives, for each input photon energy, the probability of assigning the photon to the output energy channels. Each row of the RMF redistribution matrix presents two main components: a gaussian to model the main peak, and an exponential plus a constant to model the loss of a part of primary electrons for attachment to the Beryllium window (phenomenon that produces a smaller energy deposit). Moreover, for input energies greater than 4.78 keV (the Xenon L-edge), four gaussians are also included to model the escape peaks due to the escape of fluorescence photons from the detector gas cell.

The MECS response matrix is generated by the specific XAS accumulation program *mecsmaccum*[8] and the output matrix file can be written either in XAS or in OGIP (XSPEC-compatible) format, depending on the setting of the related XAS environment variable. The output files contain 1160 input energy lines with a stepsize of 10 eV starting from 0.4 keV. Output energies are distributed in 256 channels. All of the calibration data necessary to generate the MECS response matrix are stored in a set of files, queried at run-time by the matrix accumulation program.

4 In-flight calibration

The BeppoSAX Science Verification Phase (SVP) started on July 6, 1996. Some of the most-studied X-ray sources have been monitored[9] with the purpose to verify and calibrate the response of all onboard instruments. Here we present the first results on the MECS instrumental background and on the consistency of the MECS response matrix with the in-flight calibration.

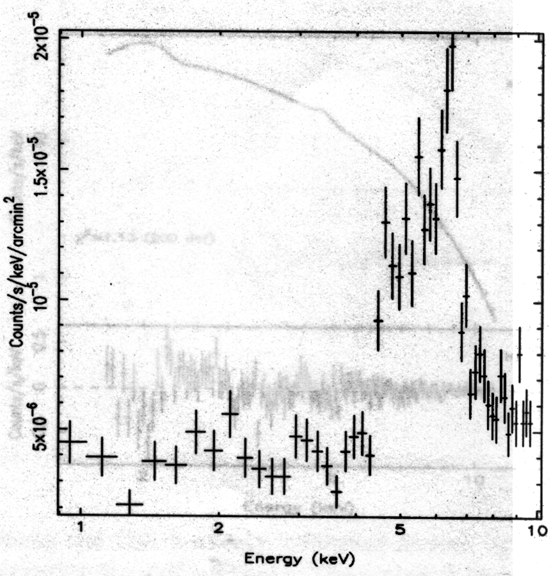

Figure 1: Residual instrumental background (M2 MECS unit).

The MECS instrumental background is mainly due to charged particles interacting with the gas in the detector. The presence of a guard ring (charged particles are more likely stopped far from the central region of the detector) and the discrimination in Burst Length (charged particles produce long bursts) permit a massive rejection of the background.

Fig. 1 shows the spectral shape of the residual instrumental background collected in 130 ks during observations of the dark Earth when the source under pointing was in occultation. The total count rate in the band 1.3–10 keV is $2{\cdot}10^{-5}$ cts/sec/arcmin^2. A feature is evident around 6 keV (present also in the on-ground calibration) [3]. Possible explanations of this feature are: a) fluorescence by detector material (as the NiCo ring surrounding the entrance Beryllium window); b) re-absorption, far from the primary interaction point, of fluorescence emitted from the ^{55}Fe calibration sources; c) combination of the two above effects. The total instrumental background is in any case very low and this will allow to deeply study the celestial background and to perform serendipitous search of weak X-ray sources [11].

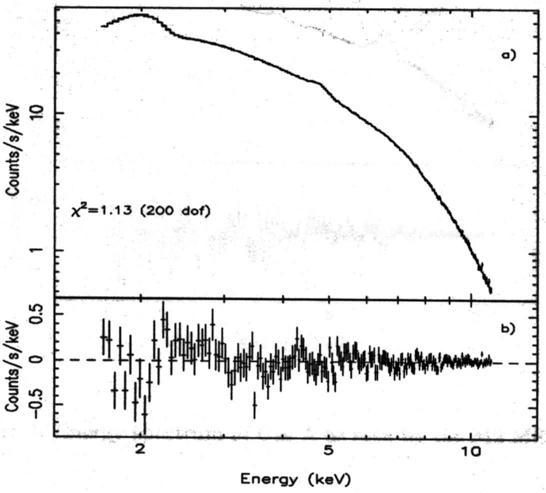

Figure 2: Energy spectrum of Crab as seen by the M2 MECS unit

The MECS response matrix has been tuned and verified by using well known X-ray celestial sources. The tuning related to efficiency and energy distribution was performed by using mainly the Crab SNR data, while gain-energy conversion was verified and tailored by analyzing the Cas A SNR data which present several lines superimposed to the continuum.

Fig. 2-a shows the Crab energy spectrum, as seen by the M2 MECS unit, fitted by using a simple model with a power law and an absorption. The results of the fit are in very good agreement with the values reported in the literature. The residuals in Fig. 2-b show a maximum discrepancy of less than 2% between data and model, so demonstrating the good correspondance of the response matrix with the actual MECS performance. MECS units M1 and M3 (not reported here) present a similar behaviour.

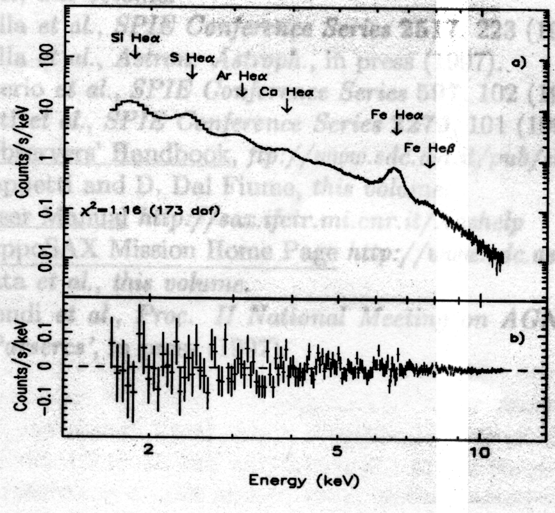

Figure 3: Energy spectrum of Cas A as seen by the M2 MECS unit

Fig. 3-a shows the Cas A energy spectrum as seen by the M2 MECS unit during an observation time of ~50 ksec. The emission lines of Si, S, Ar, Ca, Fe, ionized at the He level, are clearly evident. The line energies are in agreement with the Lab expected ones within 1%. The residuals (see Fig. 3-b) present a very flat behaviour and the values are dominated by the statistics of the source.

5 Conclusions

The first results of the in-flight Scientific Verification Phase confirm the overall performance of the MECS instrument, already well known by the on-ground deep calibration; moreover the SVP data permitted to improve the algorithms and the software which is distributed to the users for the MECS scientific data reduction.

In the light of the first in-flight results we can conclude that the MECS effective area, its energy and angular resolution together with the low level of intrinsic background make this experiment suitable and competitive for sensitive observations of X-ray celestial sources in the range 1.3−10 keV.

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