Section 9

Calibration Products

9.1 Overview of Products

This section provides a general overview to the types of calibration products, the next sections provide the HETG and HETGS products themselves.

Calibration Data are all the raw data acquired that has information to constrain the instrument models; these are the basis of a calibration.

Calibration Measurement Products are the specific results from specific manipulations of the Calibration Data and cover many levels of complexity. They represent the results when the raw data have been "analyzed" to create something, *e.g.*, "counts per second in the Al-K BND bump", "ACIS-I 5 arc min Mo-L off-axis encircled-energy curve", or "witness flat reflectivity at 8.04 keV". There are lots of these! And their meaning and organization and synthesis can require a lot of human knowledge. Many results may be ammenable to database storage, others may require memos to describe and define them. Error estimates are produced for each measurement result as well.

Fundamental Calibration Products are the most detailed "encoding" of the calibration activity into detailed (complex) models, *e.g.*, SAOSAC as a model of the HRMA. This requires a synthesizing by calibrationists of the various Calibration Measurement Products and model expectations.

Calibration Interface Products are specific, well-defined, useful parameters, tables, models which describe the essence of the instrument to sufficient accuracy to be useful yet in a more accessible form than the Fundamental Calibration Products. (The distinction is blurred and need not be too strict. For example the ACIS pixel size is about as Fundamental as can be yet it is also a very useful CIP value.) These CIPs are the main interface between the calibration activity and the rest of the system.

Analysis Reference Data is used to explicitly identify those data that are needed and used by, *e.g.*, the ASC Data System for simulation and data analysis. The formats are dictated by the analysis algorithms and software architecture; often these data may be simply reformatted versions of the CIPs. The **MARX** parameters, Section 9.3.5, are a good example of Analysis

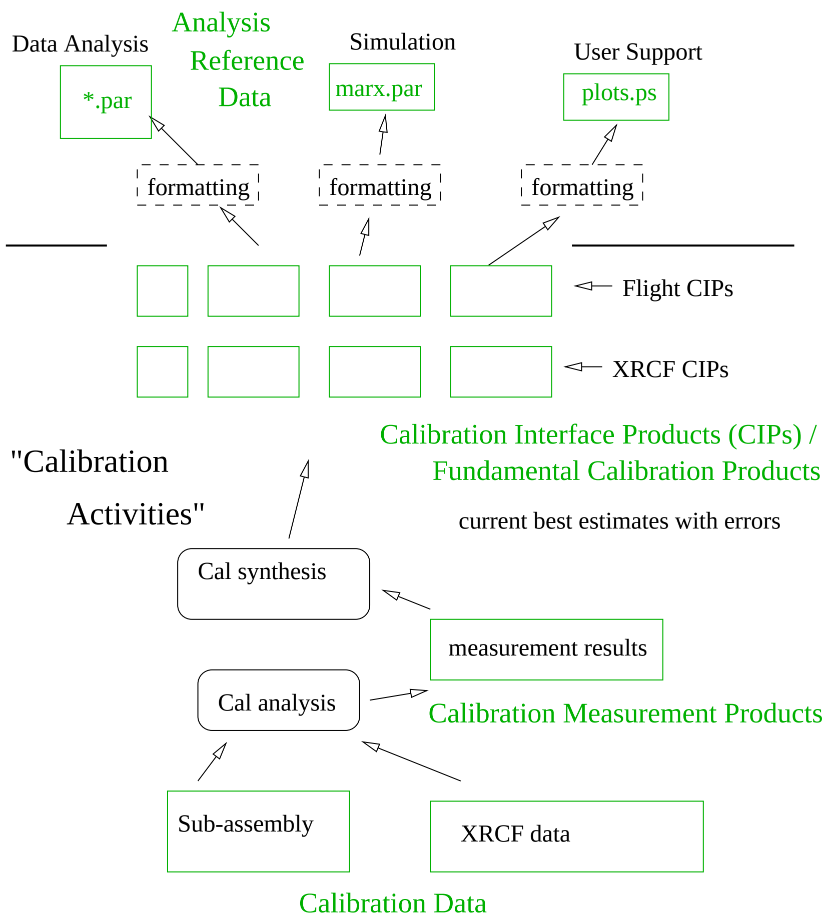

Figure 9.1: Schematic Diagram of the Types of Calibration Products

Reference Data.

The relationship of these products is schematically shown in Figure 9.1.

9.2 Fundamental Calibration Products for HETG

As we have seen, the LRF functions depend not only on shell-level quantities but on grating-level data, *e.g.*, grating mis-alignment angles[48]. For this reason, *the fundamental HETG calibration or model is at the grating facet level.*

For each grating facet, $f = 1$ to 336, we have a diffraction efficiency $g_f(E, m)$, period map in facet coordinates $p_f(x, y)$, and alignment distribution $\Gamma_f(\phi_{\rm roll})$ as well as mechanical parameters. These fundamental data can be combined with other information to produce, *e.g.*, ν_s, $G_s(E, m)$, $SEA(E, m, \dots)$, and $LRF(E, m, \dots)$.

9.3 HETG Calibration Interface Products

A discussion of and values for the HETG CIPs are presented here; data files, discussions, and updates are available at `http://space.mit.edu/HETG/xrcf.html` under "Calibration Products".

9.3.1 Basic Parameters

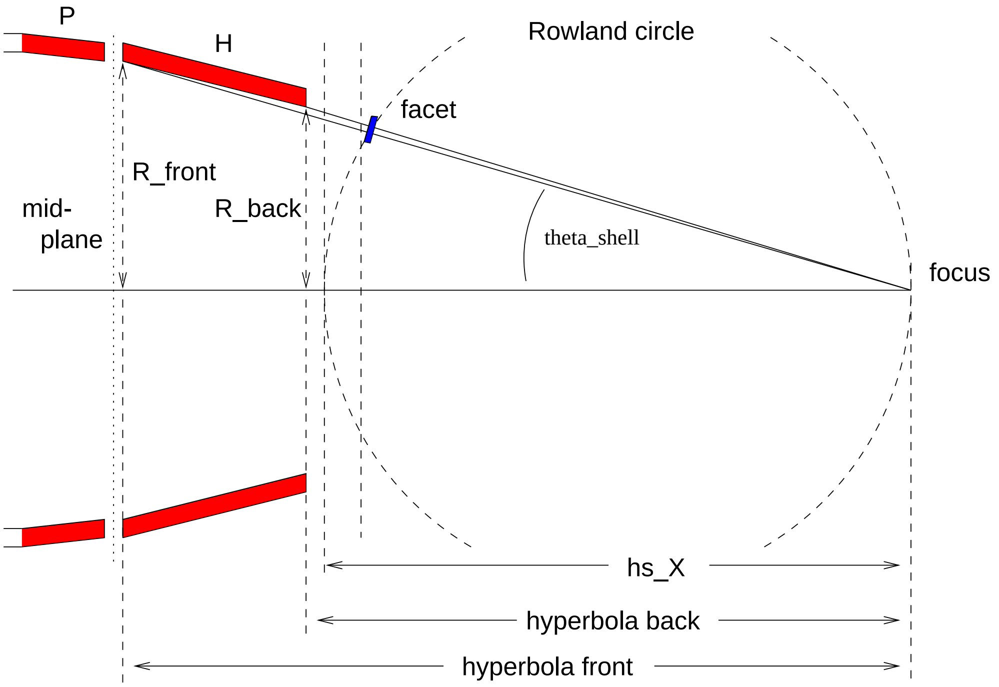

Figure 9.2: Basic Geometry for HETG Facet Location

Basic parameters of the HETG design are tabulated in the file `HETGbasic.rdb` for computer input and reproduced here in Table 9.1. The HETG radii given here are really a method to record the angle of the central ray through the shell's facets, "theta_shell" in Figure 9.2:

$$\tan\theta_s \; = \; \mathrm{HETGrad}_s \; / \; \mathrm{HETGrd} \qquad (9.1)$$

To-do:
Produce and include reference to 3-D facet location information.

name	value	error	unit
HETGrd	8633.69	0.1	mm
HETGrad1	521.66	0.1	mm
HETGrad3	419.90	0.1	mm
HETGrad4	370.66	0.1	mm
HETGrad6	275.44	0.1	mm
HETGvign1	0.937	0.01	none
HETGvign3	0.940	0.01	none
HETGvign4	0.931	0.01	none
HETGvign6	0.936	0.01	none

Table 9.1: Basic HETG Design Parameters, from `HETGbasic.rdb`.

9.3.2 Periods, Angles, and Spacing

Periods

Lab measurements were made on the flight gratings for HETG as well as on the TOGA gratings used in XRCF rehearsal. These laboratory measurements were corrected based on NIST-measured reference samples (Section 4.1.2) resulting in our best estimate "LR-NIST" periods.

The current CIP adopted periods (in Å) are the sub-assembly values because XRCF measurements are not accurate enough to require a change. In particular a spacing discrepancy still exists, Section 6.2. The period errors are all taken as the sub-assembly values, again because (with an HETG displacement assumption) XRCF measurements are in agreement and do not provide any smaller error bounds.

Angles

The mean dispersion angles have been measured at XRCF and the HETG opening angle should be the same for XRCF and flight. The flight clocking and grating angles have been modified slightly from the XRCF values by the as-installed +46 arc second HETG roll.

Spacing

The HEG/MEG period difference seen between sub-assembly (HeCd,HeNe) and XRCF-AL-K (assuming a spacing of 8788.04 mm) of about 500 ppm is assumed to be due to an inaccurate value for the HETG Rowland spacing at XRCF, Section 5.2.1. Thus, for now the HETG position at XRCF is set to be 8782.8 mm to have reasonable agreement between XRCF and sub-assembly periods (and hence calculated line energies). The cause for the (alleged) displacement has not been determined.

For flight spacing, Scott Texter reports that EK measures (mechanical means) the as-installed HETG to be 0.009 inches closer to the HRMA than designed, so expected flight spacing is 8633.69+0.009*25.4 = 8633.92 mm. The error on this is probably 0.2 mm or less (HRMA-grating spacing). However the HRMA-focus spacing may still have error of order 0.5 mm.

name	value	error	unit
HEGp	2000.81	0.05	Angstrom
MEGp	4001.41	0.10	Angstrom
HETGrsX	8782.8	0.50	mm
HETGrsF	8633.92	0.50	mm
HETGopenX	9.934	0.008	degrees
HETGopenF	9.934	0.008	degrees
HETGclockX	-0.225	0.05	degrees
HETGclockF	-0.215	0.05	degrees
HEGangleX	-5.19	0.05	degrees
MEGangleX	4.74	0.05	degrees
HEGangleF	-5.18	0.05	degrees
MEGangleF	4.75	0.05	degrees

Table 9.2: HETG Period, Angle, and Spacing Parameters, from `HETGperiod.rdb`.

9.3.3 Period and Roll Variation Parameters

A coarse characterization of the gratings LRF effect is with the period and roll variations, listed as dp/p and γ in the error budget of Table 2.2. These values are measured in the laboratory by the LR and Alignment setups. Confirmation of these laboratory values at XRCF with the XRCF LRF Core analysis has only begun, Section 6.3.

The MEG mis-aligned gratings have pointed out a mechanism whereby the alignment measurement differs from the actual grating bar orientations. It is likely that the same effect operating at a lower and randomized level will lead to an increase in the actual γ value over the alignment system determined one. A simple analysis of one XRCF data set suggests that γ may be between 1 or 2 arc minutes rms, hence a value of 1.5 arc minutes (with a large 0.5 arc minute error) is being adopted preliminarily.

As for the period variations, the LR predictions of 127 ppm and 106 ppm, Figures 4.3 and 4.4, are a lower limit to these variations. Again the limited XRCF analysis has not produced a precise value but suggests $dp/p < 300$ ppm. Unlike the alignment effect, there is currently no expectation that the dp/p measured by the LR is in error, so the proposed baseline values are the LR values increased by rss'ing them with 100 ppm to account for any mounting induced distortions.

name	value	error	unit
HEGdpop	146.	50.	ppm
MEGdpop	162.	50.	ppm
HEGroll	1.5	0.5	arc minutes
MEGroll	1.5	0.5	arc minutes

Table 9.3: Parameters Effecting the HETG LRF Core, from `HETGcore.rdb`.

9.3.4 Efficiency Products

Table 9.4 lists the available files that contain the current best estimates of the HETG diffraction efficiency, $G_s(E, m)$, for $m = -11, \ldots, +11$; note that error files are available as well. These files have equal plus and minus orders and include the shell vignetting ν_s factor. Samples of this data are plotted in Figures 9.3 and 9.4.

Shell	Data File	Error File
1	HETG_shell1_effic.rdb.gz	HETG_shell1_effic_err.rdb.gz
3	HETG_shell3_effic.rdb.gz	HETG_shell1_effic_err.rdb.gz
4	HETG_shell4_effic.rdb.gz	HETG_shell1_effic_err.rdb.gz
6	HETG_shell6_effic.rdb.gz	HETG_shell1_effic_err.rdb.gz
MEG	MEG_effic.rdb.gz	MEG_effic_err.rdb.gz
HEG	HEG_effic.rdb.gz	HEG_effic_err.rdb.gz
HETG	HETG_effic.rdb.gz	HETG_effic_err.rdb.gz

Table 9.4: CIP Efficiency Files for the HETG, available from
`http://space.mit.edu/HETG/cal_prods.html/#HETG_CIP`

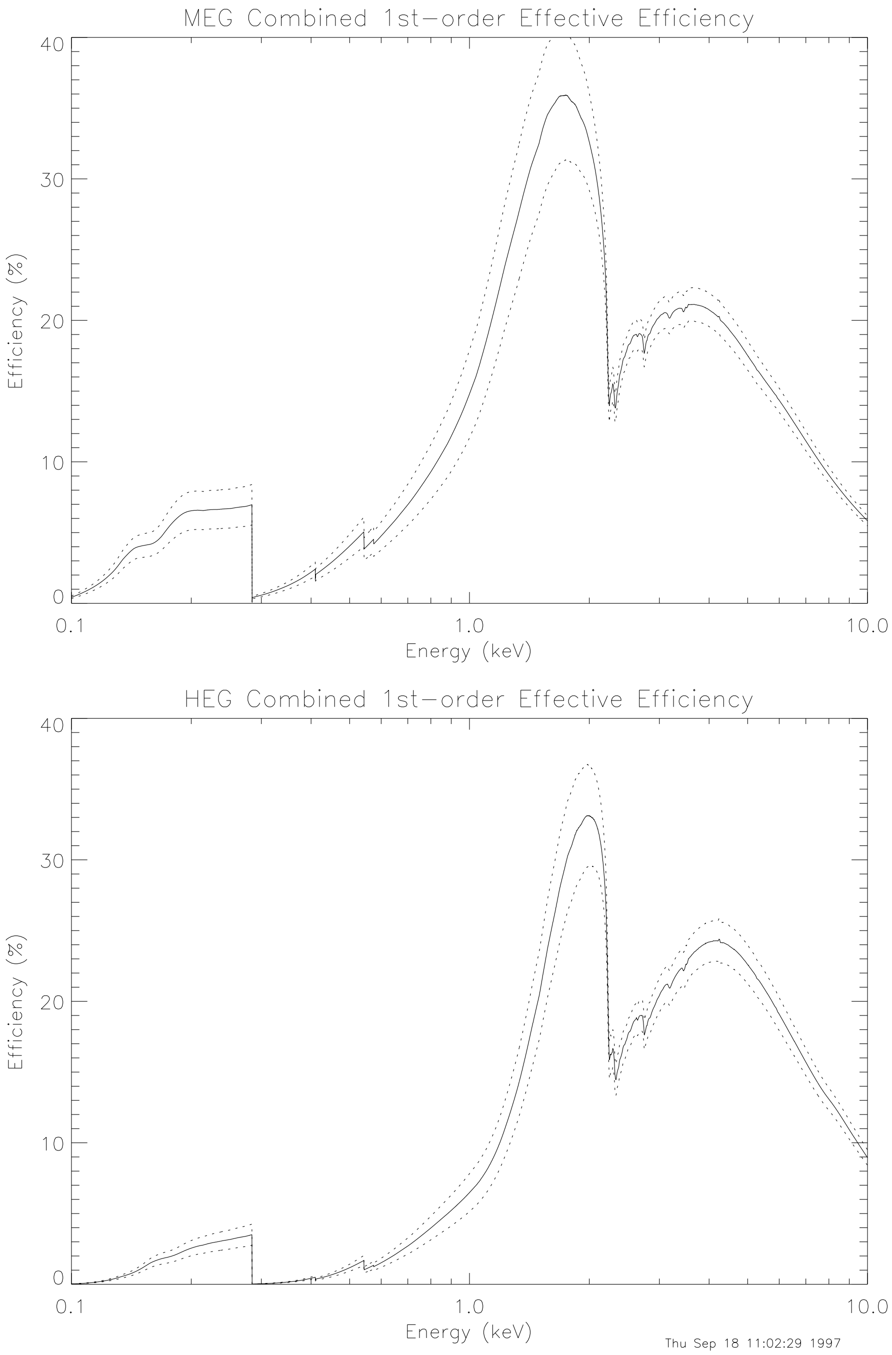

Figure 9.3: Effective Efficiency for First-order MEG and HEG. These efficiencies are the mirror weighted average of the shell-by-shell efficiencies for the appropriate pair of shells. Plus and minus orders have been combined. The dotted lines are the "2-sigma" errors of the shell efficiencies with additional error due to uncertainties in the relative area (weighting) of the HRMA shells.

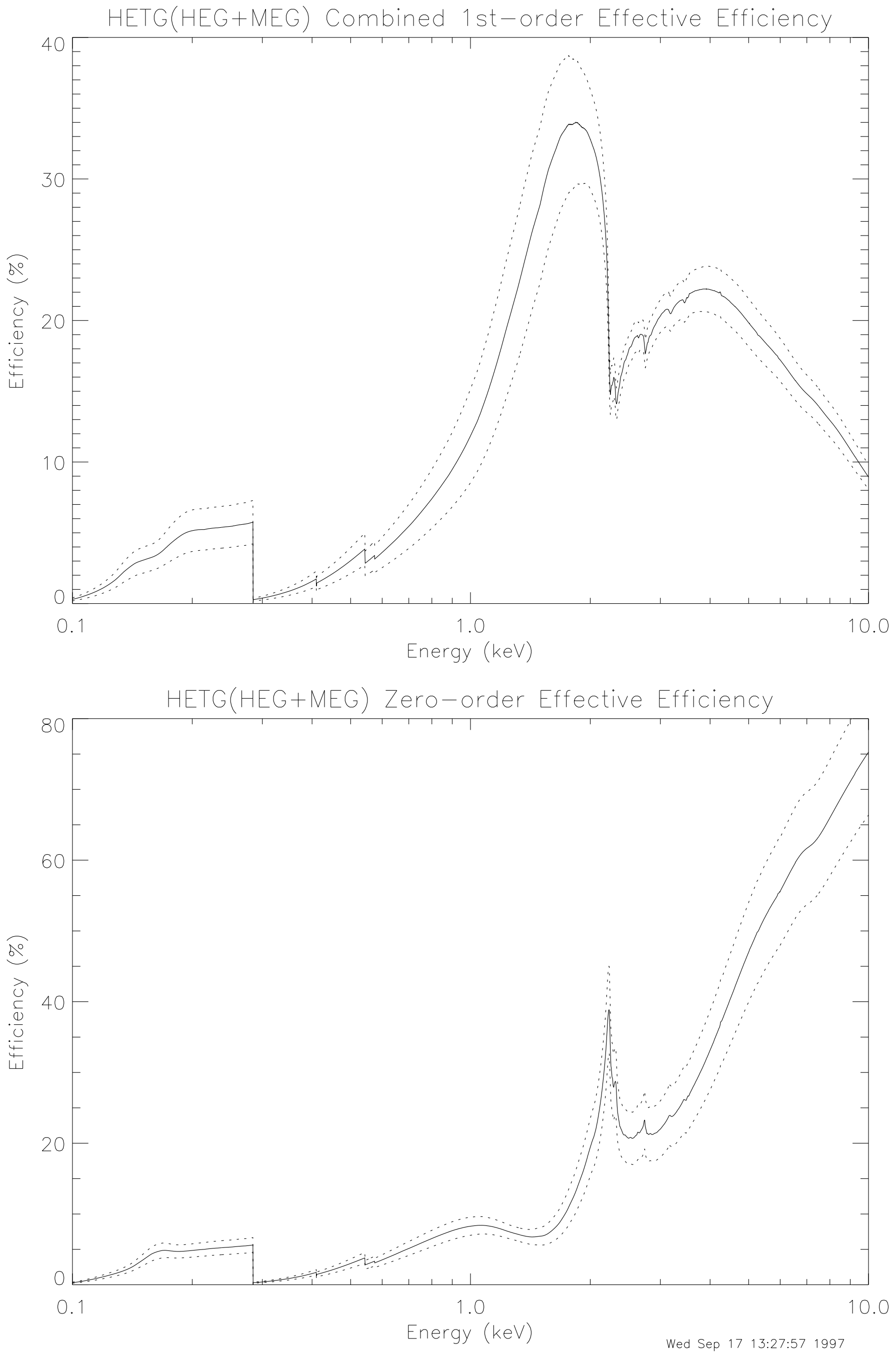

Figure 9.4: Effective Efficiency for HETG 1st and 0 orders. These efficiencies are the mirror weighted average of the shell-by-shell efficiencies. The first-order efficiency is for combined plus and minus orders for HEG and MEG. The dotted lines are the "2-sigma" errors of the shell efficiencies with additional error due to uncertainties in the relative area (weighting) of the HRMA shells.

9.3.5 MARX Parameters

The **MARX** ray-trace package, Section 2.3, provides a high fidelity model of the HETGS. To define the HETG in **MARX** there are parameters and data files to be specified. It is the HETG and ASC calibration groups domain, working with the **MARX** developers, to provide accurate values for these **MARX** inputs.

The **MARX** inputs can be divided into those directly related to the LRF and those that govern diffraction efficiency. These are presented in the following sections.

9.3.5.1 MARX HETG LRF Parameters

The LRF parameters bascially encode the Rowland design and some aspects of its real-life construction. The values presented in Table 9.5 are all taken directly from the corresponding values determined in the CIP Sections 9.3.1 through 9.3.3. Note that the MEG mis-aligned gratings and the HEG scatter are not currently included in **MARX** simulations.

Table 9.5: Flight HETG LRF parameters for use in **MARX**.

Parameter	Value	Unit
RowlandDiameter	8633.75	mm
hegTheta	-5.18	degrees
megTheta	4.75	degrees
HETG_Shell1_Theta	4.75	degrees
HETG_Shell3_Theta	4.75	degrees
HETG_Shell4_Theta	-5.18	degrees
HETG_Shell6_Theta	-5.18	degrees
hegdTheta	1.5	arc minutes rms
megdTheta	1.5	arc minutes rms
HETG_Shell1_dTheta	1.5	arc minutes rms
HETG_Shell3_dTheta	1.5	arc minutes rms
HETG_Shell4_dTheta	1.5	arc minutes rms
HETG_Shell6_dTheta	1.5	arc minutes rms
hegPeriod	0.200081	microns
megPeriod	0.400141	microns
HETG_Shell1_Period	0.400141	microns
HETG_Shell3_Period	0.400141	microns
HETG_Shell4_Period	0.200081	microns
HETG_Shell6_Period	0.200081	microns
hegdPoverP	146.e-6	rms
megdPoverP	162.e-6	rms
HETG_Shell1_dPoverP	162.e-6	rms
HETG_Shell3_dPoverP	162.e-6	rms
HETG_Shell4_dPoverP	146.e-6	rms
HETG_Shell6_dPoverP	146.e-6	rms

9.3.5.2 MARX Rectangular Efficiency Parameters

MARX offers two ways to specify a gratings diffraction efficiency. The old standby is a rectangular grating model in which a few parameters are used to specify a rectangular model and the diffraction efficiency $G_{\mathrm{config}}(E, m)$ is calculated from these parameters. The second method is to use a set of look up tables for the efficiency, described in the next section.

Although the HETG gratings are not rectangular and also vary in their properties, it is possible to select a set of rectangular parameters that comes close to approximating the effective efficiencies of Section 9.3.4. Figures 9.5–9.8 present comparisons of these rectangular efficiencies and the current best CIP values. The first-order effective efficiencies are modeled to better than 10% over the relevant ranges; orders $m = 0, 2, 3$ are largely within 20% . The rectangular parameters used in these plots are presented in Table 9.6.

Table 9.6: **MARX** Parameters for Rectangular approximation to HETG efficiency. These (non-physical) parameters provide a reasonable approximation to the HETG diffraction efficiency including higher-order contributions.

Parameter	Value	Unit
GratingOptConsts	"optical-constants.dat"	
UseGratingEffFiles	"'no"	
HEG grating		
HEGVig	0.93	
hegGold	0.0444	microns
hegChromium	0.0111	microns
hegNickel	0.0	microns
hegPolyimide	0.978	microns
hegBarHeight	0.4896	microns
hegBarWidth	0.1177	microns
MEG grating		
MEGVig	0.93	
megGold	0.0228	microns
megChromium	0.0057	microns
megNickel	0.0	microns
megPolyimide	0.543	microns
megBarHeight	0.3780	microns
megBarWidth	0.2161	microns

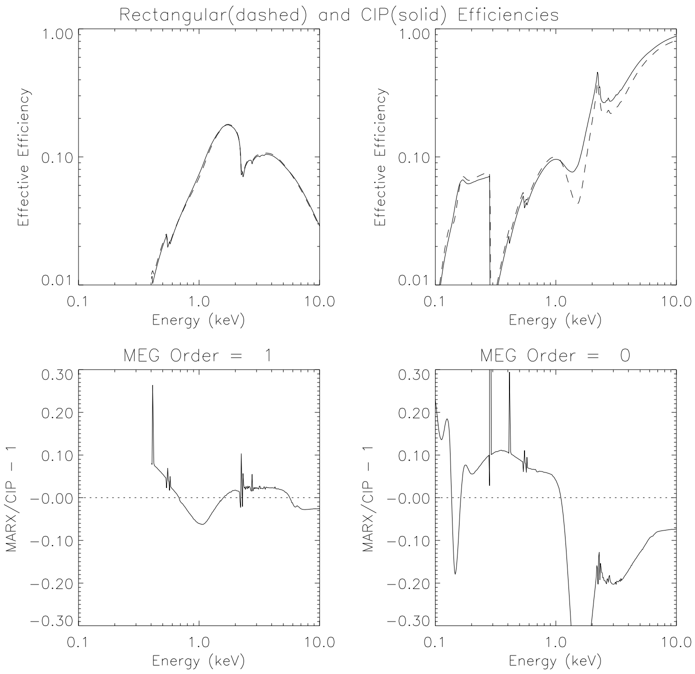

Figure 9.5: Comparing MEG Rectangular and CIP Efficiencies (orders 1, 0).

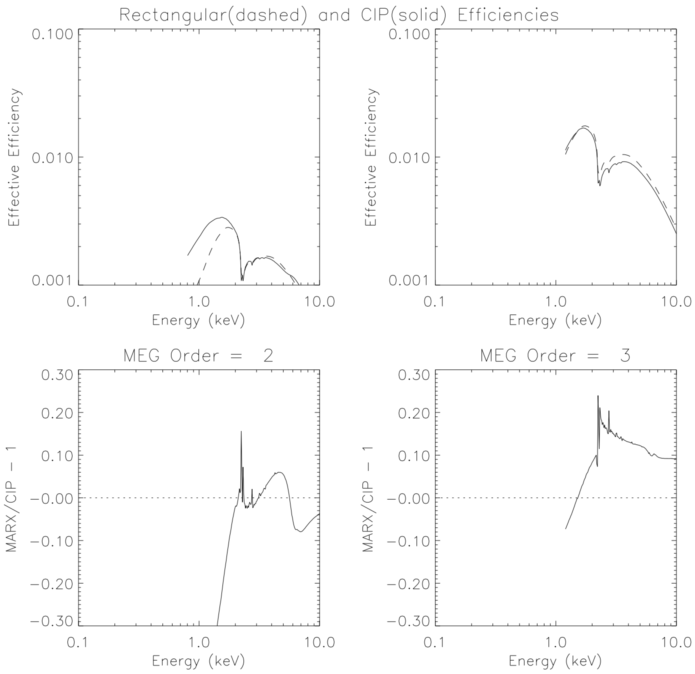

Figure 9.6: Comparing MEG Rectangular and CIP Efficiencies (orders 2, 3).

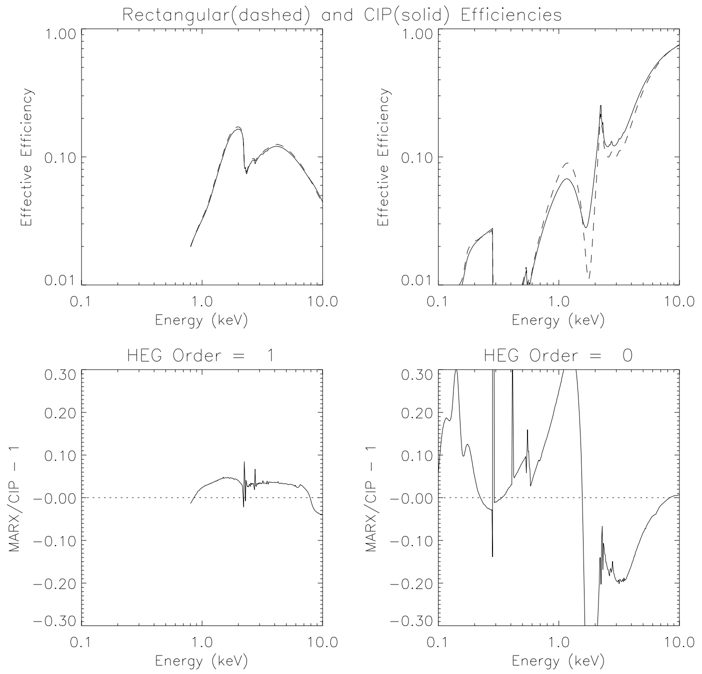

Figure 9.7: Comparing HEG Rectangular and CIP Efficiencies (orders 1, 0).

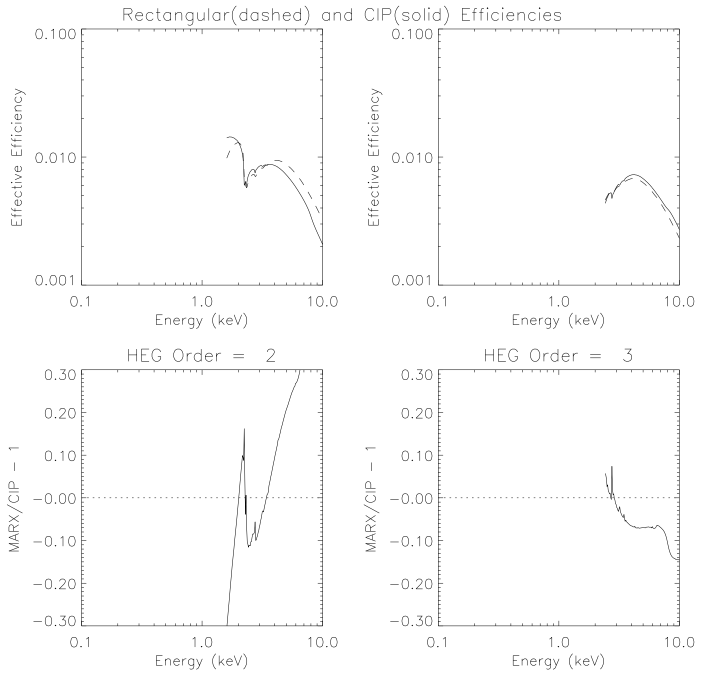

Figure 9.8: Comparing HEG Rectangular and CIP Efficiencies (orders 2, 3).

9.3.5.3 MARX Efficiency Files

MARX will soon allow the option of providing grating efficiecies as a set of lookup tables, one file for each shell. The efficiencies are tabulated on a fine energy grid and for a range of orders, currently $m = \; -11, \ldots, +11$. These tables of $G_s(E, m)$ include the shell vignetting factors (ν_s) and so the grating vignetting terms in **MARX** are set to 1.0. Table 9.7 presents the set of parameters that need to be set to implement the table lookup HETG efficiencies.

Table 9.7: **MARX** Parameters for Table-lookup HETG Efficiencies. These parameter selections allow efficiency tables encoding $G_s(E, m)$ to be read in and used by **MARX** for accurate simulations.

Parameter	Value	Unit
UseGratingEffFiles	"‘yes"	
HETG_Shell1_File	"HETG_shell1_effic.dat"	
HETG_Shell3_File	"HETG_shell3_effic.dat"	
HETG_Shell4_File	"HETG_shell4_effic.dat"	
HETG_Shell6_File	"HETG_shell6_effic.dat"	
HETG_Shell1_Vig	1.0	
HETG_Shell3_Vig	1.0	
HETG_Shell4_Vig	1.0	
HETG_Shell6_Vig	1.0	

9.4 HETGS Calibration Interface Products

9.4.1 Resolving Power

Using the resolving power error budget described in Section 2.2, estimates of the flight HETGS resolving power have been made, Figure 2.2. The "optimistic" and "conservative" E/dE curves are available in rdb format in the files:

```
MEG_res_opt.rdb
HEG_res_opt.rdb
MEG_res_con.rdb
HEG_res_con.rdb
```

9.4.2 Effective Area

In order to compute the HETGS effective area, the HRMA effective area, $A_s(E)$, and the ACIS-S quantum efficiencies, $QE_{\mathrm{ACIS}}(E, \text{grade set})$, are needed. Values for these are plotted in Section 7.1 and the HETGS combined effective area is presented in plots in Section 7.7.

9.4.3 XSPEC Response Matrices

Please see `http://space.mit.edu/HETG/xspec/xspec.html` for a discussion of HETG and XSPEC.