Center for Astrophysics

Harvard College Observatory
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MEMORANDUM

September 15, 1998

To: HRC Instrument Team

From: Ralph P. Kraft

Subject: Overview of HRC quantum efficiency calibration and discussion of uncertainties

A detailed discussion of the uncertainties of the AXAF HRC quantum efficiency (QE) calibration has been requested by several groups, and is obviously of considerable importance for inflight observations, particularly for HRC-S. In this memo, we summarize all HRC QE calibration data taken to date, and present a discussion and estimation of the uncertainties in this calibration.

The QE, $Q_{HRC}(E,\theta,\phi)$, of the HRC as a function of energy, E, incident angle, θ, and azimuthal angle, ϕ, is given by

$$Q_{HRC}(E,\theta,\phi) = Q_{MCP}(E,\theta,\phi) \times T(E),$$

where $Q_{MCP}(E,\theta,\phi)$ is the QE of the CsI coated MCPs, and $T(E)$ is the transmission of the UVIS. Our original plan was to measure the QE of the flight instrument at a several energies and angles in the laboratory at SAO, confirm these measurements and fill in the gaps (in energy) at the XRCF, and develop a simple semi-empirical model based on the data to generate a continuous curve throughout the AXAF bandpass. This data was to be combined with detailed synchrotron measurements of the QE of CsI coated MCPs and of the transmission of UVIS witness samples to map out the fine structure around the absorption edges, and with laboratory measurements of the transmission and uniformity of the UV/Ion shields.

Because of delays in assembly of the flight instrument, much of the pre-delivery calibration was not performed. After the instrument was delivered to the XRCF, several electronic problems were discovered, and it was necessary to return the instrument to SAO after the XRCF calibration for modification. These modifications measureably changed the QE of the instrument, particularly the HRC-S, limiting the usefulness of the XRCF calibration. The XRCF calibrations and subsequent modifications are described in detail elsewhere[1,2,3,4]. Flat field QE measurements were made at SAO in both the pre-fix (i.e. XRCF) and post-fix (i.e. flight) configurations after the instrument returned from the XRCF. The sub-assembly synchrotron[5], UVIS[6], and angular QE dependence[7] measurements are, however, unaffected by these changes. Each of the major HRC QE calibration data sets are summarized in the table below. A brief description of each is given, and the strengths, limitations, and uncertainties are outlined.

1. XRCF calibration: The effective area of the HRMA+HRC was calibrated at the XRCF at many closely spaced energies. There are several difficulties in using this dataset for determining the HRC QE. First, as stated above, the instrument was returned to SAO after these calibrations and was substantially modified. The flight performance of the instrument will be somewhat different. Second, there are potentially large systematic uncertainties in a large subset of this data taken using the HIREFS source. Third, extraction of the HRC QE requires a model or other measurements of the HRMA effective area, introducing another uncertainty. We have therefore only used this data to compare with the pre-fix flat field measurements.

2. SAO flat fields: After the flight instrument was returned to SAO, flat field measure-

ments were made in the pre-fix and post-fix configurations. A gas-flow proportional counter (PC) was used as an absolute detector. These measurements were made at eight (HRC-I and HRC-S segment 0) or four (HRC-S segments +1 and -1) energies. The most important uncertainty in these measurements is the determination of the PC QE. Each flat field contained $\sim 10^8$ events (10000 per mm^2). The statistical uncertainty is therefore negligible compared to the systematic uncertainties. We have relied heavily on these measurements for generating the calibration data products located on our website.

3. CsI coated MCP synchrotron measurements: The QE of CsI coated Phillips MCPs (similar to HRC-S flight plates) was recently measured at the Daresbury Synchrotron Radiation Center in two energy bandpasses: 450 eV to 1200 eV and 4500 eV to 9500 eV. These measurements were made primarily to determine the absorption fine structure around the Cs and I M and L edges, but are also useful maps of the continuous curves between the edges. These data has been analyzed, but has not yet been incorporated into the QE models. The statistical uncertainty in these measurements is negligibly small.

4. UVIS transmission and uniformity measurements: Several different measurements have been made on the UV/Ion shields. First, several witness samples were taken to BESSY in Berlin to measure the absorption fine structure around the elemental edges. Second, the transmission of these samples was also measured in the HRC lab using the McPherson monochromator. These two sets of measurements typically agree within 1%. The best fit areal densities typically have a formal 90% confidence interval that is a few percent of the thickness. Third, the transmission and uniformity of flight backup UV/Ion shields was measured in the HRC laboratory using shadowgraphs. The UV/Ion shields are well calibrated, and any uncertainty in $T(E)$ for any of the shields is small compared to uncertainties in $Q_{MCP}(E)$.

5. Angular dependence of QE: The angular dependence of CsI coated MCPs (both Galileo and Phillips plates) over the AXAF cone angles has recently been measured in the HRC laboratory. Statistical uncertainty in these measurements is also small. These results have not yet been incorporated into the QE models, however. The angular dependence is a $\sim$10% correction below 200 eV. This correction decreases with increasing photon energy, and is negligible above 1 keV.

The difficulty in determining the HRC QE lies in combining these datasets of varied completeness and usefulness. The post-fix flat fields are obviously the most useful since the instrument was then in the flight state, but are sparsely spaced in energy. The XRCF measurements are not representative of the flight QE, particularly for the HRC-S, and are generally useless below 1.5 keV at any rate because of complications with the X-ray source (HIREFS). We have provided some preliminary estimates of $Q_{HRC}(E)$ on the HRC calibration website relying primarily on the post-fix flat fields, the UVIS witness sample measurements, and on a semi-empirical model suggested by Mike Juda[8] to generate a continuous curve for $Q_{MCP}(E)$. The UVIS is well calibrated, so the major uncertainty in the QE models is in the MCP QE. More information about the current QE model can be found on the HRC calibration website. The main problems with relying on the post-fix flat fields are that we have measurements at only a few energies, and there may be systematics in the absolute normalization. There are then two major uncertainties in the HRC QE curve as it now exists. First, how precise are the flat field measurements, and second, assuming the errors in the flat field measurements are small, how accurately does the model reflect the real $Q_{MCP}(E)$?

The first issue is not easy to address, but we can compare the pre-fix data with the XRCF data at the few energies that overlap. We find that, in general, the two measurements agree to within a few percent, giving us some confidence that our post-fix values are accurate within this same uncertainty of a few percent.

If we had more points (energies), the semi-empirical curve would be very accurate. Given that we only have 8 (only 7 useful) energies from which to base our interpolation, we are required to make continuous estimates over large energy steps for which we have no data. As above, we can use the XRCF data as a guide. Above 1.5 keV, the general shape of the QE curve measured at XRCF agrees well with the modelled curve except around the Cs and I L edges. The model overestimates the jump across the edge by about a factor of 2. The same situation probably occurs around the Cs and I M edges below 1 keV, but the XRCF data does not provide a useful comparison at these energies. The synchrotron data is useful around both sets of edges, and provides supporting evidence that the size of the jumps has been over estimated. In addition, the model predicts that the QE of the MCPs will be the open area ratio ($\sim$60%) at low energy end of the bandpass. Based on earlier synchrotron measurements[9], this is clearly not correct.

From this analysis, what conclusions can be drawn about the uncertainties in the HRC QE? There are two major deficiencies in the QE model that must be addressed in the future. First, the jumps across the edges are too large. The current models my be off as much as a factor of two around the edges. Second, the low energy QE has been considerably overestimated, perhaps also by a factor of 2. The smooth portion of the interpolated curve is probably more accurate, we estimate within 10% or so. Both of these numbers will be improved when the recent synchrotron measurements are incorporated. The synchrotron data provides a direct measurement of the jumps across the edges and the shape of the curve between the edges. Any systematic uncertainties in the synchrotron data are smaller than the uncertainties that exist in the current QE model. In addition to the synchrotron data, we also have an extensive on-orbit calibration program planned that will allow us to test and further refine our QE model.

1 References

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