Grating Spectral Order Sorting with the ACIS CCDs

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Abstract

To sort overlapping spectral orders imaged by the HETG or LETG instruments onto the ACIS-S detector array, we use the CCD energy redistribution response as a function of position and energy. During analysis, we use the same response to calibrate the effective area fraction implicit in order-sorting. We attempt to maintain a high and nearly constant enclosed energy fraction, but CCD gain and response variations make this difficult. The order-sorting has not been highly visible to users. I will show some examples of good and bad order-sorting, discuss options for inspection and re-processing before analysis, and talk about plans for construction of the next generation tables, given the new formalism for defining the ACIS redistribution which is currently being implemented.

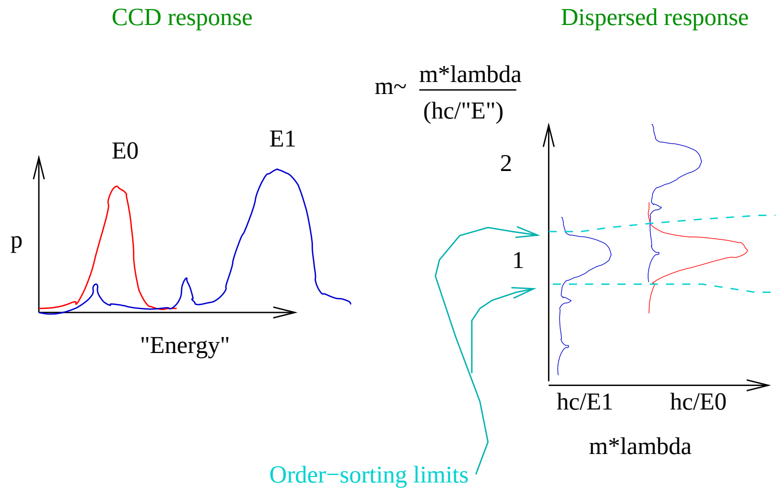

Figure 1:

Figure 1 is a schematic of the basic principles of order sorting. The CCD response is depicted on the left as the probability distributions for two different energies (in different colors) scaled to pseudo energy units ($PHA \rightarrow PI \rightarrow ENERGY$). On the right is a depiction after diffraction by a grating (positive orders only), where the x-axis is $m\lambda$ (high resolution direction), and the y-axis is $m\lambda$ divided by the CCD "wavelength", hc divided by the pseudo $ENERGY$ (low resolution "direction"). The y-axis is thus a real-valued estimate of the diffraction order, m. Each energy is diffracted m times; the figure depicts the higher energy in both first and second orders, and the second order overlaps spatially with the longer wavelength distribution, but different $m\lambda$ are spatially well separated by the grating resolution.

In the dispersed view, we can easily separate the main peaks of the CCD response at any spatial location ($m\lambda$). The light dashed lines bound a region enclosing most of the first order probability. A small fraction of the higher energy distribution is clipped, and that tail in second order overlaps the first order distribution at half the energy.

The **Order Sorting and Integrated Probability** (OSIP) table stores the high and low energy limits for order sorting as a function of energy, CCD, and x, y position on the CCD. When the program, `tg_resolve_events` sorts orders, it looks up these first-order limits for each event after computing $m\lambda$. If the event's $ENERGY$ lies within the limits, or integer multiples of the limits, it is assigned the nearest integral order. The other quantity tabulated is the fractional response (`FRACRESP`), the integral of the response within the limits. This is read by `mkgarf` in computing the effective area (also using the instantaneous location of the spectrum on the detector).

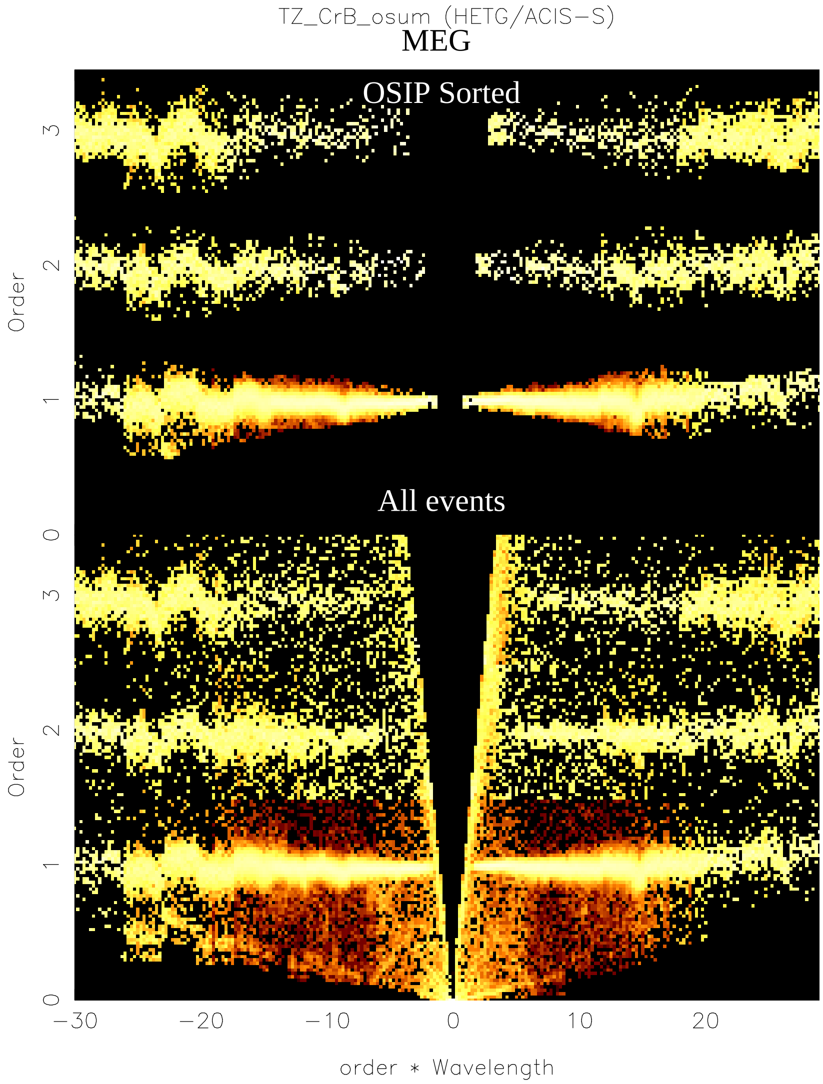

Figure 2:

Figure 2 shows an intensity image of events in the order vs. $m\lambda$ coordinates, for MEG orders 1–3. The top half shows only those events selected by the OSIP table. The bottom half is all events. (Intensity has been normalized in each order at each wavelength to remove any trend due to effective area and source flux.) Such a figure can be used to determine whether the OSIP regions are adequate. If the zero order were misplaced, the orders would curve strongly up and down near $m\lambda = 0$. For a bad gain table, there will be vertical offsets or discontinuities. A gain error can be seen in the minus orders, near $m\lambda = -28$ to -18, as an up-and-down wiggle. This is due to poor calibration of the serial CTI on chip S1.

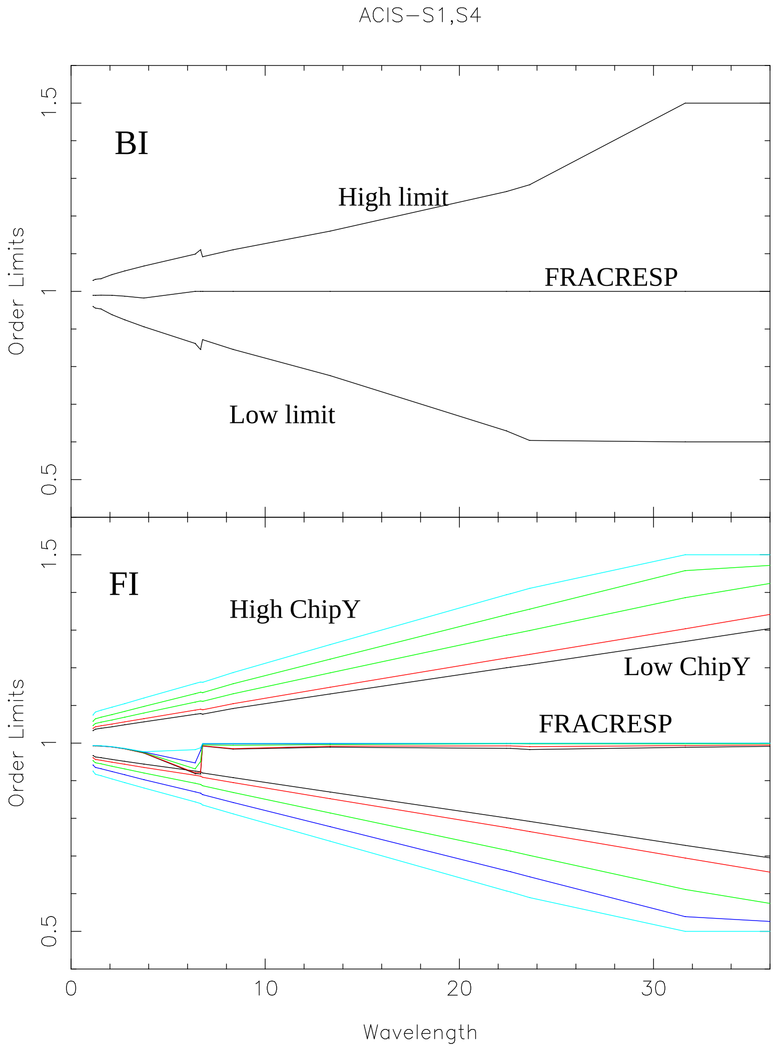

Figure 3:

Figure 3 shows the order sorting limits and the fractional responses extracted from the OSIP table for a back illuminated (BI) CCD (top) and a front illuminated CCD (FI, bottom). The FI response is highly non-uniform in the ChipY direction: the limits are broader at high ChipY where the CTI degrades the resolution.

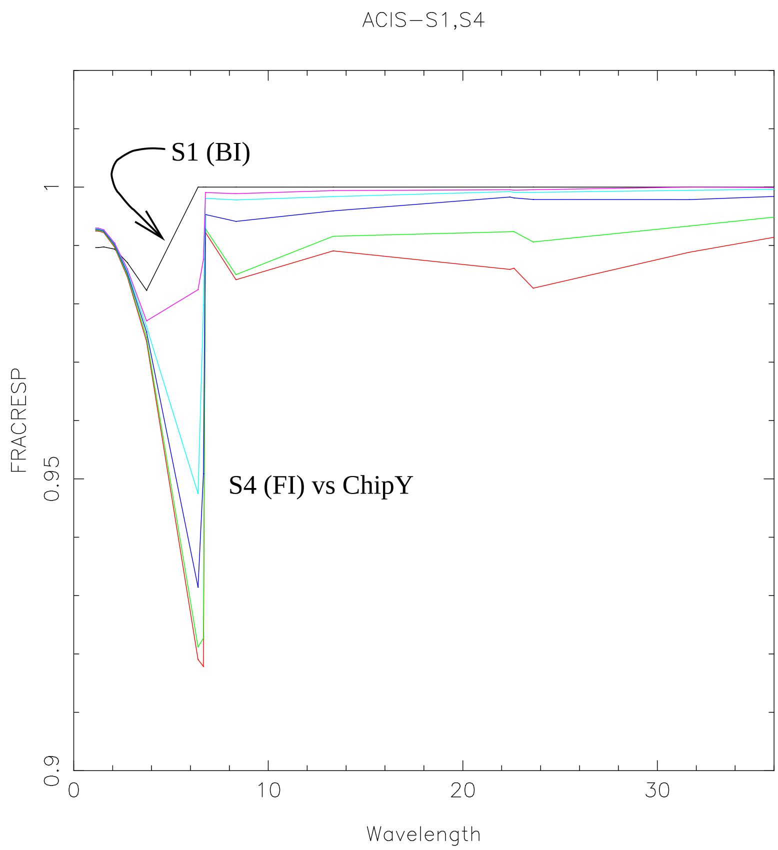

Figure 4:

Figure 4 shows detail on the **FRACRESP**. The value is very near 1.0, except for a small region near 6 Å, due to the silicon escape peak and fluorescence loss. This is also quite spatially dependent on the FI CCDs. It has a much smaller amplitude on the uniform BIs.

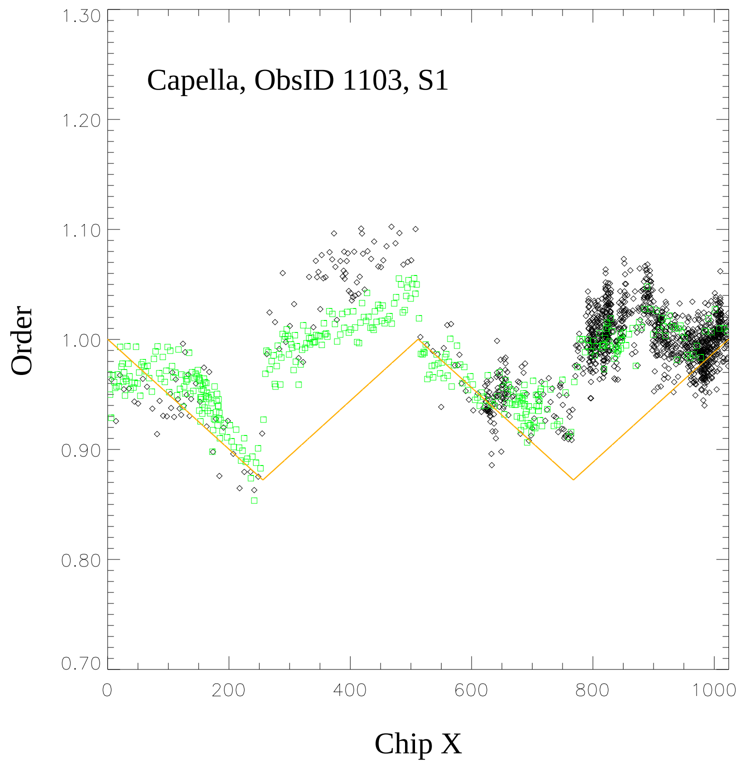

Figure 5:

Figure 5 shows detail on the S1 gain wiggle. The points are means of the distribution vs. order at each $m\lambda$. The trend is due to serial CTI as the charge is clocked towards the four nodes. It is not the simple linear affect, however, as shown schematically by the solid sawtooth lines. (The dark points are scaled third order, which shows that their might be some dependence on energy.) This serial CTI requires broader OSIP energy regions for S1 to avoid clipping the response, since this is not included in the `FRACRESP`.

Miscellaneous Details

CC Mode: CC mode is supported. An iterative step in `tg_resolve_events` makes an intelligent guess as to whether the event is HEG or MEG, and adjusts the ChipY estimate accordingly. Cases with large `SIM_Z` offset, in which HETG arms fall off the array, are also handled properly, since this adds unambiguous information on whether events are from HEG or MEG.

LETG/ACIS-S The low energy limit of the tables has been extended to accommodate the long wavelengths for use of LETG with ACIS-S.

Leakage/pile-up There is some "leakage" from high orders to low, via the tail of the CCD response. This is not accounted for, since it is source model dependent. However, the `FRACRESP` shows that this is generally quite small.

There can be pile-up from low to high orders for bright sources. For Capella, this has been estimated to be a few percent in the brightest lines in first order (using the J.Davis grating pile-up model). For X-ray binaries, it can be severe. This affect is not accounted for by the OSIP, but must be modeled.

Flat OSIP Option For cases where the OSIP just isn't good enough (epochs of CCD temperature change; poor low-energy gain; different CC-mode CCD response), there is an option for `tg_resolve_events` to use a "flat" order sorting region (parameters `osort_lo, osort_hi`). In `mkgarf`, the corresponding parameter setting is `osip=none`.

Visualization Tool A prototype slang function has been written which creates a FITS image file, from which Figure 2 was made. The file can be viewed in ds9, and it has a coordinate system in $m\lambda, m$. This will be released soon for general use (`mk_osum_img.sl`).

CTI-corrected Response Plans

Since the CCD response paradigm is changing, the OSIP generation will also have to change. However, there it is not expected that the resulting file format will change, nor will operation of `tg_resolve_events` or `mkgarf`. Since there will be no `FeF` maps in PI (energy) space, the OSIP will have to be computed empirically from the CCD response distributions directly (as opposed to generation from Gaussian parameters). CTI correction has little or no appreciable affect on the order-sorting, at least as currently provided only for S2 (an FI CCD) on the `ACIS-S` array.

Examples of Order Sorting Gone Bad

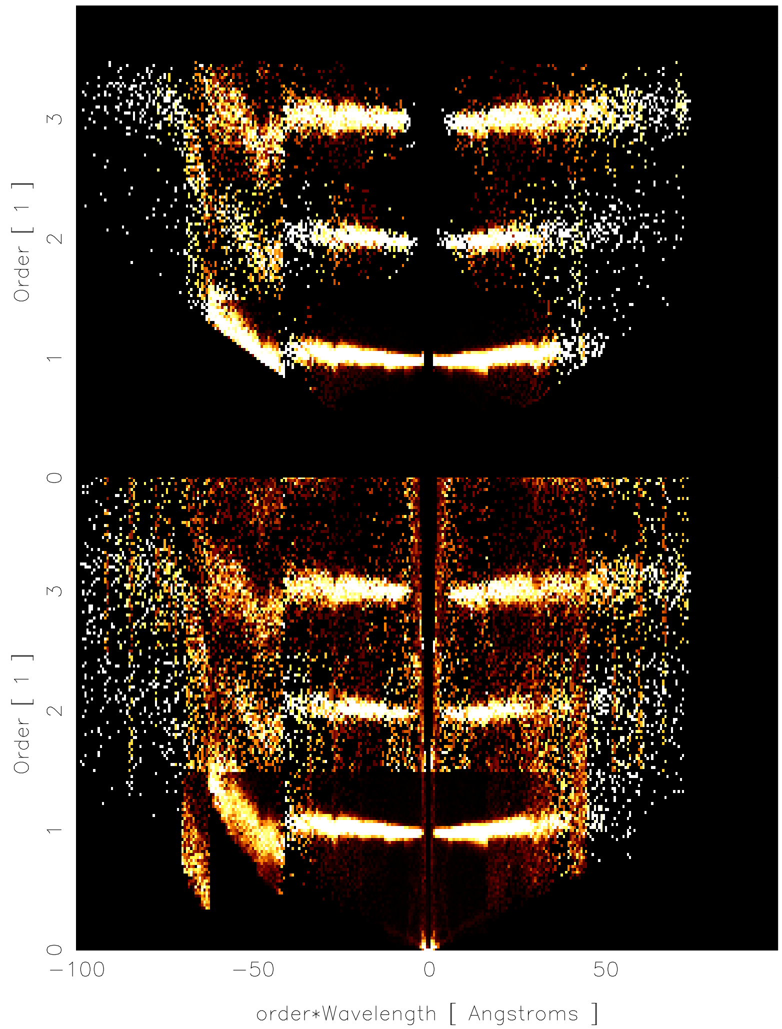

Figure 6:

Figure 6 shows an order-sorting image for an LETG/ACIS-S observation (ObsID 1703). It is clear that something is not right on the minus side longward of about 40 Å. The upper panel is the as-osip-sorted events, and the bottom shows all events (within the spatial region). (The difference between plus side and minus side in this region is due to the enhanced low-energy sensitivity of the S1 BI CCD.)

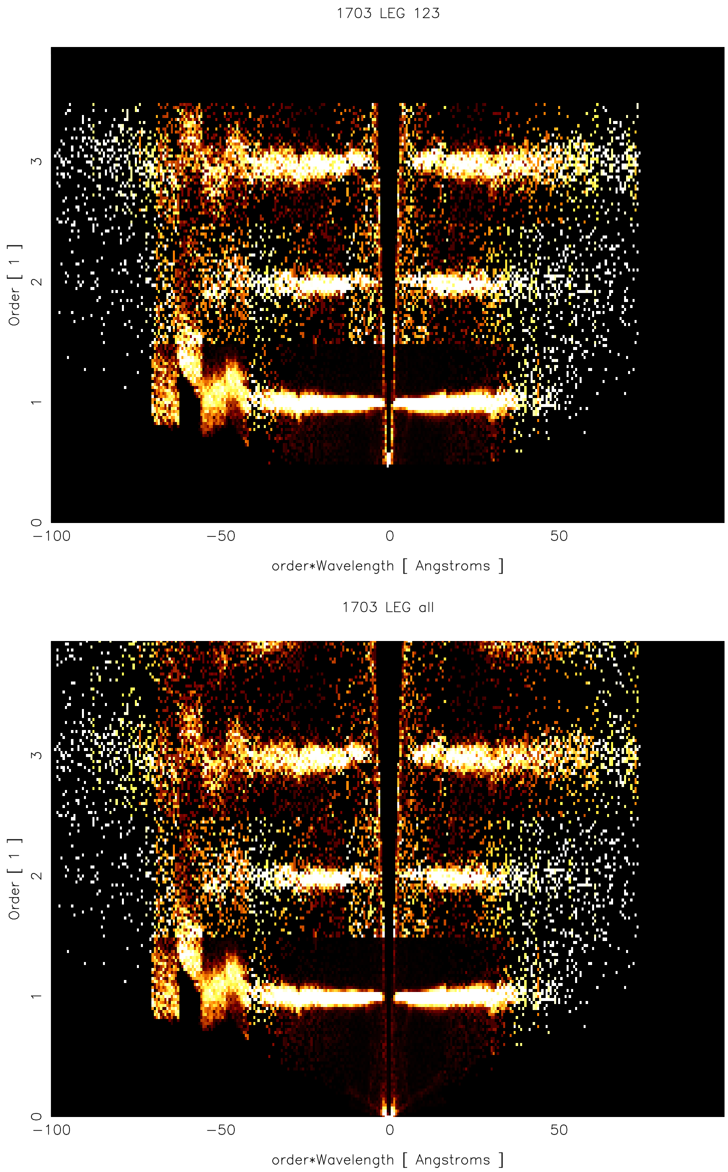

Figure 7:

Figure 7 shows a somewhat improved version, after applying a more recent gain file with improved low-energy calibration. This has also been processed with the `osort_lo, _hi` options for "flat" order-sorting regions (hence the upper and lower panels are identical). There are still some residual problems on one node of S1.

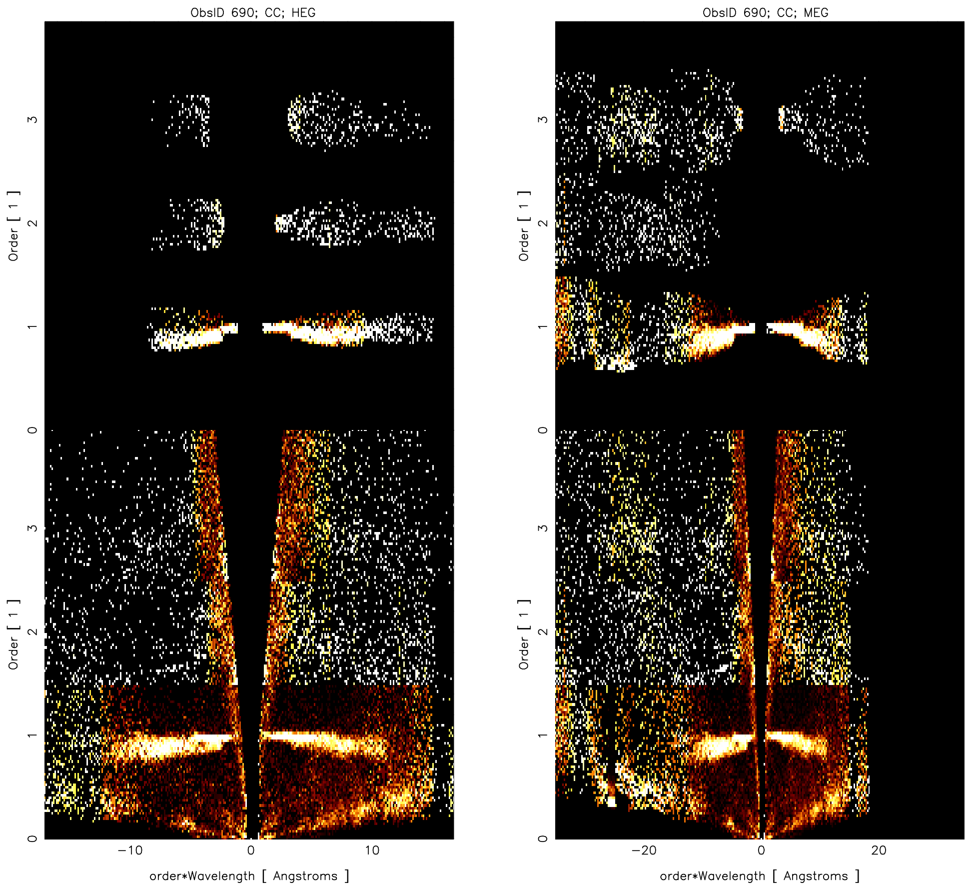

Figure 8:

Figure 8 is an example of HETGS/CC-mode data (ObsID 690). Left shows HEG orders, and right MEG. Upper are as-OSIP-sorted, and bottom are all events. We see a droop in the orders which resulted in clipping. This is due to the different CCD energy response in CC mode. We also see truncation of orders, but this is intentional, since the detector was offset in the Z direction by 10 mm. The MEG positive order is truncated by the detector, and HEG negative. Hence, all MEG $m = +2$ events were assigned to HEG $m = 1$ since they overlap spatially, but MEG $m = -1$ were not assigned to HEG $m = -1$ (as is usually the case for CC-mode, since MEG second order has low efficiency), since the HEG order is not on-chip.