AXAF Science Center

Grating Tool Specifications
Level 1.5:
ACIS Continous-Clocking Mode Processing

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(`http://space.mit.edu/ASC/docs/TBD`)

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1 Introduction

This memo is specifies how data taken with ACIS-S in continous-clocking (CC) mode and a grating (nominally HETG, but alternatively LETG) are to be processed into diffraction coordinates and diffraction orders, as described in the Grating Level 1.5 ICD[1], and is supplemental to that document.

When in CC-mode, the events' locations are only known along one axis – the serial read axis (`CHIPX`, which projects parallel to the AXAF y-coordinate for ACIS-S). In the other dimension, we only know the location to within the size of the CCD. Hence, we can no longer *spatially* discriminate high-energy grating (HEG) from medium-energy grating (MEG) photons (or cross-dispersed photons, if LETG). However, we can still (hopefully) discriminate most MEG odd-order photons via their ADU (Analog-Digital Unit, also colloquially know as "pulse-height amplitude"— PHA, or "pulse-invariant amplitude" — PI). Due to the nearly factor-of-two ratio in MEG to HEG periods, the HEG orders fall on even MEG orders in ADU, and have the same wavelength and diffraction angle as MEG photons at the same position (to within that same ratio). By design, the MEG even orders are weak (though not negligible), so the HEG orders will typically dominate. This is a mildly simplified view, since there is a "beat frequency" in odd:even order efficiency and a distribution in grating parameters. There is also a possible asymmetry in the grating clocking-angles relative to the CCD axis. The relative efficiencies will be handled in the exposure-map, which will combine grating efficiencies. Any rotational misalignments will result in a small degradation in resolution, but this is proportional to the cosine of the misalignment and so is a second-order affect.

[1] "Grating Data Products: Level 1.5 to ASC Archive Interface Control Document", **`http://space.mit.edu/ASC/docs/ICD_L1.5.ps.gz`**

Issue: Preliminary XRCF results show a long, high count-rate, low ADU tail which may require modeling the MEG+HEG distribution, rather than integrating under it. The flux calibration of the orders will be dealt with elsewhere.

The general procedure is similar to non-CC-mode Level 1.5:

1. detect zero-order;
2. determine zero-order centroid;
3. specify a zero-order region;
4. specify a diffracted order region;
5. determine event angular diffraction from zero-order, referencing each event's chip coordinates to the zero-order-centroid in chip coordinates (at the same time; an inverse, one-dimensional aspect transformation is required)
6. resolve the orders, using the event ADU (PHA), diffraction angle, and CCD response.

1.1 External Requirements

The standard aspect solution will correct events to the proper position along the projection of the chip read-row (AXAF-y for ACIS-S), but they will be smeared in the perpendicular direction. I will refer to the coordinates along and across this direction as $(\mathcal{Y}, \mathcal{Z})$, since they are effectively the projections of the AXAF (y, z) focal-plane coordinates onto the sky. The marginal distribution in $\mathcal{Y}$ (histogram of $\mathcal{Y}$) will give us the counts histogram. I will assume that this form of the aspect solution exists; it can be achieved through a rotation of coordinates by the mean roll. Any significant roll variations during the observation will smear the PSF somewhat, but roll is expected to be small.

1.2 Complications

Zero-order blocking: If CC-mode is being used, it generally means that the source is bright. If the source is very bright, it is likely that the zero-order has been deleted from telemetry via ACIS back-end-processor exclusion windows. Hence, we will need some additional logic to determine a zero-order centroid.

Grating 1D Coordinate Transformations: The current transformation from chip position to diffraction coordinates requires `CHIPX` and `CHIPY` coordinate pairs for both zero-order and the diffracted photon. We can uniquely specify a diffraction angle from:

- an assumed randomized `TG_D` distribution ($TG\_D = 0.0$ is a simple and reasonable assumption);
- an assumed zero-order `CHIPY` (such as that of the nominal source sky coordinate, transformed to chip coodinates using the aspect solution);
- a derived zero-order `CHIPX` centroid;

- the observed diffracted photon coordinate, `CHIPX`.

Such a transformation will have to be added to `pixlib`. A reasonable approximation will be to derive a zero-order centroid from the *a priori* known source sky coordinate and the aspect solution, $\mathcal{Z}_{\mathrm{zo}}$ (AXAF-z is nominally parallel to `CHIPY` for ACIS-S), and that the diffracted photon is at

$$\mathcal{Z} = \mathcal{Z}_{\mathrm{zo}} + (\mathcal{Y} - \mathcal{Y}_{\mathrm{zo}}) \tan \alpha.$$

The grating clocking angle is α, and the zero-order-centroid is at $(\mathcal{Y}_{\mathrm{zo}}, \mathcal{Z}_{\mathrm{zo}})$. This approximation ignores the tiling of the Rowland circle by flat CCDs, but the deviation from the Rowland circle is small, and the diffraction angle is invariant to translation in `CHIPY`. The transformation from (`CHIPX, CHIPID`) to AXAF-y is necessary to account for CCD gaps. This approximation is equivalent to saying that

$$tg\_r = (\mathcal{Y} - \mathcal{Y}_{\mathrm{zo}}) / \cos \alpha.$$

Multiple Sources: If an observation is in CC-mode, it is probably a good assumption that one source dominates. We will not attempt to process multiple sources. This must be left to interactive user analysis. A second source's zero-order will have to be identified interactively. Given its location the remaining Level 1.5 tools can be run. Though the diffracted spectrum cannot be isolated spatially, some photons may have uniquely determined ADU (PHA) for the zero-order position.

Document and Change Control Log

Date	Version	Section	Status
20 July 1998	1.0	all	Initial version

Unresolved Issues

The following is a list of unresolved, un-reviewed, or un-implemented items:

1. 980720: Pixlib coord transformations for grating in CC-mode need to be specified.

2 Detailed Specifications

2.1 Zero-order Detection and Centroid

2.1.1 Zero-Order Un-blocked Case

Inputs

1. ACIS Level 1 event-list (CC-mode)
2. aspect solution (or aspect offsets)

Outputs

1. $\mathcal{Y}_{\rm zo}$: $\mathcal{Y}$ coordinate of the zero-order centroid.
2. $\mathcal{Z}_{\rm zo}$: nominal $\mathcal{Z}$ coordinate of the zero-order centroid.
3. Zero-order region (limits on $\mathcal{Y}$).
4. Diffracted-order region (limits on $\mathcal{Y}$).

Processing

1. Read the source position from the event-file header: (`RA_NOM, DEC_NOM`).
2. Convert this position to $\mathcal{Y}_{\rm zo}$, $\mathcal{Z}_{\rm zo}$. $\mathcal{Y}_{\rm zo}$ is the first estimate for the observed component of the zero-order position, and $\mathcal{Z}_{\rm zo}$ is a predicted coordinate. Determine the `CHIPID` at these coordinates. Determine the off-axis angle (θ) of these coordinates. Calculate the expected zero-order radius, σ for this θ (same as for non-CC-mode).
3. Select events from the `CHIPID` determined in the previous step, and bin the $\mathcal{Y}$ column into a 1D histogram.

   TBD: FITS name of $\mathcal{Y}$ column.
4. Find the peak counts in the histogram within a couple times the predicted zero-order radius of $\mathcal{Y}_{\rm zo}$.
5. Given the peak, find the centroid within the zero-order radius, and replace $\mathcal{Y}_{\rm zo}$ with this value.
6. Detemrine the range in Y to specify the diffracted order region (which will be adjusted to accomodate the length of the detector for the value of $\mathcal{Y}_{\rm zo}$).

2.1.2 Zero-Order Blocked Case

In this case, zero-order has been deleted from the data before telemetry. We will proceed as above in predicting the position. Then we will do a cross-correlation of the left and right orders, since the spectral features on each side will be similar (not identical, due to the hybrid array and differing efficiencies). The peak of the cross-correlation will be the offset between the two sides. The guess minus half the offset is then the desired value of $\mathcal{Y}_{\rm zo}$.

Inputs

1. Level 1 event-list
2. aspect solution (or aspect offsets)

Outputs

1. $\mathcal{Y}_{\rm zo}$: $\mathcal{Y}$ coordinate of the zero-order centroid.
2. $\mathcal{Z}_{\rm zo}$: nominal $\mathcal{Z}$ coordinate of the zero-order centroid.
3. Zero-order region (limits on $\mathcal{Y}$).
4. Diffracted-order region (limits on $\mathcal{Y}$).

Processing

1. Read the source position from the event-file header: (`RA_NOM, DEC_NOM`).
2. Convert this position to $\mathcal{Y}_{\rm zo}, \mathcal{Z}_{\rm zo}$. $\mathcal{Y}_{\rm zo}$ is the estimate for the obseved zero-order position. Determine the off-axis angle (θ) of these coordinates. Calculate the expected zero-order radius, σ for this θ (same as for non-CC-mode).
3. Bin the $\mathcal{Y}$ column into a 1D histogram.

TBD: FITS name of $\mathcal{Y}$ column.

4. Break the counts histogram at the guess, $\mathcal{Y}_{\rm zo}$, into two arrays, left (lower values) and right (higher values). Reverse the order of the left side.
5. Cross-correlate the two arrays. (Note: cross-correlation is sensitive to edge-effects. Arrays are typically prepared by subtracting the mean and applying a cosine-bell filter to the edges; chip gaps may also produce a strong correlation to be ignored.)
6. Find the peak of the cross-correlation function, and its centroid. From the centroid, calculate the offset in the sense of "how far do I shift the right side to match the left" and call this $\Delta\mathcal{Y}$. The desired zero-order centroid is then
$$\mathcal{Y}_{\rm zo} \rightarrow \mathcal{Y}_{\rm zo} - \Delta\mathcal{Y}/2$$

2.2 Resolve Events: Diffraction Coordinates, Order Sorting

Inputs

1. Level 1 event-list
2. Order regions (zero-order centroid, $(\mathcal{Y}_{\rm zo}, \mathcal{Z}_{\rm zo})$, and diffracted order range)
3. aspect solution (or aspect offsets)
4. CCD PI limit table (for CC-mode)

Outputs

1. event list, with diffraction coordinates, order columns

Processing

1. For each non-zero-order event, transform the zero-order centroid from $\mathcal{Y}_{\rm zo}, \mathcal{Z}_{\rm zo}$ to chip coordinates, `CHIPX, CHIPY, CHIPID`, at the event time using the aspect solution (or aspect offsets).

   This is a new requirement on `pixlib`; details TBD.

2. Transform the event `CHIPX, CHIPID` to MEG diffraction angle, `TG_R`, assuming `TG_D`= 0, using the zero-order chip coordinate (Note: the $\mathcal{Z}$-coordinate has been *assumed*.) Assign $m\lambda$ (`TG_MLAM`) for this angle, as if MEG. Assign `TG_D`= 0. Assign `TG_PART` to MEG.

   This transformation is a new requirement on `pixlib`, details TBD.

3. Determine the diffraction order `TG_M`, using this `TG_R`, the event ADU (PI), and the CCD-PI-limit table, as if MEG.
4. If `TG_M` is even, *assume* it is actually an HEG photon. Change `TG_PART` to HEG. Repeat the prior coordinate transformations, but now for HEG: Transform the event `CHIPX, CHIPID` to HEG diffraction angle, `TG_R`, assuming `TG_D`= 0, using the zero-order chip coordinate. Assign $m\lambda$ (`TG_MLAM`) for this angle, as if HEG. Assign `TG_D`= 0.