Chandra X-Ray Center

Grating Tool Specifications
Level 1.5-2:
ACIS Continous-Clocking Mode Processing

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

Revision 1.2—22 April 1999

Revision History

Document and Change Control Log			
Date	**Version**	**Section**	**Status**
20 July 98	1.0	all	Initial Draft
16 March 99	1.1	all	Updated as per HLM remarks and ACIS CC coord. info.
22 April 99	1.2	all	Updated as per discussions w/ AA, and experience w/ CC-L1.5 s/w prototype.

Relevant Documents

The Applicable Documents required for background and detail are as follows:

1. ACIS Data Products Guide:
   Level 1 to ASC Archive Interface Control Document
   Link to be on: `http://space.mit.edu/ASC/docs/docs.html`
2. Grating Data Products:
   Level 1.5 to ASC Archive Interface Control Document
   `http://space.mit.edu/ASC/docs/ICD_L1.5.ps.gz`

Unresolved Issues

1. Do grating coordinate transformations require `CHIPX, CHIPY` for the zero-order? If so, then there will be a problem if the zero-order is dithered into, or is aimed into a CCD gap. According to JCM/990421, this case is handled properly by using focal-plane coords, and not chip. It needs a test to verify.

   990422: Looks like chip-gap/zo problem can be avioded. JCM looking at `tg_resolve_events` code.

Contents

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 (see Document 2).

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 (unless the source location is known). 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 known 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 small ($\approx 0.2^\circ$) asymmetry in the grating clocking-angles relative to the CCD axis. The relative efficiencies will be handled in the effective area ("ARF") calculation, which will combine grating efficiencies and integrate over the aspect solution. 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.

(990316) 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. An ACIS patch is being developed to implement a "3×3" grading algorithm for CC-mode.

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 coordinates to the zero-order-centroid in focal-plane coordinates (at the event-detection time).
6. resolve the orders, using the event ADU (CCD linearized `ENERGY` bin), diffraction angle, grating diffraction relation, and CCD response.

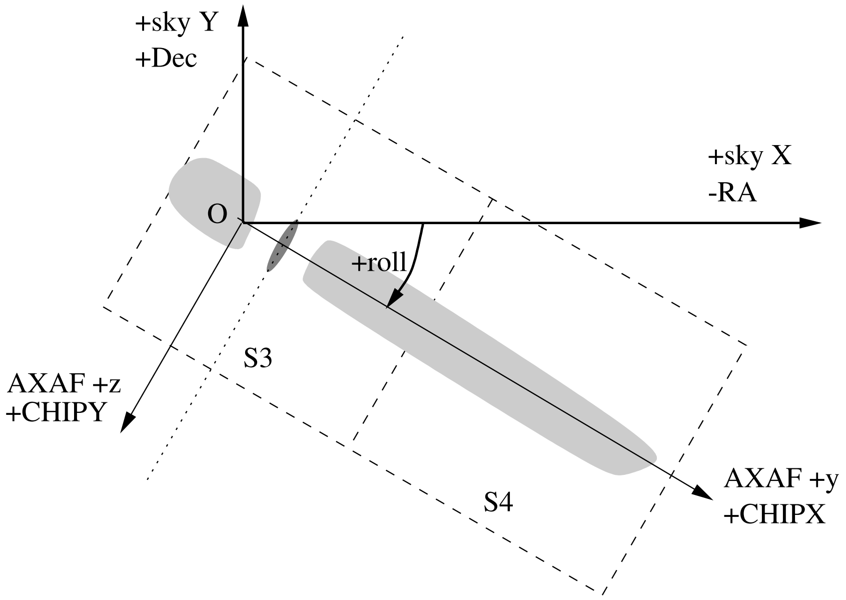
Since CC-mode is generally used for precise timing experiments, an additional step will add a time-correction for each photon so that HEG and MEG photons can be relatively synchronized. The time-correction depends on diffraction angle, since the HEG-MEG opening angle is about 10°, and the distance between HEG and MEG photons in `CHIPY` changes.

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. In CC-mode, the photon $CHIPY$ position is not determined; instead, a read-row index, running from 1 to 512 is assigned to each event. Acis Level 1 processing (see Document 1) *assumes that CC-mode events all occur at* $CHIPY = 512$ before transforming to sky tangent-plane pixel coordinates. The imaging aspect correction will thus smear events in *sky* coordinates by the amplitude of the dither in one dimension (parallel to `CHIPY`), but locate them accurately in a perpendicular direction (parallel to `CHIPX`).

I will refer to the coordinates along and across these projected chip directions as $(\mathcal{Y}, \mathcal{Z})$, since they are effectively the projections of the AXAF (y, z) focal-plane coordinates onto the sky tangent-plane pixel (X, Y) coordinates. The marginal distribution in $\mathcal{Y}$ (histogram of $\mathcal{Y}$ values) would give us the combined HEG and MEG counts histogram versus diffraction distance. Any significant roll variations during the observation will smear the PSF somewhat, but roll is expected to be small.

The relationships between the different coordinates for a small positive value of the roll is shown in the following schematic diagram. The origin, "O", is assumed to be the nominal RA and Dec, and the detector partial outline is shown by a dashed line for an instant in time when the nominal aim-point coincides with the nominal RA and Dec. Source photons are shown as the shaded regions; the small, dark ellipse represents the zero-order. In this example, the source was not at the nominal RA and Dec, so the zero-order is offset slightly along the `CHIPX` axis. The *possible* source position in the sky lies along the dotted line, which is parallel to the `CHIPY` (or AXAF-y) axis.



The extent of the photons in the `CHIPY` direction is the dither amplitude. (Had a source sky position been assumed, then photons would have been constrained to a line.) Spectral emission lines would appear as lines parallel to the `CHIPY` axis in the lightly shaded region.

1.2 Miscellaneous Details

CC-Modes: There are several CC-modes: 3×3 or 1×3, combined with `FAINT` or or `GRADED`, for examples. All will be treated the same in Level 1.5, since Level 1.5 processes ACIS Level 1 products, which have the same format. Differences will occur in the calibration of effective area ("ARF").

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 possible that the zero-order has been deleted from telemetry via ACIS back-end-processor exclusion windows. In this case, some additional logic would be needed determine a zero-order centroid. *No such cases exist in the Chandra AO-1 Observation Catalog* as of 21 April 1999. This case will not be discussed further in the current document.

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

- a zero-order source centroid in sky coordinates, transformed to focal-plane coodinates using the aspect solution. The ambiguity in source sky coordinate, as determined from the data, is in a direction to which the wavelength solution is relatively insensitive (perpendicular to the mean dispersion).
- the observed diffracted photon coordinate, `CHIPX`.
- an assigned grating arm (HEG or MEG); this can be iteratively determined from the data via the CCD `ENERGY` value, with some ambiguity.

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.

2 Detailed Specifications

2.1 Level 1.5: Zero-order Detection and Centroid

Name (TBR): `tgdetect_cc`.

Inputs

1. ACIS Level 1 event-list (CC-mode)

Outputs

1. sky (X, Y) tangent-plane pixel coordinates of the zero-order centroid. (as source table)

Parameters

1. sky box region
2. detect cell size
3. other `celldetect` params as required

Processing

The CC-mode zero-order centroid can be well determined with `celldetect` in a large box about the nominal aim-point, using a *fixed-size cell* whose size is comparable to, but larger than the dither amplitude. Using a fixed cell ensures that the centroid of the entire dither-smeared zero-order is found, and not bright points within it.

The detect region should be about 200×200 ACIS-sky pixels square (about 100×100 arcsec) to allow for some leeway in source location.

The cell size should be about 80×80 ACIS-sky pixels square to accommodate the standard dither amplitude (about 40 arcsec, peak-to-peak).

The output is the standard Level 1.5 source table.

LETG/ACIS and HETG/ACIS data are processed identically.

2.2 Level 1.5: Spatial Masks

Name (TBR): `tg_create_maskcc`

Inputs

1. source table (from `tgdetect_cc` (name TBR))

Outputs

1. region file, defining zero-order and diffracted sky regions.

Parameters

1. many (as for `tg_create_mask`)

Processing

This is very similar to the current `tg_create_mask` function. A major difference is that for HETG/ACIS, there is only one "part" for the diffracted region, since HEG and MEG overlap. The clocking angle, relative to roll, is 0.0 degrees. A minor difference is that the regions for zero-order and diffracted orders need to be larger; this can be handled by exisiting parameters.

For LETG/ACIS, there is no difference in orientation, but the same increase in width applies.

The off-axis angle is not well determined by the data. Small changes in the PSF will be subsumed by the dither smearing and subsequent region expansion, so a value of 0 will suffice (or the default calculated value, based on source centroid and nominal aim).

The output mask will need a unique index for the diffracted region to indicate CC-mode for HETGS. Currently the indices run from 0-7 to cover zero-order, HEG, MEG, LEG, HESF regions; index 8 will suffice for HETGS in cc-mode; LETG/ACIS-S can still use an index of 3 without ambiguity.

2.3 Level 1.5, Resolve Events

Inputs

1. Level 1 ACIS event-list, CC-Mode.
2. region file (From `tg_create_maskcc`.)
3. aspect offsets
4. others, as per `tg_resolve_events`

Outputs

1. Level 1.5 event list

Parameters

1. CCD `ENERGY` limit table name (appropriate for the mode)
2. others, as per `tg_resolve_events`

Processing

For HETG/ACIS-S, processing is similar to current `tg_resolve_events`, with addition of one preparatory step, and one iteration sequence (with only 2 passes).

For LETG/ACIS-S, processing needs a similar, but trivial, preparatory step, and no iteration.

(Note: Steps below are not necessarily sequential, but are logical. They may be done sequentially for each photon, or sequentially for a group of photons.)

1. Approximate `CHIPY`: `CHIPY` is required for each photon in order to determine its diffraction coordinates. Since this is not determined from the data, we have to approximate it.

   If LETG, set each photon's `CHIPY` to 512.

   If HETG, use grating geometry and zero-order location as follows for each photon:

   (a) Transform zero-order sky centroid to focal-plane coordinates ("`fc`", also known as `DETX, DETY`).

   (b) Use the zero-order coordinates, event `DETX`, and grating configuration to predict a `DETY` for the photon.

   (c) Transform the event's `DETX` and predicted `DETY` back to chip coordinates, `CHIPX, CHIPY` (the relevant function is `pix_fp_to_chip`).

   (Note: we don't change the `DETY` or `CHIPY` in the event file; these are only temporary values.)

   The event's predicted `DETY` is determined as follows:

   $$PDETY_i = DETY_{ZO}(t_i) + [DETX_i - DETX_{ZO}(t_i)]\tan(\alpha)$$

   In which

   $PDETY_i$ is the predicted `DETY` for the i^{th} photon.

   $DETY_{ZO}(t_i)$ is the time-dependent real-valued `DETY` location of the zero-order centroid, at time t_i (as obtained by de-aspecting the sky coordinate).

$DETX_i$ is the actual DETX of event, i.

$DETX_{ZO}(t_i)$ is the time-dependent real-valued DETX location of the zero-order centroid, at time t_i.

α is the clocking angle of the grating (about $+5°$ for MEG and about $-5°$ for HEG). It is in pix_grating.par, as MEG_alpha or HEG_alpha.

This approximation gives CHIPY values which differ from actual by 1 or 2 pixels for an on-axis source. For sources 3 arcminutes off-axis, the residuals are a few pixels; this is due to the increased size of the PSF.

Event resolution then proceeds as follows:

2. If HETG is the grating, resolve events as if a timed exposure (TE), assuming all photons are MEG, using the approximation for MEG CHIPY (using the MEG value of α) in place of the event-file's values. All other necessary information is the same (CHIPX, zero-order centroid, aspect, CCD resolution table format). The TG_PART values should be set to MEG for non-zero-order events. TG_D should evaluate to 0.0; it's values may be left as calculated for diagnostic purposes, but they have no meaning otherwise.
3. If HETG, repeat the resolution for even TG_M, but *assume* these events are actually HEG photons (this is because the MEG even orders have low efficiency). Use the HEG version of the CHIPY approximation (use the HEG value for α). Change TG_PART to HEG.
4. If LETG, resolution is done as for timed-exposure, using the trivial assumption for CHIPY of 512.

2.4 Level 2: Relative Time Correction

Name (TBR): `hetg_timecor`

Inputs

Level 2 (or Level 1.5) grating/ACIS-S events

Outputs Level 2 (or Level 1.5) grating/ACIS-S events, with a new column.

Parameters TBD.

Processing

In some CC-mode observations, precise timing or phasing of periodic variations is of interest. Since the HEG and MEG arms diverge with diffraction angle, the assigned event times for simultaneous arrival of HEG and MEG photons will increase with diffraction angle. To reference HEG and MEG photons to the same relative time, a correction factor can be computed for each photon and appended as a column on the event list. The time offset, relative to the zero-order location, is

$$\delta t = -\frac{\pi}{180} \frac{tg\_r_i \, X_R \, \sin\alpha_i}{\Delta_p \, t_p} \quad \text{[s]},$$

in which tg_r_i is the diffraction angle of each photon in degrees (from the Level 1.5 events), X_R is the Rowland spacing (in mm, from reference data or `pixlib` parameters), α_i is the grating clocking angle appropriate to each photon's part (either HEG or MEG; the values are in `pix_grating.par`), Δ_p is the pixel size in mm (from `pix_pixel_plane.par`), and t_r is the read-time per row (in seconds, from TBD). The sign of the correction is important; it is different for HEG and MEG at the same diffraction angle, and the sense reverses with the sign of `tg_r`. For positive diffraction angles, it should be positive for HEG and negative for MEG, *assuming the CCD readout is nearest* `CHIPY` = `1`.

2.5 Level 2: Binning to 1D Spectra

Binning the CC-mode Level 1.5 file into a PHA Type II file is done identically to TE-mode; `tgextract` will function with no changes.

2.6 Level 2: Flux Calibration

The grating effective area ("ARF") can be computed in the same way as for timed exposure, using the appropriate ACIS QE for the mode. Before application to HEG orders, however, the HEG efficiencies must be summed with the overlapping MEG even order (which is 2× the HEG order).

A Prototype Parameter Files

For existing tool counterparts to CC-mode tools, parameter files are listed. The first column flags changes: "x" means delete; "m" means modify; a blank means no change.

A.1 `tgdetect_cc`

TBS.

A.2 `tg_create_maskcc`

TBS.

A.3 `tg_resolve_eventscc`

TBS.

A.4 `hetg_timecor`

TBS.

A.5 Obsolete `CHIPY` Prediction Algorithm

This algorithm is not appropriate if zero-order falls in a gap, or off the detector, since the zero-order chip position is not defined.

$$\begin{aligned} PCHIPY_i &= CHIPY\_ZO(t_i) + \tan(\alpha) \times \\ &\quad \{CHIPX_i + [CCD\_ID_i - CCD\_ID_{ZO}(t_i)] \times (\mathrm{gap} + \mathrm{size}) \\ &\quad - CHIPX\_ZO(t_i)\} \end{aligned}$$

$PCHIPY_i$ is the predicted `CHIPY`.

$CHIPY\_ZO(t_i)$ is the time-dependent real-valued `CHIPY` location of the zero-order centroid, at time t_i.

$CHIPX_i$ is the actual `CHIPX` of event, i.

CCD_ID_i is the `CCD_ID` of photon i.

$CCD\_ID_{ZO}(t_i)$ is the `CCD_ID` of the zero order at the time of photon number i.

gap is the size of the gap between CCD's. This is available from `pixlib` parameters. It is about 0.431mm/0.024mm/pix = 17.958pix. The relevant parameter file is `pix_corner_lsi.par`, whose differences between the y-values of the "ACIS-Sn-LR" and "-LL" parameters give the gap. The pixel size is found in `pix_pixel_plane.par` in its `DET_ACIS` parameter.

size is the size of a CCD. This is 1024 pixels. It does not seem to be specified explicitly in any pixlib parameter file, but could be derived from the pixel size and the "LL, LR" parameters for any given CCD.

$CHIPX\_ZO(t_i)$ is the time-dependent real-valued `CHIPX` location of the zero-order centroid, at time t_i.

α is the clocking angle of the grating (about $+5^\circ$ for MEG and about -5° for HEG). It is in `pix_grating.par`, as `MEG_alpha` or `HEG_alpha`.

This approximation gives `CHIPY` values which differ from actual by 1 or 2 pixels for an on-axis source. For sources 3 arcminutes off-axis, the residuals are a few pixels; this is due to the increased size of the PSF.