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When and How to Avoid Pileup (or not!)

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The information in this why topic is taken from the Chandra ABC Guide to Pileup.

Avoiding Pileup

Given the deleterious effects of pileup upon spectra, images, and lightcurves, it is usually advisable to search for ways to minimize it. There is essentially one goal, achievable with a variety of strategies: one must reduce the counts per frame per pixel. Thus the strategies involve combinations of spreading the signal out over more pixels (via offset pointing, defocusing, or inserting the gratings), and reducing the integration times (via subarrays and turning off detector chips, or implementing continuous clocking mode). Defocusing is *not* a recommended strategy. Below, we outline the pros and cons of some of the better methods for minimizing pileup. Note that many of the methods can be combined (for example, performing a gratings observation with a subarray implemented).

Offset Pointing
: Placing a source several arcminutes away from on−axis pointing serves to both reduce the effective area of the mirrors, as well as broaden the point spread function. Offset pointings therefore reduce the counts per frame per pixel. There are several disadvantages to this approach, however. Aside from the obvious disadvantage that Chandra was designed for high resolution imaging and that it would be unfortunate not to utilize this capability, it should be kept in mind that calibration is best understood and described for on−axis pointings. Furthermore, the advantage that can be gained by this strategy is limited to factors of several, which means that the brightest sources must be handled by other means.

Short Exposures
: The nominal frame time for a 6 chip, full−frame ACIS observation is 3.24104 sec − a 3.2 sec integration followed by a 41.04 msec frame transfer to readout. Frame integration times as short as 0.2 sec can be chosen without any loss of detector area. The tradeoff, however, is that approximately 3.2 sec is still required to read the image from frame storage into memory. Thus, such observations are highly inefficient in terms of effective exposure time, with the exposure efficiency being approximately the chosen integration time divided by 3.2 sec. A factor of 16 reduction in counts per frame can be achieved at the price of a 94% loss of efficiency.

Subarrays and Turning Off Chips
: The minimum frame integration time can be shortened by reducing the portion of an ACIS chip that is to be read out and/or by shutting off unwanted chips. A sub−array as small as 1/8 of the chip can be chosen, which reduces the nominal frame integration time from 3.2 sec to 0.8 sec and 0.7 sec for six chip ACIS−I and ACIS−S observations, respectively. By further limiting the observation to a single chip, one can achieve frame times of 0.5 sec and 0.4 sec, respectively. Thus, up to a factor of 8 reduction in the counts per frame rate can be achieved; however, one is obviously forgoing the opportunity to study spatial structure beyond the borders of the chip and subarray selections. Again, this strategy is limited in how much pileup can be reduced. For example, if one wanted to observe a source described by a Gamma=2

power−law with a neutral hydrogen column of 10^{21} cm^{-2}, yet limit the event pileup fraction, f_e, to less than 10% (i.e., less than 10% of the detected events will be piled events), the observations would be restricted to sources with absorbed 0.5−8 keV fluxes of approximately less than 7 x 10^{-12} ergs cm^{-2} s^{-1}, assuming that alpha = 0.5. Note that for this case, the *total* pileup fraction, f_t, is approximately 40% (i.e., 40% of the incident counts are either combined into piled events or removed by grade and/or energy filters).

Gratings

The HETG or LETG gratings can also be used to reduce pileup. They act as a filter and produce a reduced count rate zeroth order, CCD quality spectrum. Simultaneously, the gratings disperse the spectrum into multiple arms, which both reduces the total count rate compared to the absence of gratings and spreads the spectrum out over a much larger range of pixels. The advantage compared to a subarray is that zeroth order can image a larger region of the sky for the same reduction in pileup, while the gratings arms simultaneously produce higher resolution spectra. The disadvantage is that the signal−to−noise is reduced, and thus longer integration times are required. How much longer these integration times need to be depends upon the source spectrum, but generally they are greater for softer sources and are less severe for harder sources. For example, if one wished to use ACIS/HETG to observe the 2−8 keV spectrum of a Gamma=2 power law source, the zeroth order spectrum count rate is reduced by approximately a factor of 6 compared to that without the gratings, while the summed count rate in the four gratings arms is also reduced by a factor of 6 compared the CCD count rate without the gratings in place. Thus, in the zeroth spectrum alone one can achieve a pileup reduction comparable to a 1/8th subarray (without gratings), at the price of requiring an approximately 3 times longer integration time to achieve the same signal−to−noise in the summed observation (i.e., zeroth order plus the four gratings arms). Softer sources, especially those with significant flux below 2 keV, are more reduced in total count rate and hence require even greater increases in integration times.

Although the flux limits for a given pileup fraction in the zeroth order spectrum are comparable to the 1/8th subarray, the dispersed spectrum can tolerate substantially greater fluxes without becoming piled up. Typically, sources with 0.5−8 keV fluxes less than approximately 10^{-9} ergs cm^{-2} s^{-1} have *total* pileup fractions, f_t, that do not exceed approximately 10% in any region of the gratings arms. This latter statement, of course, is dependent upon the shape of the incident spectrum.

Continuous Clocking Mode

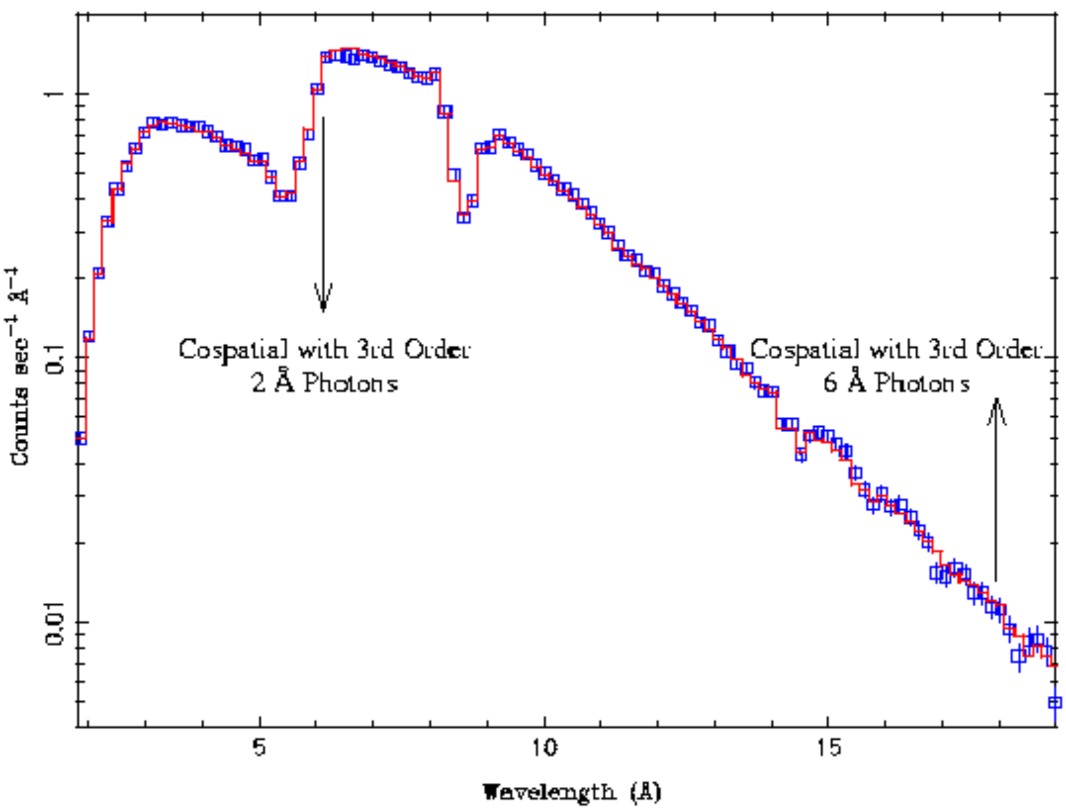
In continuous clocking (CC) mode, CCD rows are read out one row every 2.85 msec. Although this is more than 1100 times faster than the full frame readout time of 3.2 s, a 1000 times increase in flux tolerance for avoiding pileup is not obtained. Again, grades are assigned in 3x3 pixel islands, and this is true even in CC−mode where "virtual frames", consisting of 512 rows that were consecutively read out, are created to assign grades. Thus at a minimum one needs to consider the effective readout time for assessing the possibility of pileup to be at least three times longer than the nominal 2.85 msec. (That is, one needs to consider the integration times for the rows adjacent to any detected event.) Additionally, CC−mode entails a higher background, and does not allow one to perform any CTI correction. (The fact that a photon event could potentially pileup with the "trailed charge" from transfer inefficiency also might lead one to assign an "effective integration time" for assessing pileup that is even greater than three times the row readout time.) For a given pileup tolerance, CC−mode therefore allows one to observe sources perhaps 50 times brighter than is achievable for a single chip, 1/8 subarray observation. Using the example of the Gamma=2 power law source with a 10^{21} cm^{-2} column, for event pileup fractions, f_e, less than 10% (assuming alpha = 0.5), one is restricted to 0.5−8 keV fluxes approximately < 4 x 10^{-10} ergs cm^{-2} s^{-1}. (Again, the *total* pileup fraction is larger, at f_t approximately 40%.) This limiting flux is slightly less than the allowed limits when inserting the gratings; however, higher signal−to−noise (but obviously worse spectral resolution, and only one dimension of spatial information) is obtained for a given integration time.

Piled Gratings Spectra

For sources with 0.5−8 keV fluxes approximately > 10^{-9} ergs cm^{-2} s^{-1}, even the spectra in the gratings arms can become significantly piled. (Note that the zeroth order spectrum becomes severely piled at substantially lower flux levels.) Again, the relative figure of merit for determining the degree of pileup is counts per frame per pixel. From this point of view, gratings pileup is typically worst in the MEG as opposed to the HEG gratings. The MEG gratings have slightly larger effective area and half the spectral resolution, and thus more than twice the counts per pixel (compared to HEG) near the peak of their effective area curves. The MEG effective area is largest between 6 and 8 Å (1.5−2 keV), so this is often the spectral regime most effected by pileup. This statement, of course, depends upon the incident spectrum.

Aside from choosing a subarray (typically one can choose a 1/2 subarray without significant loss of spectral information from the gratings arms) or CC−mode, it may be possible to further mitigate spectral pileup in the gratings by looking at higher order photons. This suggestion comes with an important caveat: it is possible to show that to simplest approximation the fractional loss term in *each* spectral order is dependent in the same manner upon the *total* count rate at the detector location associated with the wavelength and order of interest.

That is, if 6 Å first order photons are piled up, 2 Å third order photons at that same location are equally piled. Furthermore, these third order events are possibly contaminated by piled events from first and second order combining to yield a false third order event. Choosing a higher order only avoids pileup if the wavelength of interest, at higher order, comes from a low observed count rate portion of the detector. These points are illustrated further in this figure:



A count rate spectrum (counts s^{-1} Å^{-1}, which is proportional to counts per frame per pixel) of an X−ray binary observed with ACIS/HETG. This spectrum corresponds to MEG +1 order, which dominates the total count rate in the positive orders of the MEG arm. The peak of the observed count rate is near the peak of the effective area at approximately 6 Å. Estimations are that in this detector location, the total pileup fraction, f_t, is approximately 10−15%. (This observation used a 1/2 subarray, and thus had a frame time of 1.74104 sec.) The positive third order 2 Å photons also come from this peak count rate location, and hence are actually more piled up than first order 2 Å photons. On the other hand, third order 6 Å photons are co−spatial with 18 Å first order photons, and come from a low count rate region of the detector. Thus, the third order 6 Å photons are less piled up than their first order counterparts.

The combination of the gratings plus CC−mode allows for the highest limiting fluxes for a given pileup fraction.

We again note that the above mitigation methods can be combined. Perhaps the most extreme example is the Chandra observation of Sco X−1 (Observation ID 3505). Sco X−1 is usually the brightest X−ray source in the sky (aside from the Sun), so this particular observation employed an offset pointing, the gratings, CC−mode, *and* the subsequent analysis involves choosing higher order photons for certain wavelengths of interest! Which method, or combination of methods, is best for any particular observation will of course depend upon both the incident spectra and the desired science goals.

Not Avoiding Pileup

There are times when one knows full well ahead of time that some portions of an observation will be piled up, yet the chosen instrument configuration is the best for the desired science goals. There are a number of obvious examples. The X−ray image of a globular cluster might subtend an entire ACIS chip and produce fluxes and spectra for a hundred sources. Only a small handful − the very brightest − of these sources might exhibit detectable pileup. Subarrays or CC−mode would forgo valuable information from the majority of sources to improve the spectra of the minority of sources. Likewise, X−ray binary surveys of external galaxies will often have a small fraction of their sources that are piled up. For example, the nucleus and several ultra−luminous X−ray (ULX) sources might be mildly piled. Again, accepting mild pileup in a small fraction of sources might be considered a fair trade−off for measuring spectra in a larger field of view.

There also are instances when one might accept pileup in gratings spectra. Gratings observations of arc−minute scale dust scattering halos in front of a central point source might be performed best without the use of CC−mode. This is especially true if one wants to be able to spatially model the effects of CTI on the point spread function. There are also cases where imaging mode is required to spatially separate nearby sources. As an example, Observation ID 4572, a gratings observation of an "accretion disk corona" source, reveals two bright X−ray sources separated by 2.8 arcsec. This is far apart enough that the resulting gratings spectra are easily distinguished, although the MEG spectra exhibit mild pileup.

The common feature of all of the above examples is that for each observation one is accepting a degree of pileup in exchange for enhanced imaging coverage and information. There are two "best advice" strategies for minimizing pileup in an observation that scientifically requires imaging information. The first strategy is to limit the integration time per frame as much as possible by choosing the smallest subarray that still contains the extended regions of interest. (As mentioned above, for a gratings observation one can often choose a 1/2 subarray without loss of spectral information from the gratings arms.) However, one is obviously forgoing the opportunity for "serendipitous science" in the regions excluded by the subarrays. The second strategy is to insert the gratings. The drawback is that an increased integration time (a factor of three, or more for soft sources) is required to achieve the same signal−to−noise.

Summary

The truth is that the only Chandra CCD observations that are *not* affected by pileup are ones where both the source is faint enough and the observation is short enough that one does not statistically expect there to be any frames (or row readout times) where two photons have arrived in the same detector region of interest. Pileup is present, to greater and lesser degrees, in almost all Chandra observations. Careful planning of an observation, however, can help to minimize the presence of pileup, and maximize the science return.

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