

# Summary of physical effects in RHESSI spectroscopy:

Gain

Resolution

Relative Efficiency

Livetime

Pileup

Background

Ge K-shell photon escape

Individual detector anomalies

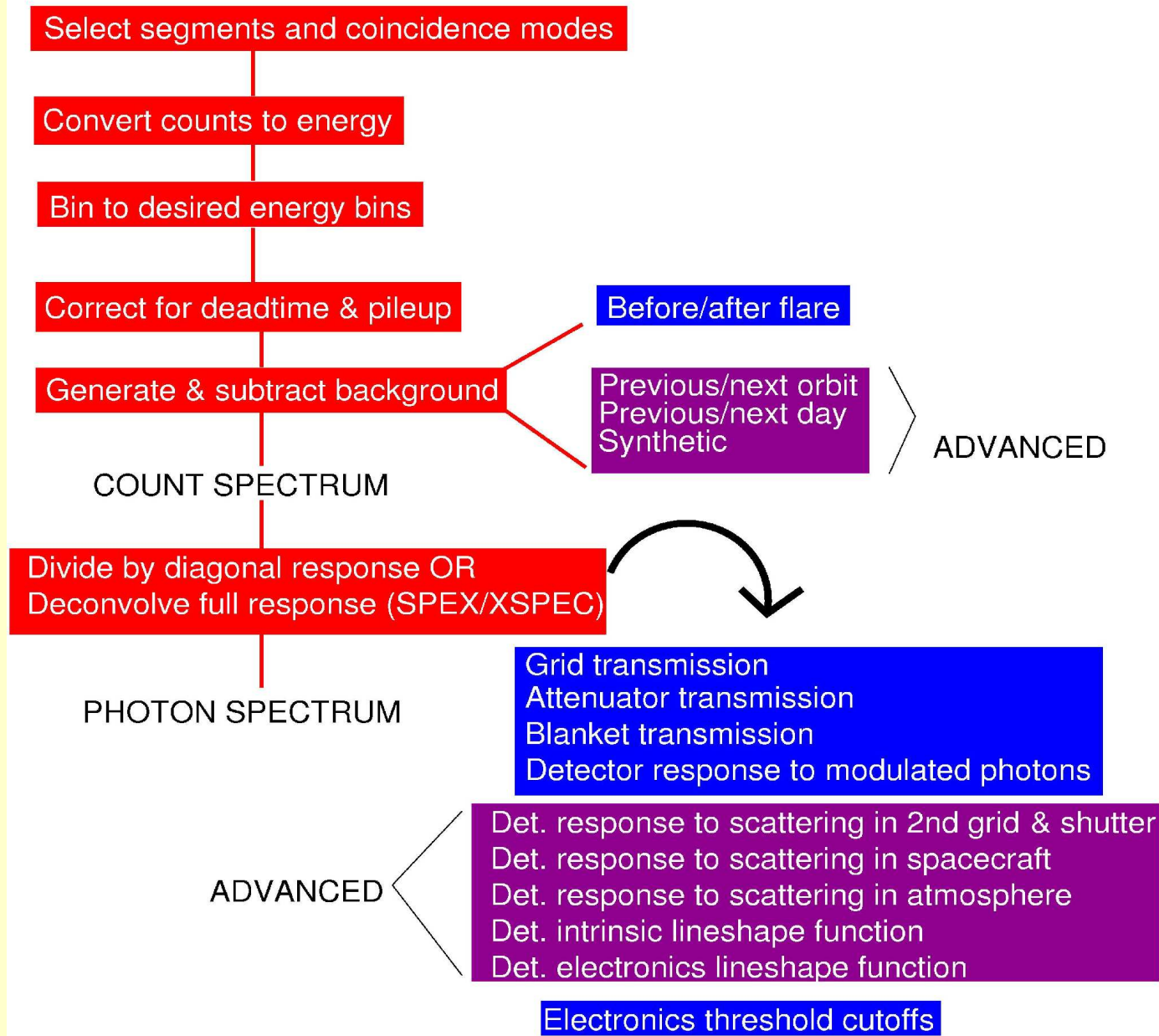
## Special issues for high energies/rear segments:

Radiation damage

Compton scattering

Other anomalies

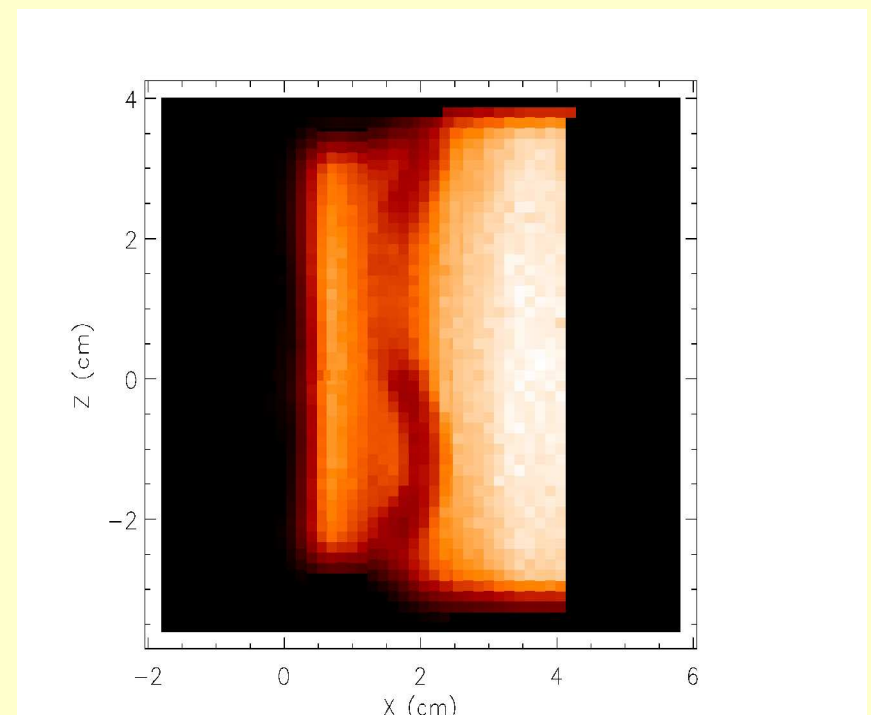
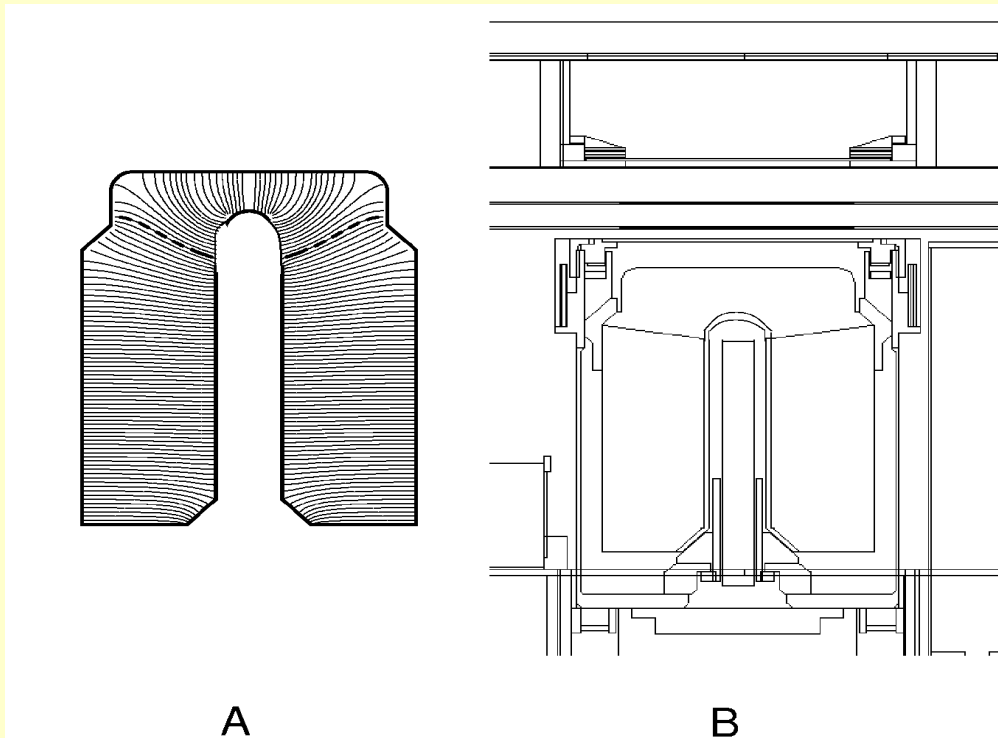
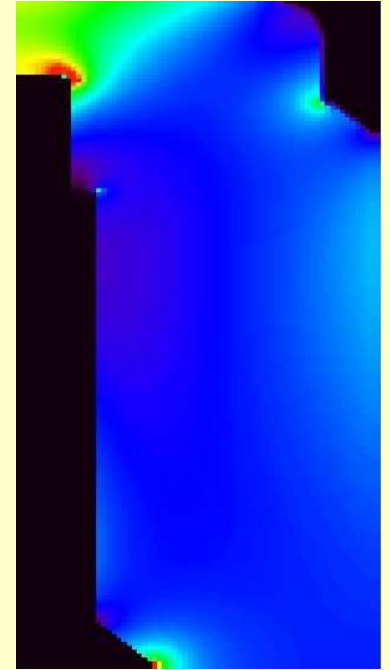
# SPECTROSCOPY TASK FLOW CHART



# DETECTOR CHARACTERISTICS:

Coaxial cylinder with interrupted inner contact for electronic segmentation (2 channels).  
Outer shoulder stabilizes segmentation boundary.

Front and rear segment efficiencies cross around 250 keV;  
higher rear background makes sensitivities cross around 800 keV for background-dominated case.



## DETECTOR ELECTRONICS:

Cooled front-end FETs inside cryostat; ribbon traces to preamps mounted on side of cryostat; preamp output sent to IDPU electronics box on spacecraft deck

Front segment range 3 keV - 3 MeV; rear segment range 20 keV - 17 MeV in two gain ranges: split around 2.8 MeV.

Front channel optimized for best resolution at low energies; rear for best resolution at higher energies.

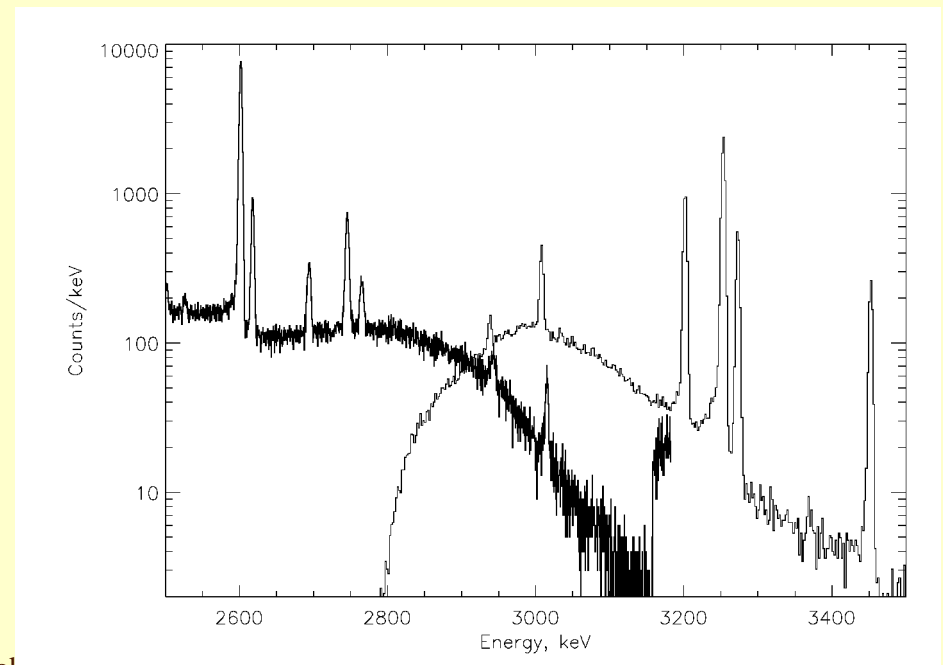
# DETECTOR ELECTRONICS: FAST & SLOW CHAINS

The preamplified signal from each detector is split into a slow-shaping chain (for spectroscopy), and

A fast shaping chain for tasks that need fast timing:

- 1) pileup rejection
- 2) quick switching of the gain level in the analog-to-digital converter downstream (rear segments only)

The higher noise in the fast shaping channel causes problems in 1 and 2, and in 2 there is additional uncertainty due to different pulse shapes at different detector radii (these are completely smoothed out in the slow channel)



# DETECTOR ELECTRONICS (c't): EVENT LOGIC

Each photon is returned with 13 bits of energy, timing to 1 binary microsecond, and segment of interaction

By default, coincident front/rear events are vetoed to lower front background.

Raw event lists show some very low-energy events in one detector coincident with opposite segment; these are not Compton scatters but a false "echo" event due to image charge on the wrong segment's contact. These can be rejected by their timing.

Compton scatters between detectors and between front and rear can be identified and summed to slightly improve photopeak efficiency (not normally done)

Upper Level Discriminator (= overload = cosmic ray) events are also telemetered, as are preamp reset events in the front segments only (rear resets take up too much telemetry)

# ATTENUATORS:

Moved in front of the detectors when deadtime reaches a certain level.

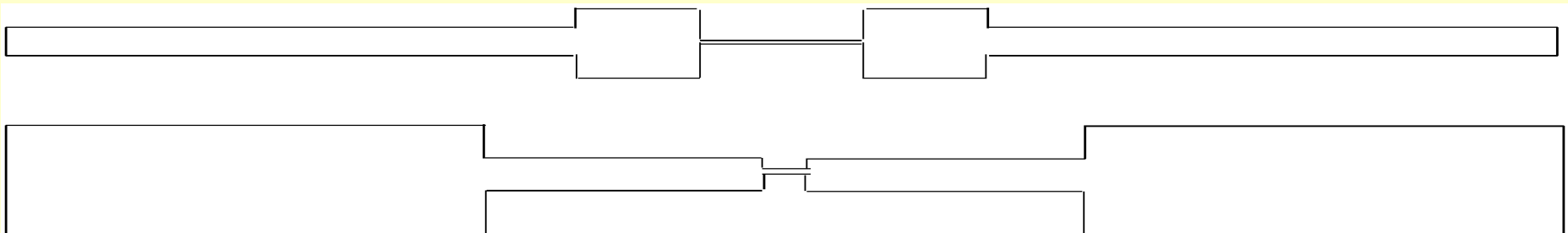
State 0: no attenuators

State 1: "thin" attenuator only

State 2: (UNUSED!) "thick" attenuator only

State 3: both attenuators in front of detector

The thin and thick attenuators each have 3 regions of varying thickness meant to remove most photons at low energies while leaving enough to get an idea of the spectral shape (but see issue of Ge K-shell escape later on!)



# GAIN:

8192 channels in each front segment cover 0 to  $\sim 2.7$  MeV

The electronics are linear to within 0.1 keV over this range

Gain is calculated from the 93.3 keV and 511 keV background lines about twice per week and interpolated in time

Inter-detector agreement during a typical flare was 0.03 keV at 1 sigma in the solar Fe K-shell line (H. Hudson)

A small countrate-related dependence has been discovered by H. Hudson but is insignificant except for studies of the Fe K centroid to get flare temperature

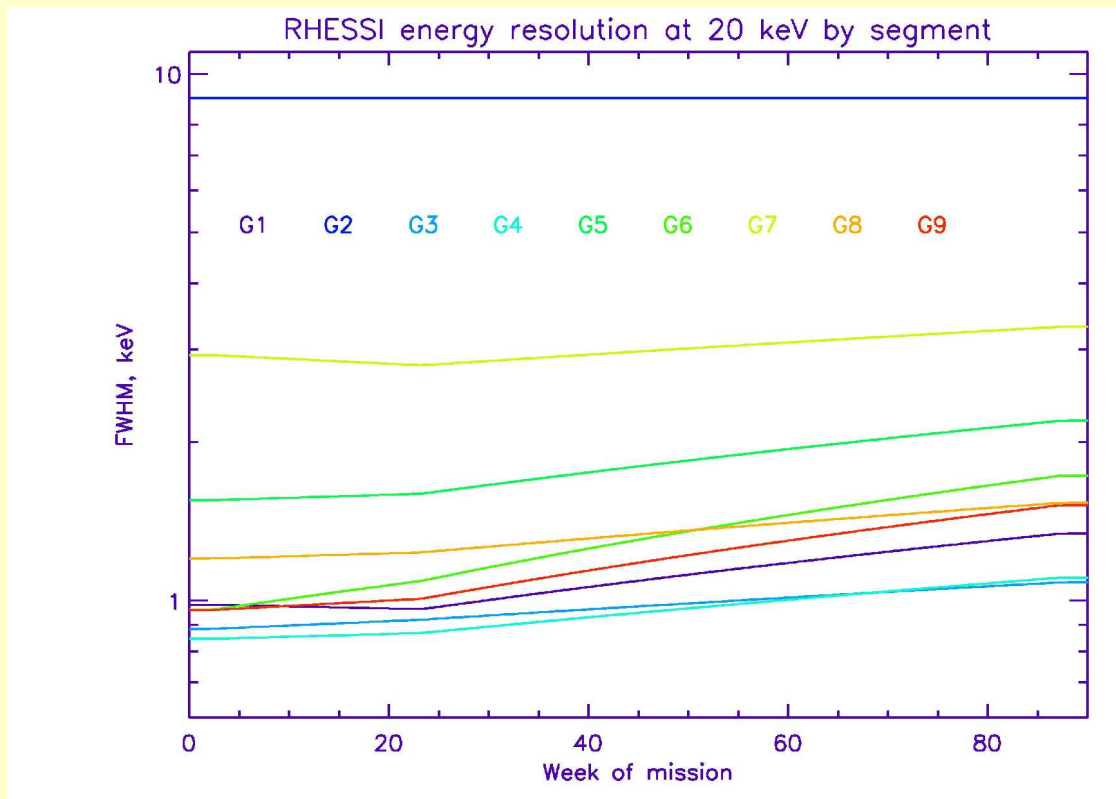
Gain issues should otherwise be transparent to the user



# ENERGY RESOLUTION:

The resolution contains contributions from:

|   |                |
|---|----------------|
| Counting statistics of electron/hole pairs in the Ge crystal  | $\sim\sqrt{E}$ |
| Noise in the electronics (mostly high frequency)              | const.         |
| Microphonics from cryocooler vibration (mostly low frequency) | const.         |
| Crystal impurities and radiation damage (high energies only)  | $\sim E$       |



Do not use G2, G5, G7  
fronts for spectroscopy.

For imaging, consider the  
contribution of neighboring  
energy bands, particularly:  
When using G2  
When using narrow bands  
When the spectrum is  
very steeply falling

# LIVETIME:

Two events coming within 850ns have their energies summed (pileup)

Between 850ns and 6us, both events are vetoed (bad energies)

Between 6us and 9us, the second event only is vetoed (first OK)

Resulting maximum throughput is ~25000 c/s per segment, all the way from about 30 to 70% deadtime (rate out vs. rate in turns over).

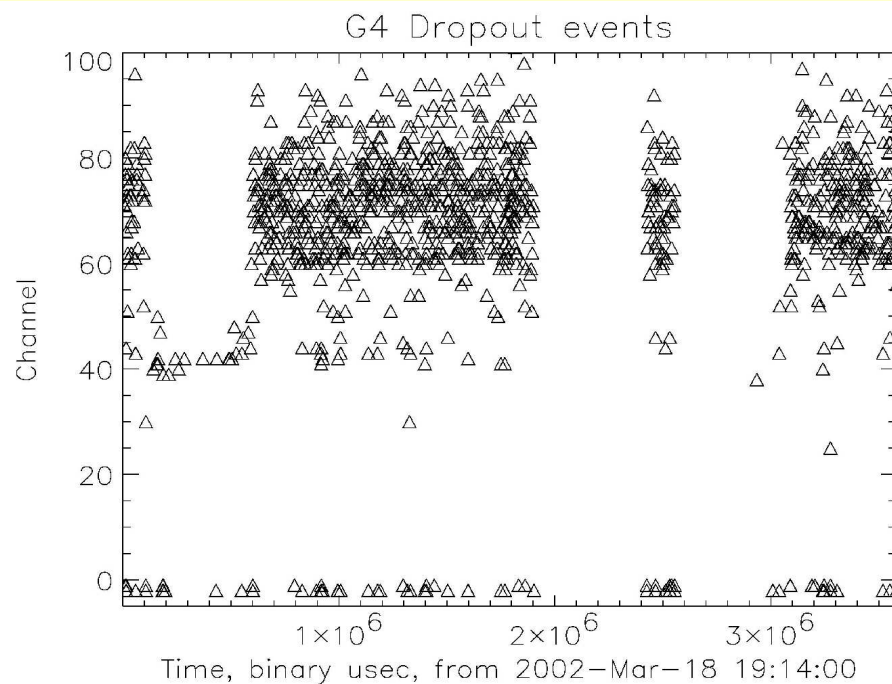
# DATA DROPOUTS (corrected as part of livetime):

On orbit we found that 8 front segments (all but G5) and one rear (G5) frequently go offline for short periods (10 ms to 0.5 s), and are about 15-30% out of service. (G5 may have front/rear preamp boards swapped).

Best guess is large energy deposits from cosmic-ray iron nuclei.

When included as part of the livetime, photometry is mostly corrected.

Spectroscopy and imaging are affected mostly through counting statistics.



Channel zero events are preamp resets and ULDs (cosmic rays). Events near channel 40 convert to zero energy (noise) and sometimes occur during dropouts.

## DECIMATION (corrected as part of livetime):

To save memory, both front and rear segment data can be decimated:  $(N-1)/N$  events are deleted below a threshold channel  $C$ .

Since the gain of each segment is different,  $C$  corresponds to a slightly different energy.

Front segment decimation is based on the fill level of the onboard memory, the attenuator state, and a choice of table (changed every week or so depending on solar activity). The energies are 5-30 keV (flare energies).

Rear segment decimation is performed when the spacecraft is at high magnetic latitude and often encounters outer-belt electrons; decimation is usually done below  $\sim 375$  keV.

# PILEUP:

Because solar spectra fall rapidly, even a small fraction of soft photons with summed energy can have a major influence on the higher part of the spectrum. Pileup importance depends on

Livetime (basically as input count rate squared)

Steepness of the input spectrum

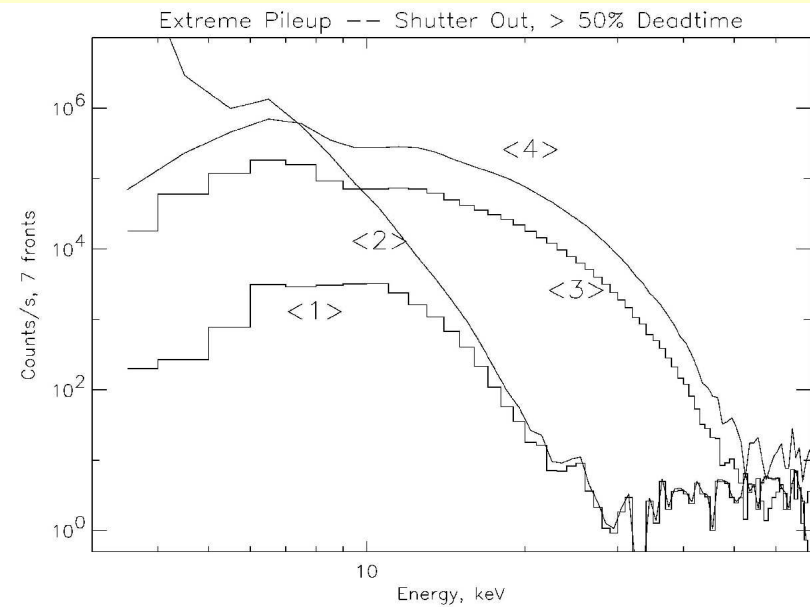
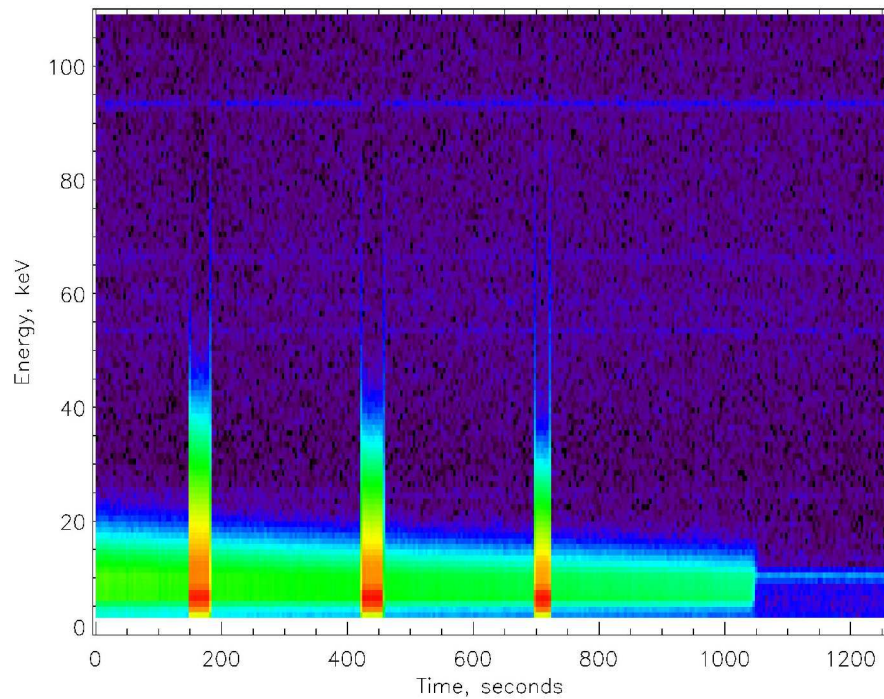
Attenuator state (affects shape of spectrum and rate)

Modulation from imaging or fast rate variations  
(second order effect, but important)

Lowest energy photons ( $< 7$  keV can pile up more freely since they don't trigger the fast threshold

# PILEUP (c't):

The effect of severe (uncorrectable) pileup can be seen when the attenuators are briefly removed during the course of a flare:



# PILEUP (c't):

(Mostly) correctable pileup occurs at livetimes of ~60 to 95% (between dropouts).

The correction algorithm is as follows:

The count spectrum is convolved with itself to find an approximate shape for the piled-up component.

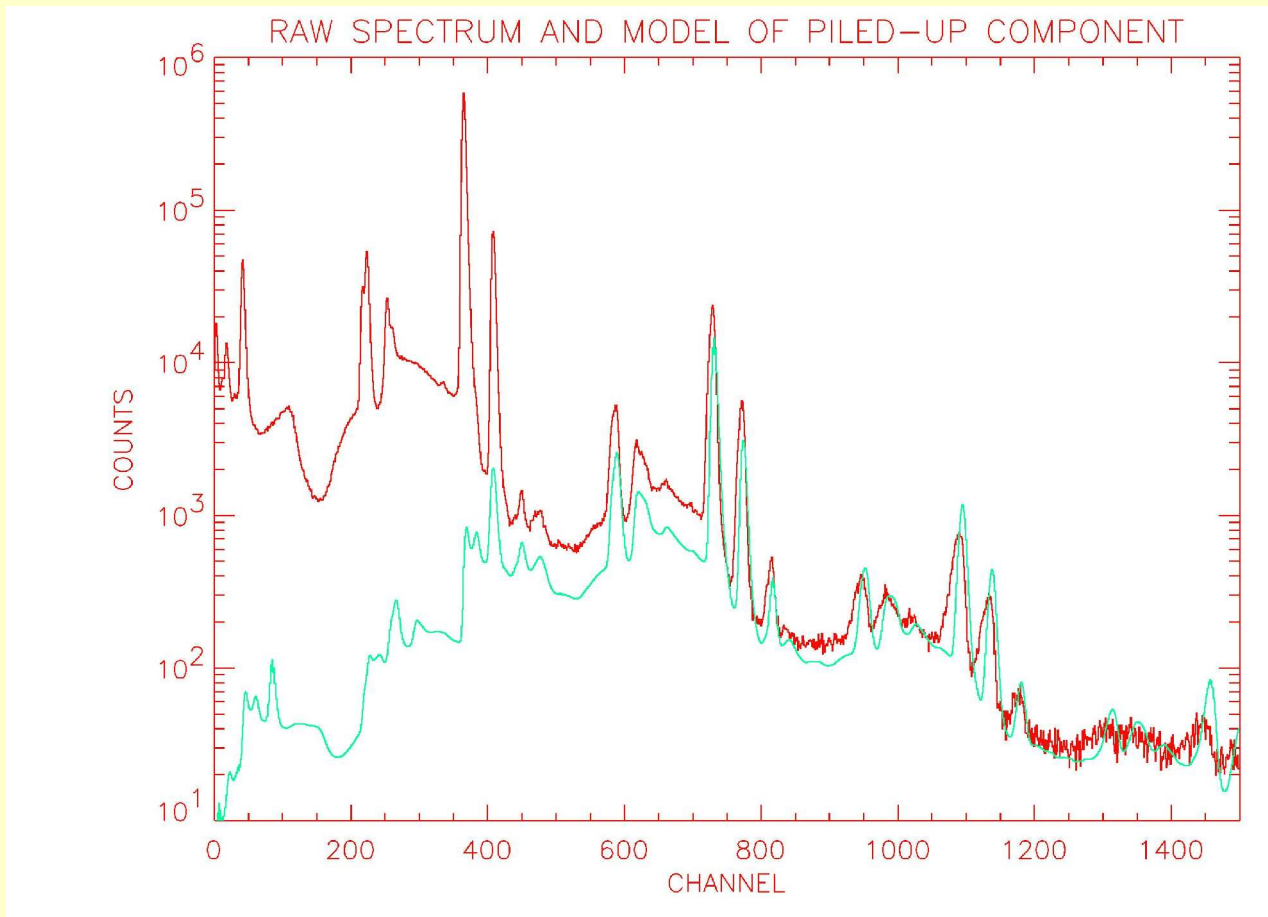
This shape is scaled based on ground calibrations and the scaled component subtracted from the full spectrum.

The three-photon pileup is calculated by convolving the piled-up shape with the full spectrum and is scaled and subtracted as well.

The process is iterated several times, with the corrected spectrum used as input to the first stage above.

# PILEUP (c't):

First, second, and third order pileup illustrated with a radioactive source. The calculated piled-up component is in blue.

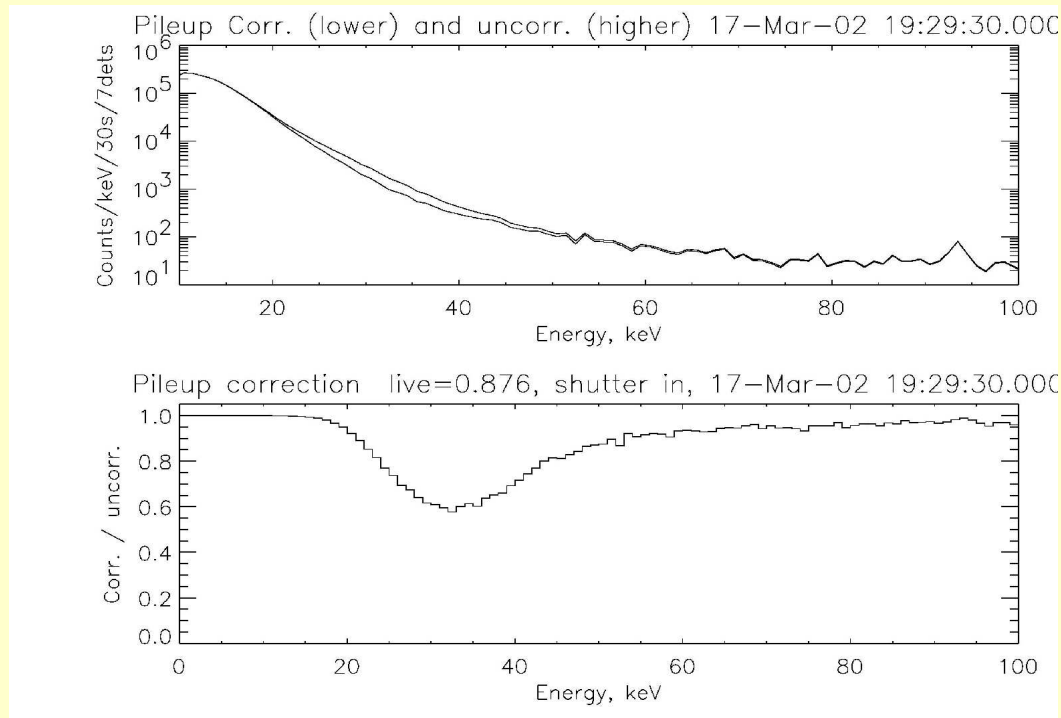




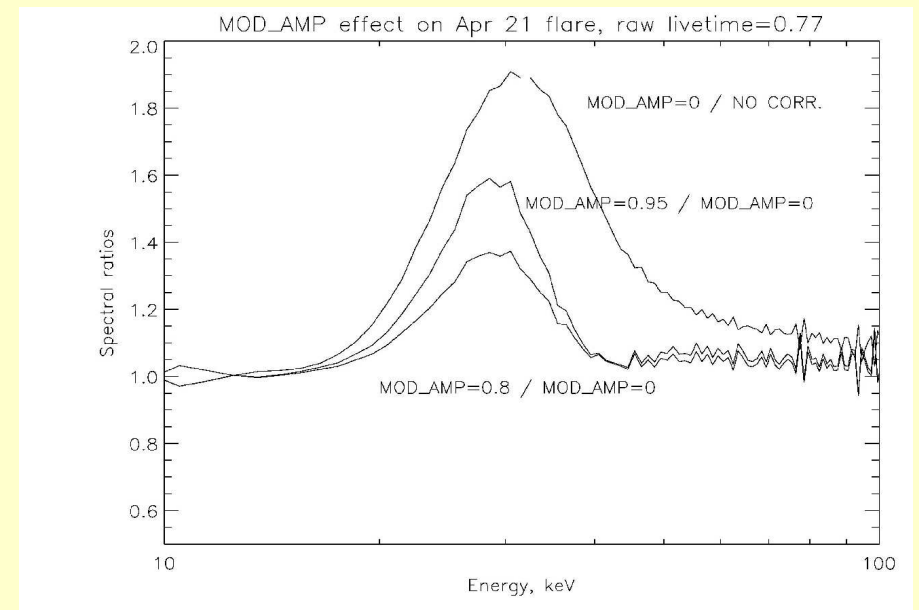
# PILEUP (c't):

The pileup correction is currently only good to about 20% in the amount of pileup it removes; the tendency seems to be to overcorrect. The amount of pileup removed can be adjusted with a parameter.

Pileup correction under normal conditions:

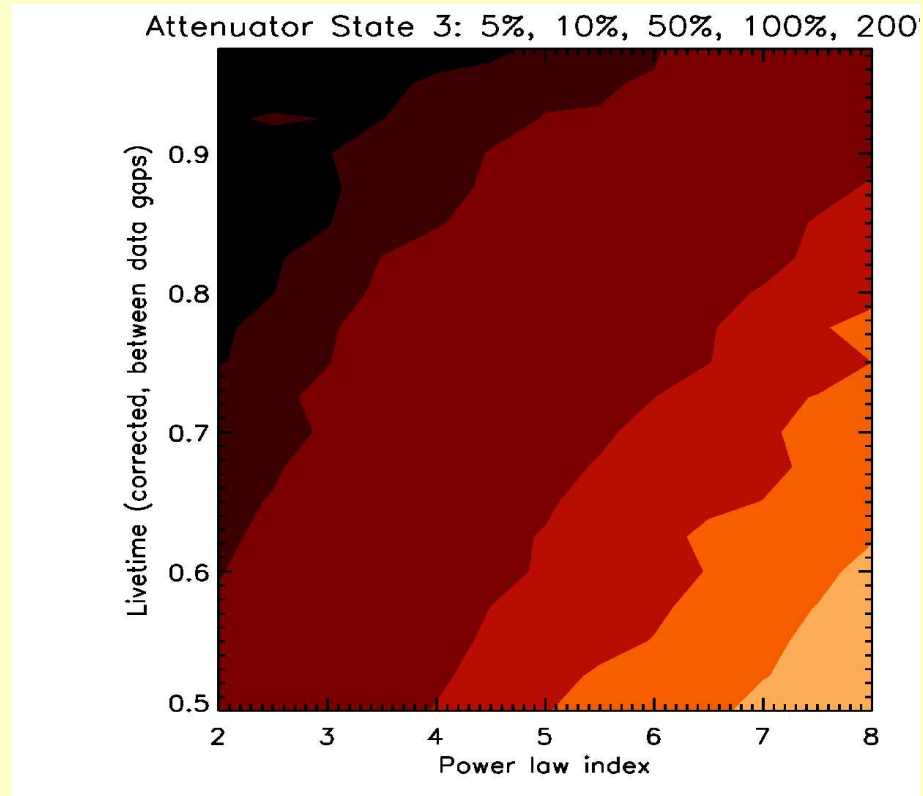
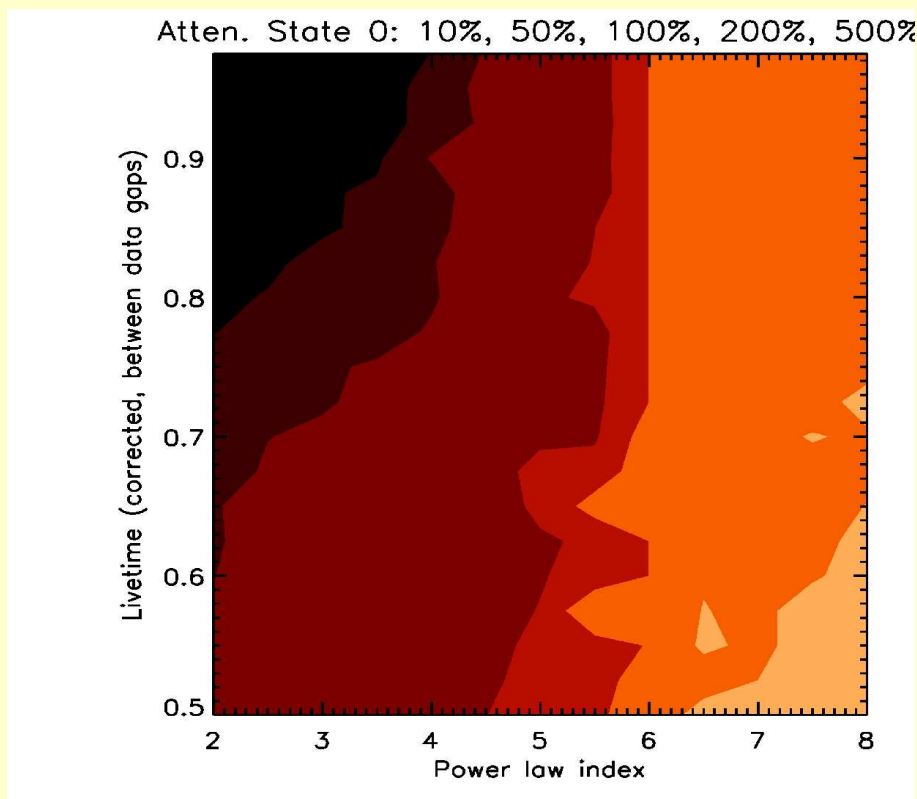


Effect of modulation:



## PILEUP (c't):

Severity of pileup as a function of spectral index, attenuator state, and livetime: simulations. The contours show the worst percentage difference between true and piled-up spectra at any energy. The pileup correction should decrease this difference by a factor of  $\sim 5$ .

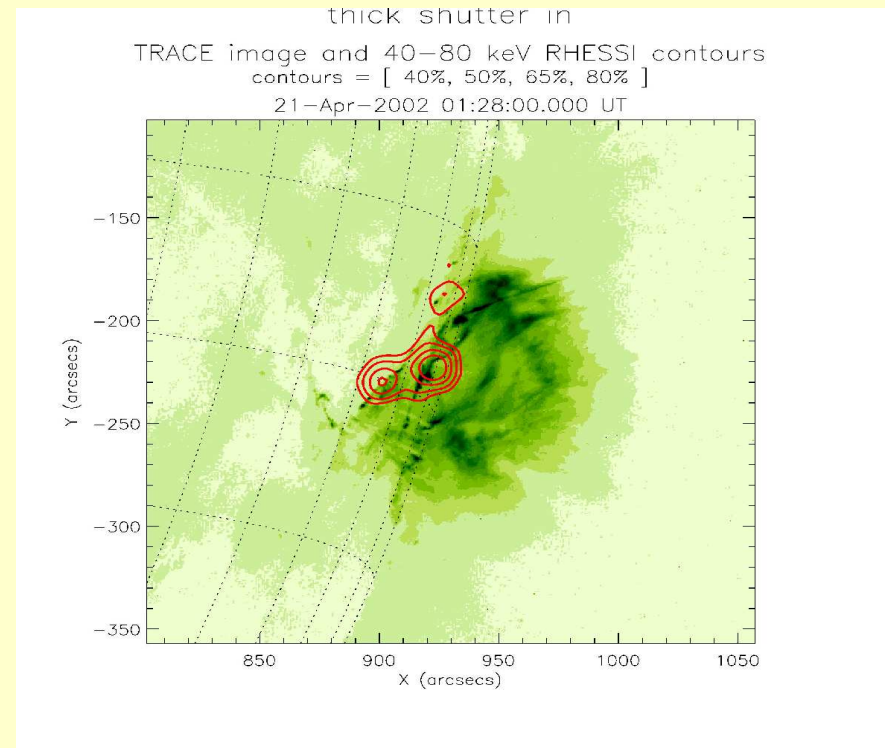
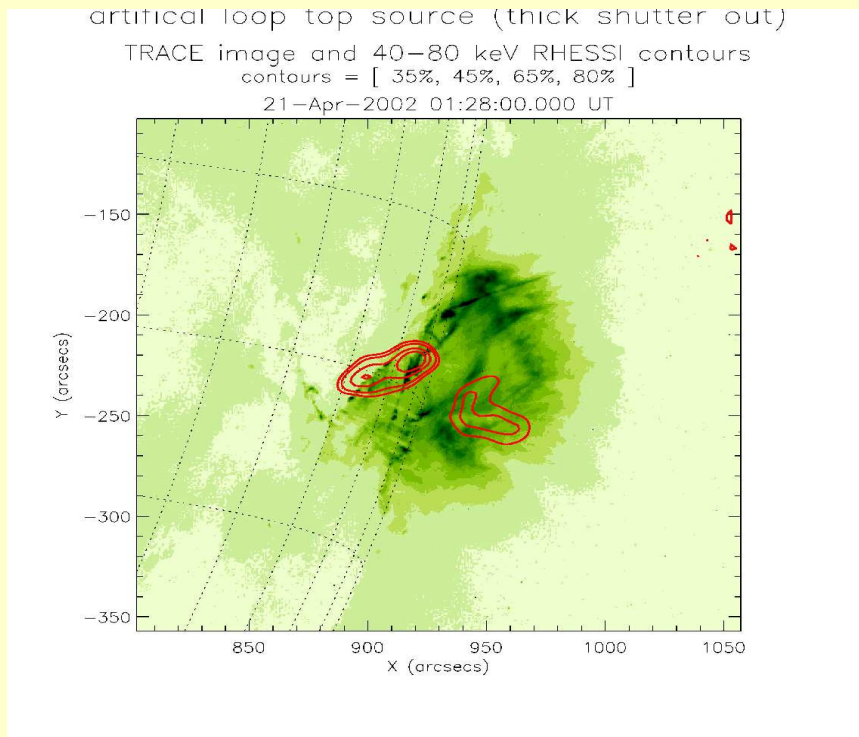


# PILEUP (c't):

Pileup affects imaging as well, by making a ghost of the low-energy image in a higher-energy band; no correction currently in place.

Attenuator out; high pileup; high-energy image includes a coronal component

Attenuator in; coronal component goes away, indicating it was due to pileup of thermal x-rays.



Figures courtesy of Sam Krucker

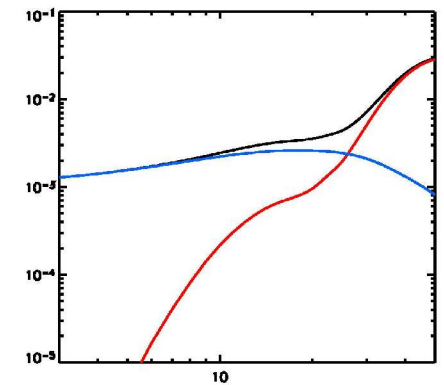
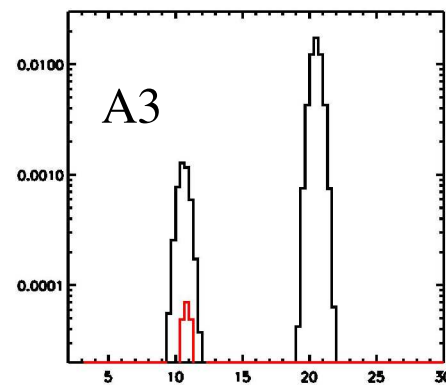
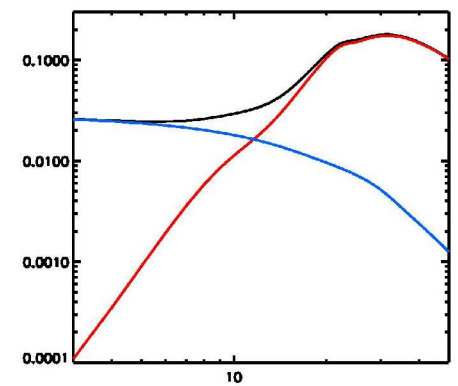
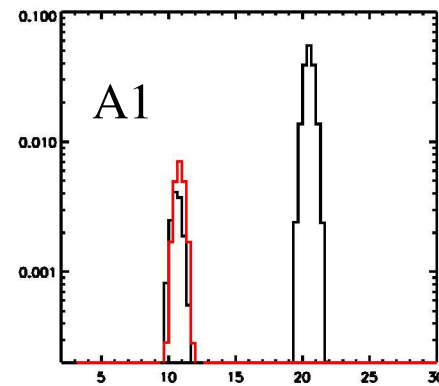
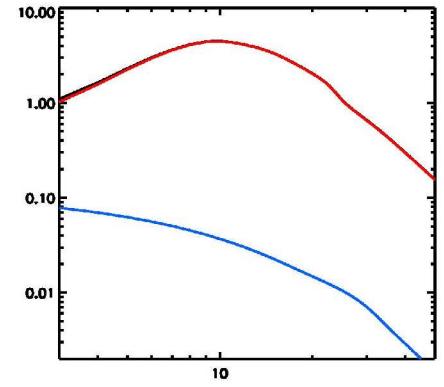
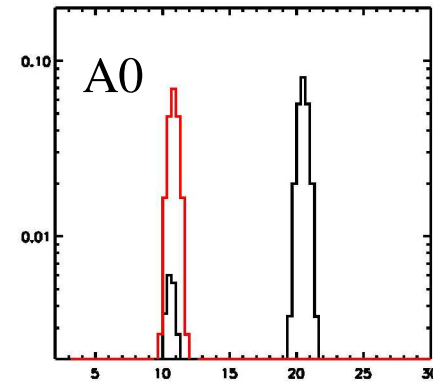
# Effect of Ge K-shell escape:

"Opposite" of pileup: shifts counts down 10 keV at low energies.

When attenuators are in, e.g. 18 keV photons shifted down can dominate 8 keV photons.

This effect is corrected fairly well when using full detector response matrices with off-diagonal components, but

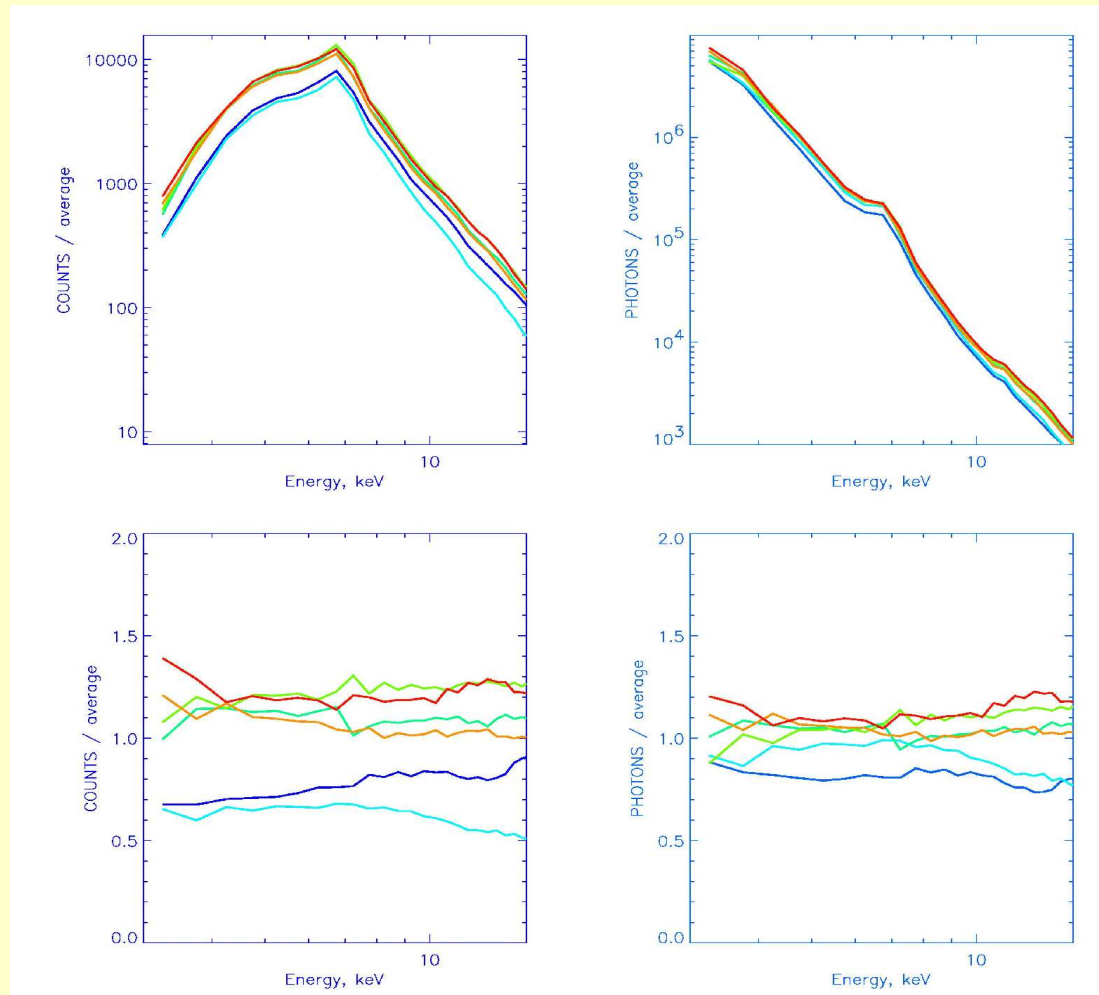
For now, work above 8 keV in A1 and above 15 keV in A3.



# Relative calibration of detectors:

Effective area of detector front segments calibrated to a few % on the ground; unknown differences of  $\sim 20\%$  for full system on orbit.

Principle issue is weighting of Fourier components in imaging, not photometry.



# BACKGROUND:

Because the background spectrum falls more slowly than any flare, all flare observations become background-dominated above **some** energy.

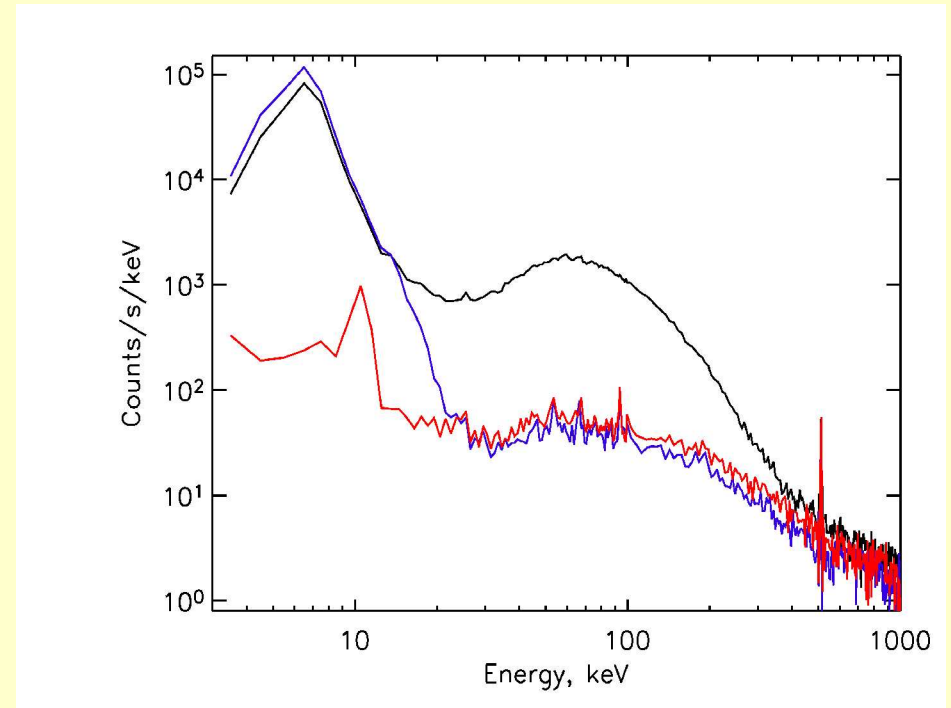
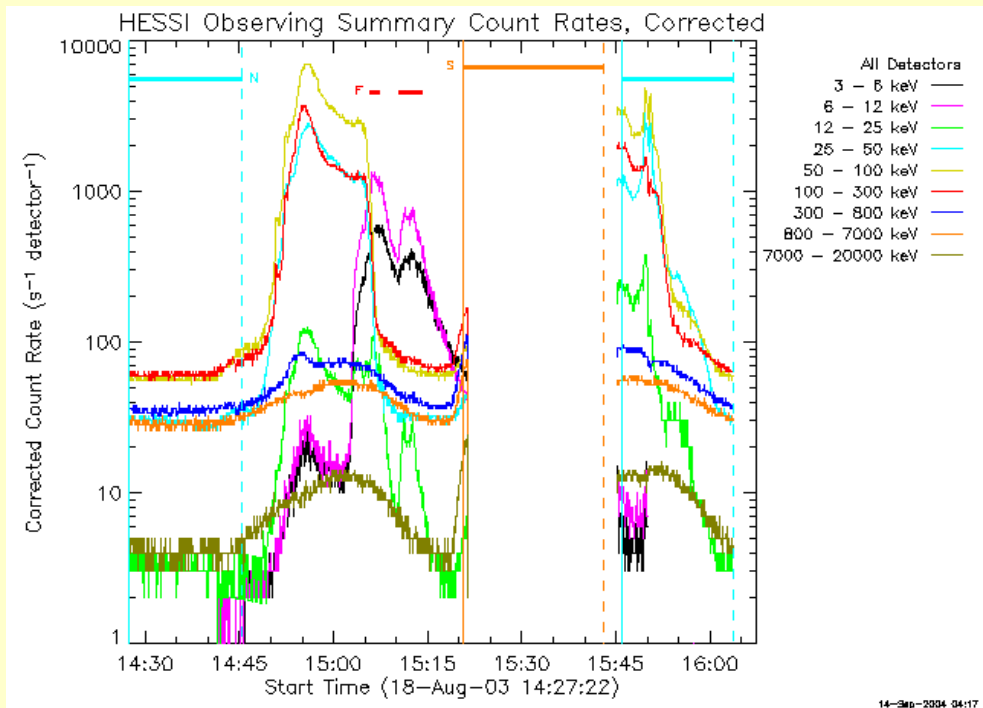
Sources of background variation:

Geomagnetic latitude (cosmic ray flux)

Satellite orientation w/r/t Earth (cosmic vs. atmospheric x-rays)

Outer-belt electron fluxes (only ~5% of the time, but bright)

Recent exposure to inner-belt protons at the South Atlantic Anomaly



## Background strategies:

- 1) Take intervals before and after flare within same orbit (natural with GUI). **Short-medium flares, low energies.**
- 2) For much longer flares, use data +/- 15 orbits (about 1 day): reproduces most background conditions. **Long flares, high energies.**
- 3) Search for times with similar background-inducing parameters, including particle precipitation conditions. **Pathological cases, experts only.**

# INDIVIDUAL DETECTOR ANOMALIES:

G2: Had a HV/mechanical problem and began arcing in the first few weeks of the mission; HV was lowered until it stopped, which desegmented it: 20 keV threshold, ~10 keV resolution, high bkg. In April 2004 radiation damage had lowered the segmentation voltage enough to run it segmented; threshold lowered to 3 keV but resolution still poor (related to microphonics from cryocooler).

G7: high-frequency noise very high for unknown reason, 3 keV FWHM resolution and 7 keV threshold.

G8: Extremely noisy when spacecraft rear transmitter operating (about 2% of the time). Otherwise fine.

G5: Thickest front segment means higher background; slightly microphonic (1.5 keV resolution vs. normal 1.0 or so).



# ISSUES FOR GAMMA-RAY ENERGIES: RADIATION DAMAGE

Cosmic rays, trapped protons, and albedo neutrons damage the Ge crystal lattice

Dislocation sites trap holes when the charge clouds are propagating through the crystal

Holes travel outwards; deposits near the center of the crystal mean many holes are lost from those events; line profiles have a tail

RHESSI radiation damage rate was successfully modeled

Damage continues to worsen but has no effect below  $\sim 300$  keV

Response matrix includes time-dependent tailed line profiles (currently updated only through November 2003).

# ISSUES FOR GAMMA-RAY ENERGIES: COMPTON SCATTERING

Photons scatter in the spacecraft, grids, and even Earth's atmosphere and enter the detectors with partial energy;

Photons interacting first in the detector can also scatter out;

# in photopeak / # in tail is about 1 at about 100 keV;

But falling solar spectra mean that most 50 keV photons are really 50 keV photons and not, e.g., scattered 100 keV photons

At MeV energies, only ~10% of interactions are photopeak

Full (non-diagonal) response is essential for MeV spectroscopy

# ISSUES FOR GAMMA-RAY ENERGIES: HIGH-ENERGY ANOMALIES

"Full-scale" anomaly: the top 64 channels of the 8192 channels of the rear segment low-energy range get filled with events that should have been in the high-energy range but got analyzed with the wrong gain. Affects all detectors; 3.08-3.23 MeV should be excluded from all fits. G8 (only) has this problem so badly that a significant dip also appears just above this, where many events that should have been in the high-energy range are missing.

"Half-scale" anomaly: the 64 channels just preceding channel 4096 show a rate-dependent excess of events (cause not certain). Very bad in G5; not so severe in other detectors. Usually enough to eliminate G5 in this range only.

"9 MeV dips": Detectors G1 and G3 show mysterious dips around 9 MeV for reasons that are not known (events getting somehow vetoed?)