Multiresolution deglitching routines for Herschel-PACS data

Algorithms based on multiresolution median transform and à trous wavelet transform signal decomposition and adaptive noise filtering

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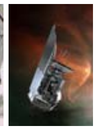

Abstract

One of the main limitations to the sensitivity of Herschel-PACS detectors is related to responsivity variations and glitches caused by the impacts of charged particles. We present deglitching algorithms for data that is based on (i) multiresolution median transform (MMT) similar to what has been developed for ISOCAM and (ii) an à trous wavelet transform based routine. These algorithms separate spikes from the useful part of the signal in the multiresolution space. Adaptive thresholding based on the noise distribution of the MMT/wavelet coefficients allows the efficient reconstruction of a cleaned, glitch free signal. Application to laboratory test measurements where the PACS detector arrays have been exposed to charged particle irradiation show promising results on both Photometer and Spectrometer data.

The PACS instrument

The PACS instrument (Photodetector Array Camera and Spectrometer) is part of the Herschel scientific payload, to be launched in late 2008 and operated in a Lissajous orbit around the Sun-Earth L2 point. PACS consists two sub-instruments and four sets of detectors [1]:

- **[Imaging Photometer]** Simultaneous two-band (common FOV) 60-85 µm or 85-130 µm and 130-210 µm imaging. Two filled Si-bolometer arrays of 3.5'x1.75' FOV :
  - ❑ blue array (60-130 µm), 64x32 pixels, 8 sub-matrices
  - ❑ read array (130-210 µm), 32x16 pixels, 2 sub-matrices
  - ▪ Sensitivity: point-source detection limit is ~3mJy (5σ, 1 hour)
  - ▪ Bolometers are sampled at 40 Hz what is reduced to 10 Hz by averaging 4 frames on-board.
- **[Integral field Spectrometer]** Diffraction grating spectrometer, simultaneous 57-98 µm and 102-210 µm spectroscopy over a 47"x47" FOV (5x5 pixels). The FOV is rearranged onto two 16x25 pixel Ge:Ga detector arrays:
  - ❑ blue array (57-98 µm) under low stress (LS)
  - ❑ red array (102-210 µm) under high stress (HS)
  - ▪ Spectral resolution: λ/Δλ~1500
  - ▪ Sensitivity: ~5x10E-18 W/m² (5σ, 1 hour)
  - ▪ Raw signal is made of integration ramps of 1/4 s, sampled at 256 Hz; this sampling is reduced to 32 or 16 Hz on-board

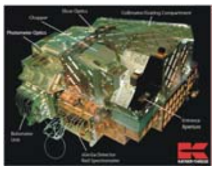

Figure 1: The PACS Focal Plane Unit (FPU). Components which are visible on the envelope are shown on the image.

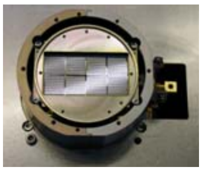

Figure 2: Fully assembled 64x32 bolometer array of the short-wave Photometer. The detector consists 4x2 submatrices of 16x16 pixels each. The Photometer Focal Plane operated at ~0.3 K , suspended within its ~2 K housing. The 0.3 K thermal interface is seen on the right side of the assembly.

Figure 3: The pre-assembled 25 stressed Ge:Ga photoconductor modules with their light-cones. On the top module, the integrated cryogenic readout electronics can be seen. Detector modules are mechanically stressed by the U-shape structure. The high stressed module is cooled down to ~1.8 K, whereas the low stressed is cooled to ~2.5 K, the readout electronics to ~4 K.

PACS was developed by a consortium led by the Max-Planck-Institut für Extraterrestrische Physik, Germany. More information about the instrument and its control centre can be found in:
http://pacs.mpe.mpg.de/
http://pacs.ster.kuleuven.ac.be/

Facts about radiation effects and impact on PACS detectors

- The so-called glitch phenomenon is the result of an energy deposit from charged particles in detectors operating in space
- The energy deposited produces a spike in the signal which can be tens or hundreds times larger than the detector intrinsic noise
- Cosmic ray hits strongly influenced the performance of detectors used in space such as ISOCAM and ISOPHOT on board the Infrared Space Observatory (ISO), their signal were largely affected for time periods long enough to corrupt a large amount of data
- The PACS Ge:Ga photoconductor arrays are similar to those on board of ISO, we expect therefore that they will be strongly by cosmic ray hitting
- Cosmic background predicted in L2 orbit is similar to ISO but the operating conditions will be very different (high telescope background, no regular detector curing foreseen)
- Herschel will start its routine operations phase in L2 shortly after a solar minimum but it will operate until an epoch of increasing solar activity what may result a noticeable higher glitch rate
- PACS photoconductor arrays have been tested in proton irradiation environment applying representative fluxes for the L2 orbit. Particle hits produce discontinuities in the ramps and result a highly skewed noise distribution on the reduced spectrometer signal. These instantaneous response changes (IRCs) show different nature for the low & high stress detectors.
- PACS bolometer arrays have been lab-exposed to proton and alpha particle beams. Both kind of particles leave strong glitch like structures in the detector signal, although long-term changes in responsivity due to particle impacts has not been proven for this detector type.

References

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Deglitching of PACS Photometer data

Algorithm is based on the work that Stark and Murtagh have done to deglitch ISOCAM data [5] [6].

- Calculate the Multiresolution Median Transform (MMT) of the signal
- MMT is done by application of a median filter with a subsequently increasing filtersize L:

  S(row, col, time) = w_0(row, col, time) + Σ w_j(row, col, time)
  c1 = S, L=1
  cj+1 = MedianFilter(S, 2L+1)
  wj=cj - cj+1
  j->j+1, L->2L

- Find a noise estimate:
  - Start with a mean filtered signal
  - Calculate the noise in wavelet space
  - Find the detector pixels whose signal is smaller than n*σ_{noise}
  - Refine the noise estimate with the new found subset of pixels
- Discriminate in wavelet space (wj(row, col, time) > n* σ_{noise_wj} -> wj(row, col, time) = 0)
- Reconstruct the signal: $S_{deglitched}$ (row, col, time)= ∑ wj(row, col, time)

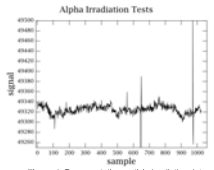

Figure 4: Representative particle irradiation dataset from a single Photometer pixel.

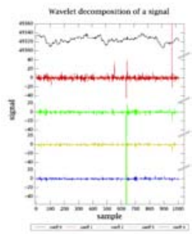

Figure 5: MMT coefficients of the decomposed signal. Largest glitch events can be easily recognized.

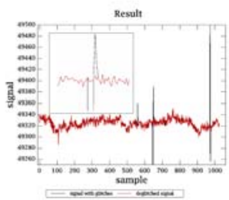

Figure 6: The reconstructed glitch free, cleaned signal

- Powerful and fast deglitching algorithm, suitable for standard product generation
- More than one pixel is needed to calculate the noise
- Assumption that every pixel has the same noise has to be improved:
  - Correlation of noise between detector pixels has to be investigated
  - Algorithm allows to feed in an externally calculated noise estimate
- Algorithm has to be extended to treat chopped measurements

Deglitching of PACS Spectrometer data

The discrete approach of the wavelet transform can be done with the special version of the so-called à trous algorithm [8]. Similar to the MMT routine, the input signal is analysed and filtered by using the wavelet coefficients and an adaptively determined noise threshold:

- Calculate the wavelet transform $w_i(k)$ of the signal: $w_k(k) = c_{i-1}(k) - c_i(k)$ where the signal difference $c_{i-1}(k) - c_i(k)$ contains information between two wavelet scales
- Find an initial noise estimate:
  - Decompose a simulated signal in wavelet space which have Gaussian noise of the same variance as the intrinsic noise of a detector pixel
  - The initial threshold values are determined from this simulation in each of the wavelet planes
- Discriminate in wavelet space samples if $w_i(k) \geq n\sigma_i$ and replace outliers with $\sum_{j=m}^{n} w_j(k)$ where $1 < m < n$
- Continue iteratively and re-calculate σ_i until no more outliers found
- Reconstruct the cleaned signal $c_{cleaned}(k) = c_n(k) \sum_{j=1}^{n} w_j(k)$

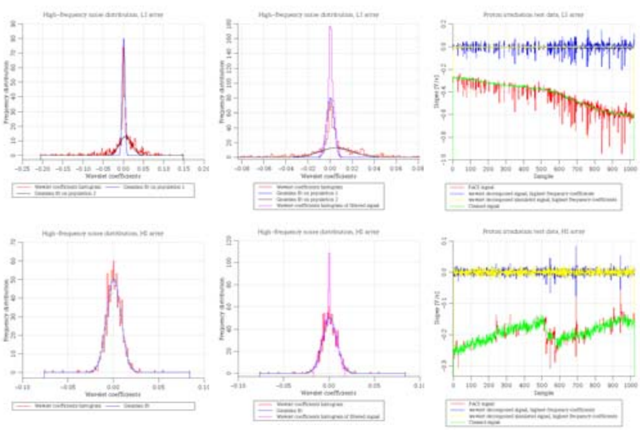

Figure 4: The upper three figures show results on the low stressed (LS) detector signal, the lower three figures are for the high stressed (HS) data. The first column shows the noise distribution at the highest frequency wavelet coefficients. There is a clear difference between the LS and HS noise characteristics: the LS data is a composite set of two noise populations (i) a narrow intrinsic and a (ii) broad and skewed population of glitch affected samples while the HS dataset can be well represented by a single Gaussian noise component. Initial noise thresholds have been determined from the Gaussian fits on the intrinsic noise. The second column shows the noise distribution of the cleaned signal and the third column represents the final product: the cleaned, glitch free reconstructed signal.

The proposed deglitching algorithms prove high performance in terms of glitch free signal reconstruction even for extremely high impact rates. Nonetheless, a Q-test based flagging and removal of glitch affected samples could be more efficient [9] if the in-orbit glitch rate will be significantly lower.