THE HERMES CALIBRATION PIPELINE: MESCAL

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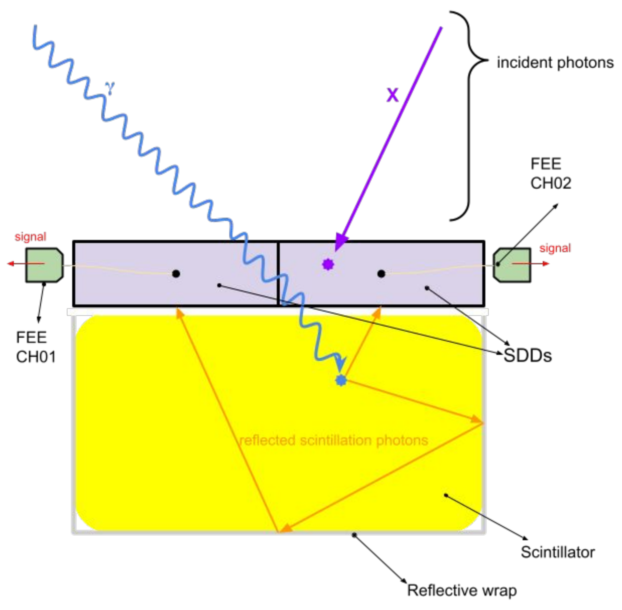


Figure 1: A diagram detailing the double-detection mechanism of a typical siswich detector, like that of HERMES.

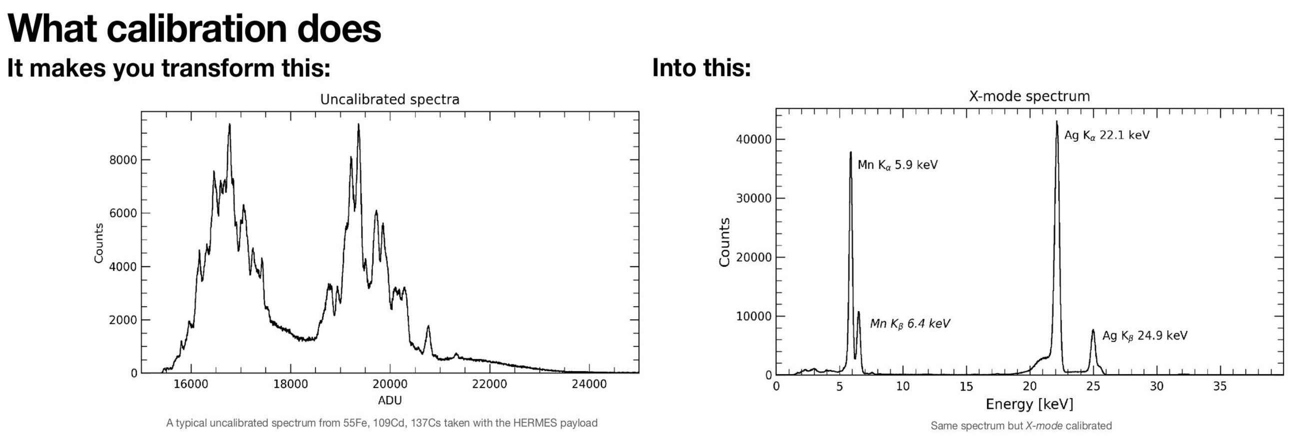
HERMES will be the first high-energy transient localization experiment through a distributed space architecture realized with a **3+3 CubeSat constellation**. Each unit will be equipped with a new miniaturized instrument, hosting a hybrid Silicon Drift Detector (SDD) and a cerium-doped gadolinium-aluminium-gallium garnet (GAGG:Ce) scintillator photodetector system [1]. This instrument concept is called **"Siswich": Silicon-Scintillator Sandwich.**

While most astronomical detectors work with only one detection principle, the **siswich detectors exploit two**: the SDD as a direct X-ray photon detector, and the scintillator as an indirect gamma-ray detector (see Fig. 1). This "double detection" mechanism yields a **broad sensitivity energy range from 2 keV to 2 MeV, unprecedented in astrophysics**.

A new data-reduction pipeline must thus be built, since this detection mechanism has not been standardized yet. Here we present our HERMES data reduction pipeline, **MESCAL** (her**MES CAL**ibration pipeline) [2].

This pipeline is intended for on-ground, laboratory data, indispensable for calibration and testing during each and every integration step. Thus, *it assumes the energy of the calibration sources is well known, which is not necessarily the case for astrophysical sources.* For the latter scenario, an ad-hoc scientific data reduction pipeline will be developed by ASI-SSDC.

MESCAL, step by step



The main algorithms in the **HERMES** data calibration process that differ from (or are non-applicable to) other high-energy detectors are:

1. **X-ray/gamma-ray event discrimination**
2. **Automatic calibration lines detection**
3. **Energy calibration**

1. X-ray/gamma-ray event discrimination

The initial event list lacks details on whether events are detected directly by the SDD ("X mode") or indirectly by the scintillator ("S mode"). Our algorithm differentiates these modes for accurate energy calibration.

Events are grouped by arrival times to identify those detected by SDD channels linked to the same scintillator. The method is reliable due to the low probability of two simultaneous low-energy photons hitting SDDs on the **same** scintillator.

To avoid intra-scintillator Compton scattering, we consider only single-channel (multiplicity 1) and double-channel events within the same scintillator (multiplicity 2) for calibration. Internal Compton scattering results in multiplicities of 4 or higher. This approach reduces contamination, with multiplicities of 1 and 2 comprising over 96% of expected events.

3. Energy calibration

The energy calibration can be summarised as follows [3]:

A. **X-tagged Events Calibration**:
   - Once the lines have been identified, estimate channel gain and offset through linear regression:

     A [ADC] = Gain x E [keV] + Offset

   - Convert X-tagged event amplitudes to energy units.

B. **S-tagged Events Calibration**:
   - Convert event amplitudes to photoelectrons using the X-mode calibration parameters:

     A [ADC] = Gain x E [keV] + Offset

   - Sum electron amplitudes of coincident S-events in coupled channels.
   - Create histograms for each scintillator, run the peak detection algorithm to find the lines and derive the light output of each channel:

     LY [e−/keV] = A [e−] / A [keV]

   - Assign light output to each channel following the relations:

     LY1 / LY = A1 / A and LY2 / LY = A2 / A

   - Convert S-tagged event amplitudes to energy units.

2. Automatic calibration lines detection

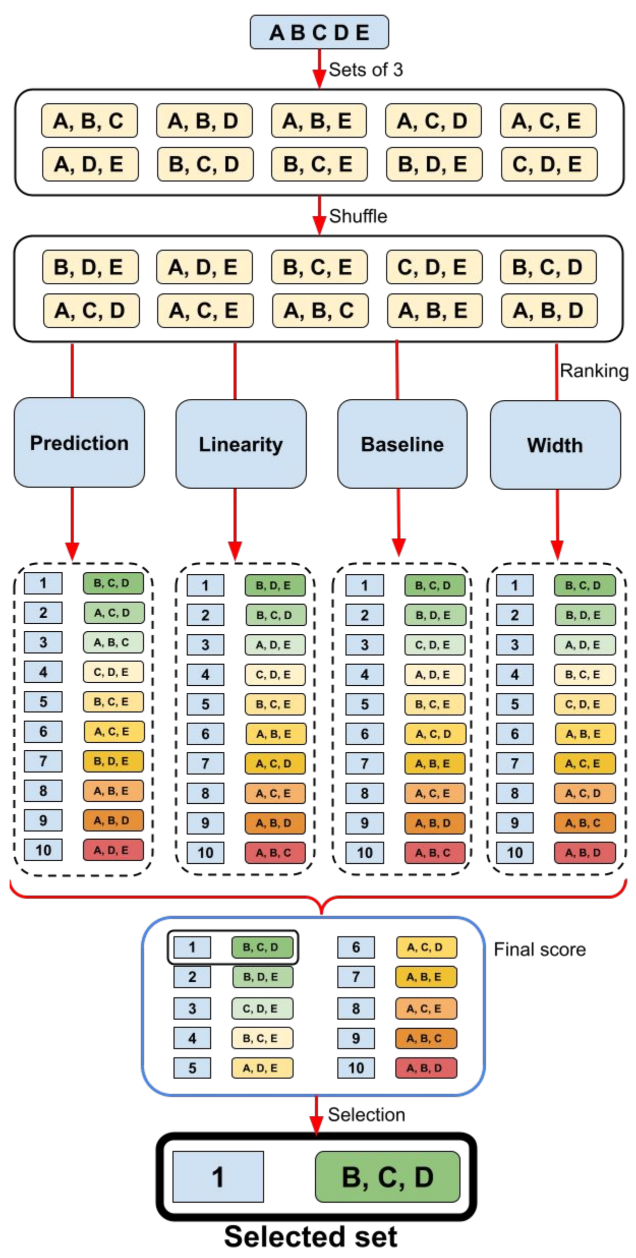


Figure 2: Flux diagram illustrating the line identification process using a simulated example. Given 5 local maxima (A, B, C, D, E in increasing order of energy) in an X-mode histogram and 3 calibration lines as input, the algorithm builds all possible combinations of these peaks. It then ranks each set according to various criteria and selects the best-ranked set, which in this case is B, C, D.

Energy calibration of the detector uses spectra from radioactive sources (mainly Fe-55, Cd-109, and Cs-137) with known emission lines to create calibration functions for each of the 120 channels. Calibrating all 6 modules means processing 720 spectra per run.

Calibration is also performed at various temperatures and during different assembly stages to ensure accuracy, as calibration parameters change with temperature. Testing multiple hardware and software configurations further increases the number of spectra to several thousand. **This volume necessitates automated calibration to manage the extensive data efficiently.**

The main challenge in automation is identifying emission lines amid electronic noise and other artifacts. Our algorithm detects peaks using the findpeaks function from the scipy package.

Once all peaks on a spectrum have been detected, they are grouped into all possible combinations of the expected emission lines. Note that the algorithm can find more features than the expected emission lines, due to artifacts and noise. **The algorithm takes every peak into account.** These groups are then ranked according to the following priors:

- **A priori error**: The distance, in energy units, between observed lines is known.
- **Linearity**: We expect the detector to be linear at 98% over a specific energy range.
- **Baseline distance**: We expect the detector to have a sensitivity threshold at ~2 keV.
- **Peak prominence**: The relative flux of each emission line is known.
- **Feature width**: Although the energy resolution is unknown a priori, the FWHM should be consistent for all features.

The best combination of peaks is selected based on these scores (see Fig. 2), effectively identifying emission lines and discarding artifacts and noise. **The algorithm has shown a >97% success rate over ~10,000 spectra.** This approach does not depend on the instrument configuration: **is highly adaptable!**

CONCLUSIONS

>97% SUCCESS RATE OVER 10000 SPECTRA

HIGHLY ADAPTABLE!

REFERENCES:
[1] FIORE ET AL. 2020, SPIE 11444, 1R
[2] DILILLO ET AL. 2024, A&C 46, 100797
[3] CAMPANA ET AL. 2022, SPIE 12181, 5K

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