DATA PROCESSING PIPELINE FOR DAWN'S GAMMA RAY AND NEUTRON DETECTOR AT CERES.

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Introduction: The Gamma Ray and Neutron Detector (GRaND) on board NASA's Dawn spacecraft was designed to measure the elemental composition of Vesta and Ceres [1]. Data are acquired in circular polar, low altitude mapping orbits (LAMO) to maximize elemental sensitivity and to enable global mapping with regional-scale resolution. At Vesta, GRaND measured elemental ratios (Fe/O, Fe/Si, K/Th) and mapped concentrations of H and Fe and compositional parameters [2-7]. At Ceres, GRaND will map the concentration of H and major elements, and search for minor elements diagnostic of aqueous alteration [8]. Long accumulation times are required to detect or bound the concentration of some elements. More than six months of data will be acquired during Dawn's primary mission to Ceres. In this abstract, we summarize data processing steps required for accurate determination of elemental concentrations using gamma ray spectroscopy. Similar processing steps are applied to determine neutron counting rates from spectra acquired by GRaND's phoswich and plastic scintillators.

Overview of Operations: Dawn spacecraft was successfully inserted to Ceres' orbit in March, 2015. Since then, GRaND has been continuously measuring the signal from Ceres and backgrounds at various distances (Figs 1, 2). Measurements of background spectra far away from Ceres (>9 body radii altitude) are crucial for accurate elemental determination. Spacecraft backgrounds must be subtracted from spectra acquired at low altitude to determine the signal from Ceres.

As Dawn approached Ceres and descended to low altitude, instrument parameters were adjusted to optimize performance. Radiation damage caused by prolonged exposure of the sensors to energetic particles in the space environment caused a gradual decrease in gain, as measured by the position of prominent peaks in pulse height spectra (e.g. Figs. 1, 3). Gain can be adjusted by changing the high voltage (HV) applied to scintillator photomultiplier tubes (PMTs). HV adjustments were required for the bismuth germanate (BGO) gamma ray spectrometer and neutron sensors to obtain the required energy range. The HV settings were increased in several steps while the spacecraft was far from Ceres. Final adjustments were made as Dawn transitioned from Survey to high altitude mapping orbit (HAMO). An increase of 12% in gain for the BGO sensor was required to match the gain measured at Vesta (Figs. 1, 3).

BGO Data Processing Pipeline: The following data reduction processes and corrections are applied to the raw time-series spectra of GRaND BGO to produce a high quality data set suitable for scientific data analysis and archiving.

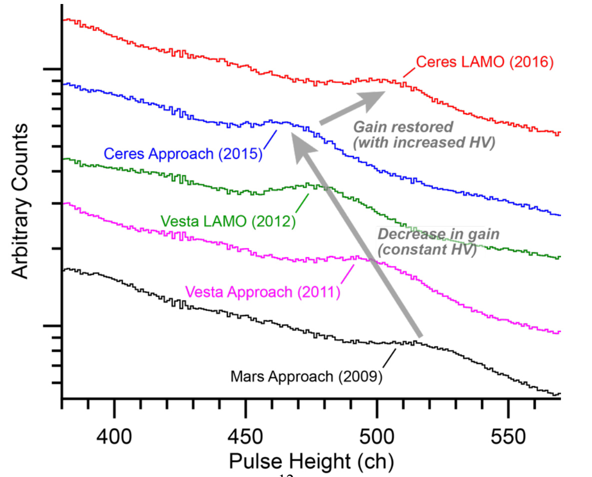

Figure 1. Change in gain of ^{12}C 4.4 MeV peak in raw gamma-ray spectra acquired at various periods of time since launch.

Differential non-linearity. The digitizing artifacts produced by GRaND's analog-to-digital converter are corrected by identifying the pattern of artifacts, which occur at higher frequencies than expected based the energy resolution of the spectrometer.

Peak centroid detection. The light output of the BGO scintillator increases with decreasing temperature of the BGO crystal. Small changes in temperature, which occur in flight, result in shifts in the position of gamma ray peak centroids. The gain of the BGO was monitored using an automated method [9], optimized for BGO, to determine the centroids of major gamma ray peaks (e.g. Fig. 1).

Gain correction. The centroid positions and known energies of major gamma-ray peaks are used to derive the gain and offset for each spectrum to put it on the same energy scale.

Archiving of the data set at PDS. The gain-corrected time-series spectra will be included in the Level-1B, reduced data records archived data at Planetary Data System Small Bodies Node.

Vicinity spectrum. At the time of writing, data from only three weeks of observation at LAMO were available. A sharp increase in BGO counting rates was observed as Dawn transferred from HAMO at about 3 body radii altitude to LAMO at 0.8 body radii altitude (Fig 2). The increase in counts is due to radiation originating from Ceres.

Background spectrum. Gamma ray backgrounds (e.g. produced by galactic cosmic ray interactions with the spacecraft) were measured far from Ceres. Because the increase in HV caused the change in spectrum shapes and counting rates, the background spectrum needed to have the same parameter settings as in LAMO. Careful selection of data in and around the Survey orbit at 9 body radii altitude enabled precise determination of the background gamma ray spectrum (Fig. 2). As Dawn descended from Survey orbit to HAMO, small increases in counting rates were observed, especially for the Fe peak at 7.6 MeV, which made HAMO data unsuitable for evaluation of backgrounds. Total effective observation time of 2.49×10^6 s was accumulated for background. Although this is lower than achieved at Vesta, the accumulation time is sufficient for high precision measurements of gamma ray emissions from Ceres.

Difference spectrum. The background spectrum is subtracted from spectra acquired in LAMO to reveal contributions from Ceres. In order to avoid introduction of spectral artifacts, peak widths of the LAMO and background spectra are adjusted by convolving each spectrum with energy-dependent Gaussian functions, such that both spectra have the same energy resolution.

Results: A gamma ray difference spectrum for Ceres was determined using the methods described here. Although the precision of the spectrum was limited by the short accumulation time, significant changes in the gamma spectrum relative to Vesta were evident, including changes in the intensity of prominent peaks and the gamma ray continuum. An analysis of the spectral data is presented by [8]. Longer accumulation times will enable quantification of key elements needed to fully characterize the composition of Ceres' regolith.

References: [1] Prettyman T.H. et al. (2011) *SSR, 163,* 371-459. [2] Prettyman, T.H. et al. (2012) Science, *338*, 242-246. [3] Prettyman, T.H. et al. (2013) *MAPS*, 48, 2211-2236. [4] Yamashita, N. et al. (2013) *MAPS*, 48, 2237-2251. [5] Peplowski, P.N. et al. (2013) *MAPS*, 48,, 2252-2270. [6] Lawrence, D.J. et al. (2013) *MAPS*, 48, 2271-2288. [7] Prettyman, T.H. et al. (2015) *Icarus*, 259, 39-52. [8] Prettyman T.H. et al. (2016) *LPS,* XLVII, #2228. [9] Mariscotti M.A. (1967) *Nucl. Instrum. Meth.* 50, 309-320.

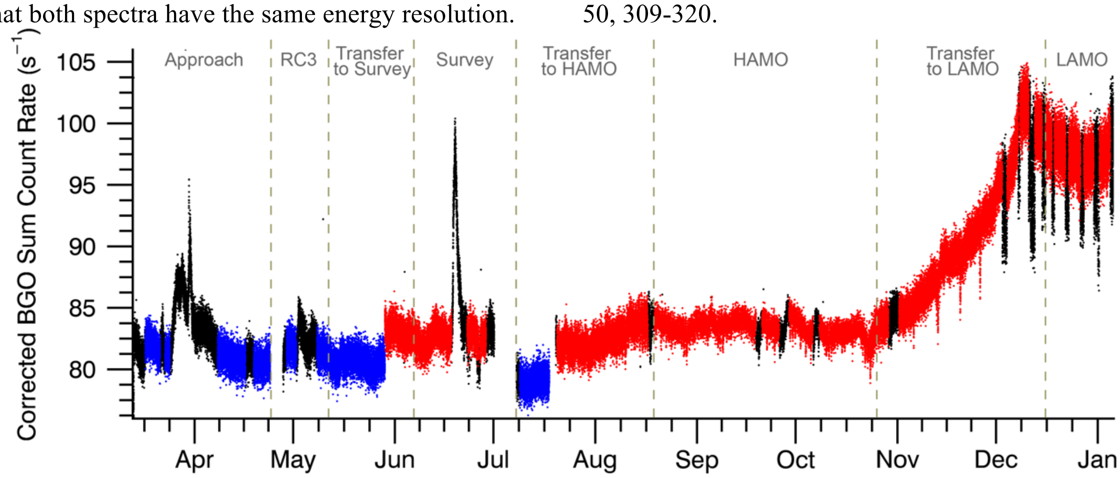

Figure 2. Total counting rate of the BGO scintillator of GRaND during Ceres encounter starting in March, 2015. Counts were corrected for cosmic rays. Black dots indicate all the observations including those during solar energetic particle events, while blue indicates measurements with the original (lower) HV, and red with higher HV under quiet Sun conditions. Each phase of Ceres encounter is delineated in gray broken lines. RC3 stands for rotation characterization 3. See text for other abbreviations.

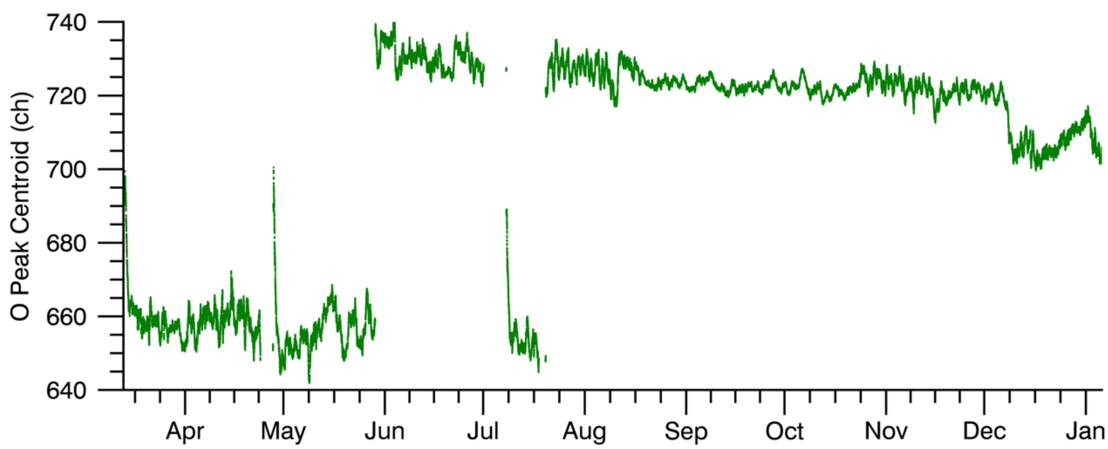

Figure 3. Temporal variation for centroid positions of ^{16}O peak at 6.1 MeV during Ceres encounter. The HV for BGO PMT was permutated on 5/28/2015 and 7/18/2015, resulting in significant increase in gain.