# DATA REDUCTION AND ARCHIVING FOR DAWN'S GAMMA RAY AND NEUTRON DETECTOR

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**Introduction:** The NASA Dawn mission's Gamma Ray and Neutron Detector (GRaND) will map the surface elemental composition of asteroids 4Vesta and 1Ceres, providing new insights into processes underlying their formation and evolution. So far, GRaND has acquired data during cruise, a very close flyby of Mars, and at various distances from Vesta. Early findings from low altitude mapping of Vesta are reported at this conference [1,2,3].

Within a couple of body radii, GRaND is sensitive to neutron and gamma ray emissions from planetary surfaces. The gamma ray and neutron spectra convey information about the chemical composition of the top few decimeters of the body's surface. High quality data products are needed in order to accurately determine elemental abundances from these data.

A detailed description of the GRaND instrument, data processing, and archiving is described in a recently published manuscript [4] and in documents accompanying the archived data in the Planetary Data System (PDS) at the Small Bodies Node. Here, we provide a brief overview of the processing steps and discuss anticipated future developments. As an example, we illustrate basic steps used to determine the abundance of Fe from gamma ray spectra acquired in low altitude mapping orbit around Vesta.

**Sensors and event categories:** GRaND consists of twenty-one sensors, including four different types of spectrometers, arranged to measure gamma rays and neutrons from planetary bodies. At the center of GRaND, is a large bismuth germanate (BGO) scintillator, which is the primary gamma ray spectrometer. The BGO scintillator can measure gamma rays over a wide range of energies (up to 10 MeV). We focus on this sensor for our example. GRaND also contains an array of 16 CdZnTe semiconductors for higher resolution gamma-ray spectroscopy at relatively low energy (less than 3 MeV) and four surrounding scintillators that serve as an anticoincidence shield and neutron spectrometer.

Radiation interactions with the sensors are categorized by a field-programmable-gate-array, which reads the pattern of pulses produced by the sensors. There are six different event categories, for which gamma ray and neutron spectra and event data are recorded. For example, the digitized pulses from a single interactions with BGO are accumulated in an 1024-channel histogram. The histograms, event data, and housekeeping data are packetized on regular accumulation intervals and stored in virtual recorders on board the spacecraft.

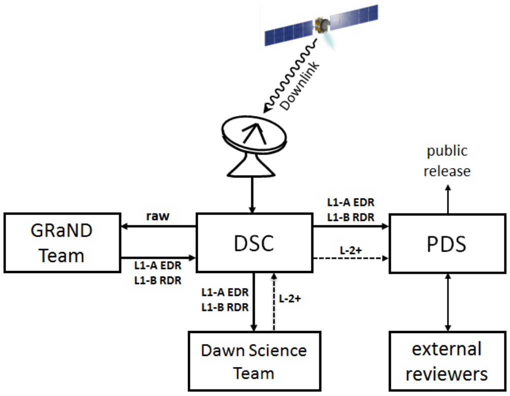

Fig. 1. Conceptual diagram of the data flow for GRaND Level 1 data products (L1-A & L1-B) from downlink through to release of the data to the public. The GRaND team produces the Level 1 data products which are distributed to the Dawn Science Center (DSC) and Science Team. The data are subjected to internal and external review before public release. The Dawn Science Team, Geochemistry Working Group is responsible for Level 2 and higher order products (L-2+).

**Data flow**: Data from the virtual recorders are down-linked periodically and processed on the ground (Fig. 1). Raw telemetry packets are delivered to the GRaND team, which produces the Level 1A (L1-A), Experimental Data Records (EDR). The EDR are time-ordered and have undergone reversible processes, including decoding, decompression, and conversion of selected data numbers to engineering units. An automated pipeline has been implemented to ensure rapid delivery of the EDR to the Dawn Science Center (DSC) [4]. The DSC distributes the EDR to the Dawn Science Team and ultimately to the PDS, which archives the data. All higher level products are produced from the EDR.

The next step is the production of the Level 1B (L1-B), Reduced Data Records (RDR). The RDR are a time series of calibrated spectra, consisting of net counts and propagated uncertainties for selected gamma rays and reaction peaks. For each accumulation interval, ephemeris and pointing data (subsatellite longitude and latitude, and the direction and distance to body center) determined by SPICE [5], scaler data, and live time are provided. The solid angle of the target body, determined by the methods described in [4] from a global topography model is also provided. The RDR contain all of the information needed to determine maps of counting rates and spectra, corrected for solid angle and variations in the flux of cosmic rays.

Corrected data are sensitive to surface composition and are the basis for Level 2 maps and higher order data products. These will include absolute and/or relative elemental abundances and parameters determined from neutron spectroscopy. Neutron parameters include thermal neutron absorption cross section and effective atomic mass of the regolith. These parameters give weighted sums of the elemental abundance, which, for example, can be combined with the abundances of specific elements to determine the ratios of end members for geochemical models [4]. The higher level products will be developed by the Dawn Science Team, Geochemistry Working Group. Scientific evaluation of the data by a collaborative team of spectroscopists and geochemists ensures that high fidelity data will be delivered to the PDS.

**Delivery timeline**. The Dawn mission and PDS are planning to deliver the GRaND EDRs 3 months following the completion of each mapping phase. The RDR will be available from the PDS within 6 months of departure of the Dawn spacecraft from Vesta. Level 2 and higher order products will be released starting 1 year following departure. Departure from Vesta is scheduled for July of 2012.

**BGO processing steps:** The BGO pulse height spectrum contains peaks and continua from gamma rays made by nuclear reactions with elements in the planetary surface such as Fe, Mg, O, and Si, as well as gamma rays from the decay of natural radioisotopes ($^{40}$K and Th and U decay products). The spectrum also contains backgrounds from interactions with the instrument and spacecraft, which can obscure signatures from the planet. Both peak analysis and spectral unmixing have been successfully applied to lunar gamma ray spectra acquired by the Lunar Prospector [6,7]. Before these methods can be applied, the spectra must be subjected to some basic processing steps. These include two main corrections: (1) *Differential nonlinearity*: The raw histograms for BGO contain artifacts of the differential nonlinearity of the analog-to-digital converter (ADC). Because the ADC channel-widths are not exactly the same, fluctuations in the spectrum can be observed on an energy scale much smaller than the energy resolution of the spectrometer. The artifacts are removed by dividing the channels by their known widths, which are determined from spectra accumulated over long periods of time. (2) *Gain and offset*: The gain of the BGO sensor varies, such that peaks in the raw histograms shift with time. Consequently, peaks with known energies, such as the 511 keV gamma ray from positron annihilation and peaks from neutron inelastic scattering with oxygen, are used as markers to determine the gain and offset of the BGO sensor as a function of time. The time series spectra are then corrected to a constant gain (8.9 keV/channel) and an offset of 0 keV.

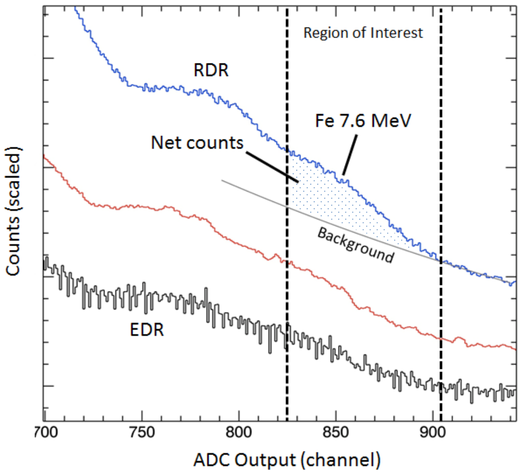

Fig. 2. Corrections applied to produce calibrated (RDR) pulse height spectra for the BGO sensor from the EDR are shown. The spectrum in black shows DNL artifacts, which are removed in the red spectrum. The blue spectrum was obtained by applying a gain correction and summing only spectra for which pointing criteria were met. The gray exponential was fitted to the background continuum above the Fe 7.6 MeV peak. The spectra have been arbitrarily scaled for visualization. A simple method to extract the peak area (net counts) is illustrated.

**Example**: Neutron capture with $^{56}$Fe produces intense gamma rays at 7.631- and 7.646-MeV. These appear as a distinct peak in the BGO pulse height spectrum, when in close proximity to Vesta. The net counting rate of this peak is proportional to the abundance of Fe in Vesta's surface. Fig. 2 shows the application of the aforementioned processing steps to produce a corrected spectrum, which can be subjected to analysis by peak fitting and spectral unmixing. A simple scheme for peak extraction is illustrated, wherein the background above the peak is extrapolated to estimate the background within the peak region of interest.

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**References:** [1] Prettyman T.H. et al., submitted to *LPS* XLIII. [2] Mittlefehldt D.W. et al., submitted to *LPS* XLIII. [3] Lawrence D. J. et al., submitted to *LPS* XLIII. [4] Prettyman T. H. et al. (2011) *Space Sci. Rev.*, DOI:10.1007/s11214-011-9862-0. [5] Acton C. H. (1996) *Planet. Space Sci.* 44(1), 65–70. [6] Lawrence, D.J. et al. (2002) *JGR*, doi:10.1029/2001JE001530. [7] Prettyman, T.H. et al. (2004) *JGR*, doi:10.1029/2003JE002139.