CATALOG OF TRANSIENT RADIATION EVENTS DETECTED BY GRaND AT VESTA AND CERES.

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Introduction: The Gamma Ray and Neutron Detector (GRaND) on board NASA's Dawn spacecraft has conducted radiation measurements in the vicinity of Vesta at ~2.4 au and Ceres at ~2.8 au [e.g. 1-4]. While the primary objective of the GRaND investigation is to obtain elemental information about the surfaces of these bodies, GRaND also records transient radiation events such as electron bursts [5], solar energetic particle events (SEP) [6], solar flares, and gamma-ray bursts (GRB) [5]. In this study, we catalog these events and summarize their detection criterion. Here, we focus on the detection of solar x-rays and gamma-ray bursts, which have some attributes in common with electron bursts. Electron bursts provided evidence for a transient exosphere at Ceres [5].

Methods: We analyzed level 1A and 1B time-series data from exterior sensors (+Z phoswich and +Y and –Y side scintillators) and shielded sensors (–Z phoswich and bismuth germanate (BGO) scintillator) of GRaND archived at the Planetary Data System [7,8]. For each sensor, total counting rates were derived. We excluded a small portion of the data which were obviously corrupted (i.e. under-threshold channels and overshoots). GRaND has adjustable science accumulation intervals [6], which ranged from 70 to 210 s at Vesta and Ceres, depending on mission phases. The accumulation time limits the time resolution for the detection of prompt events such as gamma-ray bursts.

Roll-over correction. GRaND is equipped with a 16-bit dead time counter to determine live time. However, this counter frequently rolls over multiple times in a single accumulation interval. This results in discontinuities in time series of dead times with a multiple of 13.4 s, which is the full range of the counter. The roll over becomes even more significant during transient events due to high counting rates. Such discontinuities were manually corrected throughout the dataset to thoroughly detect transient events and derive the counting rates properly.

Threshold energies. GRaND sensors are contained in a housing [6] that shields most low-energy charged particles. The housing material contains C and O. During the SEP events, we have observed significantly increased counting rates for C and O gamma-ray peaks at 4.4 and 6.1 MeV in the BGO histogram [6,9].

Protons with > 4.4 MeV that excite carbon nuclei in the housing can induce the emission of 4.4 MeV gamma rays, which contribute to the response of the +Z phoswich. However, 4-MeV protons themselves have insufficient range to penetrate the housing. Only protons with kinetic energies greater than a few 10s of MeV interact directly with the sensors. Electrons greater than about 2 MeV can penetrate GRaND's housing [5]; however, low energy electrons can make bremsstrahlung photons that can reach the outer scintillators. Consequently, both protons and electrons can contribute directly and indirectly to the response of GRaND's scintillators. Therefore, when studying interplanetary particle fluxes with GRaND data, especially in comparison with other near-Earth satellite data, it is important to pay a special attention to the reaction types, energy ranges, and sensitivity of the measurements that are compared.

Neutral radiations, such as x-rays and gamma rays, have much lower energy-thresholds for detection. The BGO scintillator has a lower threshold of ~300 keV, determined by the electronics [6]. Therefore, some of the transient events with neutral radiation, such as solar flares and GRBs are sometimes detected only with exterior sensors, which have lower thresholds. For example, the +Z phoswich has a threshold of ~20 keV.

Results: We identified and characterized transient events during Dawn's encounter with Vesta and Ceres. For illustration, a time-series of counting rates is shown in Fig. 1 for a period of one week. This time period contains all types of transient events (solar flares, an SEP, and a GRB) except for electron bursts.

Solar flares. Emissions of x-rays by M- and X-class solar flares were detected and correlates well with those reported by GOES 15 X-ray Sensor [10]. Note that it takes electromagnetic waves about 20 min to travel the distance between Earth and the main belt objects, consistent with the time difference between the Dawn and GOES data. Solar flares typically precede SEPs, which are described below. When detected, solar flares causes the sudden and significant increase in the temporal counting rates followed by relatively quick decay (Fig. 1). The intensity of the flare is correlated with the number of GRaND sensors that respond to the solar x-rays. The shielded sensors are triggered only by X-class flares [10].

Solar energetic particles. SEPs can increase the counting rates of all the GRaND sensors by an order of magnitude for days to weeks. For example, elevated counting rates were measured by GRaND in September, 2017 for more than two weeks (Fig. 1). SEP events are often intense and require significant correction for roll over of counters and histograms. In some cases, corrections are not possible, which can limit the ability to determine proton fluxes.

Gamma-ray bursts. GRBs are detected by GRaND as a single event that accompanies an increase in counting rates. Their detection can often be confirmed by Fermi Gamma-ray Burst Monitor data [11-13]. GRBs typically last less than one minute and have energies < 1 MeV. Consequently, they usually produce elevated counts in a single science accumulation interval (> 70s). In addition, they are preferentially detected by the +Z phoswich, which has a much lower energy threshold for detection than the BGO scintillator.

Unlike Selene/Kaguya Gamma-Ray Spectrometer [14] or MESSENGER Neutron Spectrometer [15], GRaND does not have a gamma-ray burst mode and is not optimized for GRB detection; however, the detection time for GRBs varies from almost simultaneous (within GRaND's time resolution) to ~20 min ahead or behind the Fermi detection. The timing information could be used to estimate the direction of the GRB sources relative to the long baseline connecting the Earth and the Dawn spacecraft. The placement of a sensor optimized for GRB detection in the main belt could be beneficial to the astrophysics community.

Electron bursts. Sporadic detection of transient events not classified as either an x-ray flare, GRB, or SEP event was reported while Dawn was in Survey Orbit around Ceres (about 4400-km altitude) [5,16]. Given the pulse-height distribution measured by the +Z phoswich and lack of signals in the shielded sensors, these bursts were determined to be bremsstrahlung produced by the interaction of swift electrons with the instrument housing. Russell et al. (2016) hypothesized that these electrons were accelerated to 10s of keV at a bow shock resulting from a transient atmosphere [5].

False positives. In some instances, data glitches can produce changes in counts that mimic a transient radiation event. These artifacts can be identified by monitoring live time, triples, and total event counters [6] and examining status logs.

Conclusions: We've catalogued nearly all transient radiation events detected by GRaND during Dawn's mission to Vesta and Ceres. These fall into four categories: x-ray flares, gamma-ray bursts, solar energetic particles, and electron bursts. Electron bursts, likely produced by the interaction of solar wind with a transient bow shock at Ceres, have only been observed during a short period of time (1 week) at Ceres. The ability to classify and characterize transient events supports ongoing studies of the heliosphere and planetary interactions at ~2.8 au. Work is underway to determine fluxes of energetic particles from GRaND data for comparison with measurements by other spacecraft.

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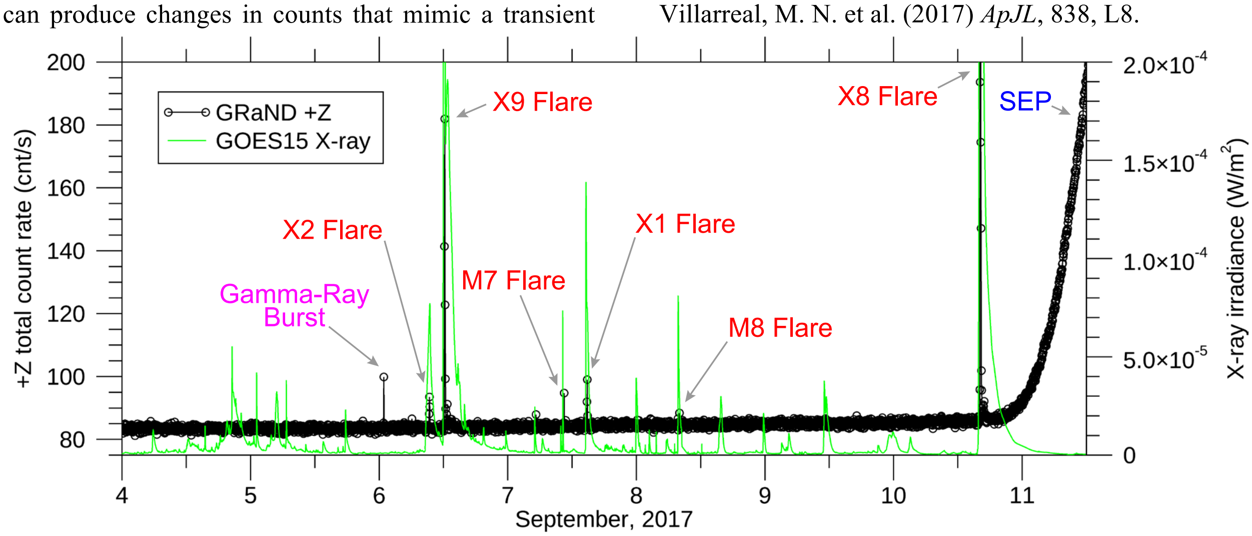

Fig. 1 Transient radiation events found in the time series of the counting rates of GRaND sensors in Sept, 2017. X-ray fluxes reported by GOES 15 X-ray Sensor is also shown for comparison [10]. The single event on Sept. 6, 2017 is most likely a gamma-ray burst detected as GRB170906030 by Fermi Gamma-ray Burst Monitor [11-13].