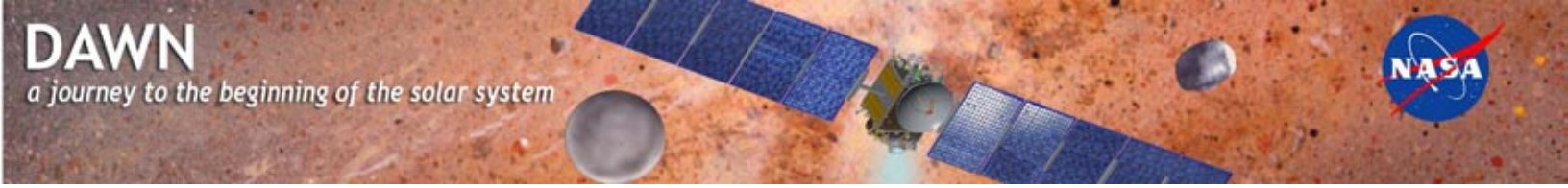

Interaction of Energy and Matter: Dawn Instrumentation Exploration Fact Sheet: The Gamma Ray and Neutron Detector (GRaND)

The GRaND Instrument

The Gamma Ray and Neutron Detector (GRaND) for the Dawn mission was developed by the Los Alamos National Laboratory. GRaND is managed by the Planetary Science Institute. Tom Prettyman is the GRaND Principal Investigator.

What does the GRaND do?

- The Gamma Ray and Neutron Detector (GRaND) will measure the chemical composition of the surfaces of Vesta and Ceres. Using a combination of gamma ray and neutron spectroscopy, the GRaND will measure the abundance of:
- near-surface major rock-forming elements such as oxygen (O), magnesium (Mg), aluminum (Al), silicon (Si), calcium (Ca), titanium (Ti) and iron (Fe);
- long-lived radioactive elements such as potassium (K), thorium (Th) and uranium (U) ; and
- volatiles such as hydrogen (H), carbon (C), nitrogen (N) and oxygen (O), which are the major constituents of ices.

How does this fit with the overall Dawn mission objective?

The Dawn Mission is designed to yield a significant increase in the under-standing of the conditions and processes acting at the solar system's earliest epoch by examining the geophysical properties of two complementary bodies—(1) Ceres and (4) Vesta. Data from GRaND will provide information about the asteroids' accretion materials, thermal evolution, and differentiation processes.

What region of electromagnetic radiation (EMR) interaction does the GRaND measure?

The GR in GRaND indicates that this Dawn payload instrument will detect and measure radiation in the gamma ray region of EMR. These gamma rays result from cosmic rays interacting with the chemical elements in the regolith of Vesta and Ceres.

Since neither Vesta nor Ceres have an atmosphere, cosmic rays can penetrate to their surfaces to depths of several meters to interact with the nuclei of atoms in the asteroid's regolith. (See the interaction labeled "1" on the GRaND Instrument.) These interactions:

- occur as cosmic ray protons with energies, many times nuclear binding energies
- collide with the nucleus of an atom; and
- release fast neutrons as a part of a cosmic ray shower made up of many other kinds of particles and energy from the nucleus.

Fast neutrons interact with other nuclei, losing energy in the process. Three basic interaction mechanisms are illustrated in the diagram:

- neutron capture, in which a neutron is absorbed and characteristic gamma rays are emitted (Interaction 2);
- inelastic collisions which produce characteristic gamma rays (Interaction 3); and,
- moderation (Interaction 7) in which neutrons lose energy in billiard-ball type elastic collisions.

GRaND can also detect the presence of gamma rays emitted by naturally radioactive elements in the asteroid's regolith (6).

The Neutron Detectors (ND) in GRaND

The ND, Neutron Detectors, in GRaND are sensitive to thermal, epithermal and fast neutrons, which are products of the interaction of cosmic rays with the asteroid's regolith (Interaction 1). These neutrons are intact particles of matter. Some of them lose energy during scattering collisions with other nuclei in the asteroid's surface (moderation, 7). Neutrons in all three energy ranges leak from the asteroid's surface (8) and can be detected by GRaND.

How does GRaND do what it does?

The GRaND uses a combination of gamma ray and neutron spectroscopy to measure the abundance of major rock-forming elements, as well as radioactive and volatile elements. Each element in the regolith is associated with a unique pattern of gamma rays—a "fingerprint" which can be analyzed to determine elemental abundance.

Gamma rays reaching the GRaND show up as sharp emission lines in the instrument's spectrum output.

- The energy (Pulse height in MeV) represented in these emission lines determines which elements are present; and
- the intensity of the emission lines (Counts/sec) is related to the element's concentration.

Gamma rays intercepted by GRaND are detected by an array of semiconducting cadmium zinc tellurium (CZT) crystals (Interaction 4) and/or interactions with a bismuth germanate (BGO) crystal (Interaction 5). Although the CZT array has a more restrictive energy range (0 to 3 MeV), it has somewhat higher energy resolution than the BGO sensor. The CZT array is more accurate in the low energy region of the spectrum, the region where gamma rays from many radioactive decay and nuclear reactions are found. Emission Spectrum b shows an ore sample spectrum of gamma rays from the decay of ^{214}Bi, one product of the ^{238}U decay chain.

The BGO sensor has a high efficiency for gamma ray detection and can measure gamma rays over a wide energy range. Neutrons interacting with iron nuclei produced the BGO spectrum shown in emission Spectrum c. GRaND's Neutron Detectors are four boron-loaded plastic scintillators surrounding the BGO crystal and the CZT array. Fast and epithermal neutrons interactwith two of these borated plastic scintillators (Interaction 9), which are, in turn, shielded by a layer of ^{6}Li-loaded glass that detects and absorbs thermal neutrons (Interaction 10). The gamma rays generated by the interaction of the neutrons with the scintillators are measured by the BGO and CZT detectors. Emission Spectrum a is an energy distribution of a neutron source similar to that which may leak from an asteroid's surface.

What can scientists learn about Vesta and Ceres by analyzing the information from GRaND?

The geochemical information measured by GRaND will give scientists a better understanding about the material from which the asteroids accreted, as well as constraining thermal evolution and differentiation processes (e.g. volcanism).

- GRaND's gamma-ray spectra will measure the composition and abundance of many rock-forming elements on Vesta and Ceres.
- GRaND's neutron detectors will provide information about light elements, such as hydrogen, carbon, nitrogen and oxygen—which are the constituents of ices—as well as strong thermal neutron absorbers, such as iron, titanium, chlorine, gadolinium, and samarium.
- GRaND's measurements of hydrogen will be used to determine the distribution of water, which may be present on Ceres as ice or hydrated minerals. From a circular, polar mapping orbit, GRaND will map the abundance of these elements over the entire surface of Vesta and Ceres.

The information from GRaND will help answer a number of questions about how the asteroids formed and evolved by mapping the location and abundance of key elements.

- The ratio of potassium to thorium concentrations will provide information about the material that grew to form the asteroids and may be useful in determining how the composition of solar nebula, the cloud of gas and dust which formed the sun, and the rest of the bodies in the solar system changed with its distance from the Sun.
- The abundance of rock-forming elements, such as iron and titanium, provides information about how igneous rock formed from magma on Vesta.
- Measurements of the abundance of hydrogen and carbon will enable scientists to understand aqueous processes that may have shaped Ceres.
- The elemental abundance data will help verify that Vesta is the source of a certain type of meteorites.

Definition of Terms

Energy Units:—1 keV = 10^3 eV; 1 MeV = 10^6 eV; 1 GeV = 10^9eV

Emission spectrum—A spectrum of energy released from a source, usually in the form of electromagnetic radiation

Epithermal Neutron—A neutron that has undergone energy loss due to scattering collisions, but is not in thermal equilibrium with the regolith (E = ~0.3 eV to ~600 keV)

Fast Neutron—A neutron ejected at high kinetic energy in a nuclear reaction (E = ~10^3 eV to 6 MeV)

Galactic Cosmic rays—Ionizing radiation, mostly protons, with energies in the GeV range, that originate outside the solar system *Gamma rays*—Very energetic EMR photons with energies between 1 MeV–10 GeV

Inelastic collision—A collision between two particles in which part of their kinetic energy is transformed into another form of energy (gamma rays); the total amount of energy remains the same

Neutron capture—A process in which a neutron is absorbed by a nucleus to produce an excited nucleus that transitions to ground state by emission of one or more gamma rays.

Regolith—The layer of rocky or icy debris and dust made by meteoritic impact that forms the uppermost surface of planets, moons and asteroids.

Scintillator—A phosphor-containing radiation detector that absorbs a photon or ionizing particle

Semiconductor—A substance or material, typically crystalline, that conducts electricity better than an insulator, but not as well as a conductor, because it allows current to flow only under certain condictions—common semiconductors are silicon, germanium, gallium, and arsenide *Thermal Neutron*—A neutron produced by fission and slowed by a moderator, so that it is in thermal equilibrium with its surrounding medium; (E< ~0.3 eV)

Volatiles—Substances that change into a vapor at relatively low temperatures