GEOCHEMISTRY AT 4 VESTA: OBSERVATIONS USING FAST NEUTRONS.

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Introduction: Dawn is currently in orbit around the asteroid 4 Vesta, and one of the major objectives of the mission is to probe the relationship of Vesta to the Howardite, Eucrite, and Diogenite (HED) meteorites. As Vesta is an example of a differentiated planetary embryo, Dawn will also provide fundamental information about planetary evolution in the early solar system [1]. To help accomplish this overall goal, the Dawn spacecraft carries the Gamma-Ray and Neutron Detector (GRaND). GRaND uses planetary gamma-ray and neutron spectroscopy to measure the surface elemental composition of Vesta and will provide information that is unique and complementary to that provided by the other Dawn instruments and investigations. Gamma-ray and neutron spectroscopy is a standard technique for measuring planetary compositions [2], having successfully made measurements at near-Earth asteroids, the Moon, Mars, Mercury and now Vesta. GRaND has made the first measurements of the neutron spectrum from any asteroid (previous asteroid measurements were only made with gamma-rays).

Dawn has been collecting data at Vesta since July 2011. The prime data collection period for GRaND is the Low-Altitude Mapping Orbit (LAMO), which started on 12 December 2011 and will last through spring 2012. During LAMO, the Dawn spacecraft orbits at an average altitude of ~210 km above the surface of Vesta, which allows good neutron and gamma-ray signals to be detected from Vesta. A description of the overall goals of GRaND and a summary of the initial findings are given elsewhere [3,4].

The subject of this study is to present the information that will be returned from GRaND using fast neutron measurements. Here, we discuss what fast neutrons can reveal about Vesta's surface composition, how such data can address Dawn science goals, and describe fast neutron measurements made in the early portion of the Vesta LAMO phase.

Background on Fast Neutrons: Fast neutrons are created by spallation reactions from high-energy galactic cosmic rays (GCR) hitting planetary surfaces. Fast neutrons are the initial products created from such reactions and have energies in the range from 0.5 – 5 MeV. Planetary fast neutrons were first measured at the Moon using data from the Lunar Prospector (LP) mission [5](Fig. 1). As determined from a combination of simulations and comparison with other geochemical data, it was determined that fast neutrons on a dry body like the Moon (~<100 – 200 ppm H) provide a good measure of average atomic mass, <A>[6]. On the Moon, <A> is primarily driven by variable Fe

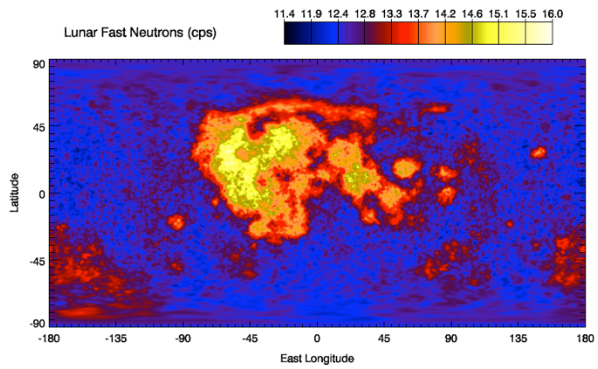

Fig. 1. Fast neutrons measured from the Moon using LP data [5,6]. This map, shown here for illustrative purposes, indicates the strong signal dynamic range and signal-to-noise that is provided by fast neutrons.

and Ti concentrations, which explains why fast neutrons show a clear delineation between lunar mare and highlands terrains. Lunar fast neutron fluxes varied by 37% over the range of <A> values from 21.2 to 24.2, which is easily detected and characterized from orbital measurements. For planetary surfaces containing large amounts of water (~>1 wt.%), fast neutrons are also strongly affected by hydrogen variations [7]. Thus, depending on compositional context, fast neutrons can provide information about both <A> and hydrogen concentration.

Fast Neutrons at Vesta: While Vesta is expected to have more hydrogen than non-polar regions of the Moon [3], GRaND data have already shown that Vesta has much less hydrogen than Mars [4]. Thus, we conclude that fast neutrons at Vesta will be more closely related to <A> than hydrogen content. Based on particle transport studies of HED elemental concentrations [3], the primary composition driver for <A> on Vesta is likely to be Mg, where <A> is strongly anti-correlated with Mg concentrations. The range of <A> values in HED meteorites is 21.75 to 23. Because Mg and Al are also highly anti-correlated in HED meteorites [e.g. 8], measurements of fast neutrons may also provide a measure of Vesta's Al content.

In a more general sense, the particle transport models of Prettyman et al. and studies of HED compositional trends [9] show that measurements of <A> can provide independent discrimination of diogenitic, howarditic, and eucritic materials on Vesta. Based on experience from lunar measurements, if such a variation exists across the surface of Vesta, it should be detectable with fast neutrons. Some have suggested that mesosiderites, which are a class of stony-iron meteorites with petrologic similarities to HED meteorites, may in fact be present on Vesta [10]. The distinguishing feature of mesosiderites in relation to fast neutrons is that their large Fe content causes their <A> to be significantly larger ($\langle A \rangle_{meso}$ = 30) than other HED materials [11]. If a large enough mesosiderite-dominated region is present on Vesta, it would manifest as a clear fast neutron enhancement along with other neutron and gamma-ray measurables.

Fast Neutrons on GRaND and Initial LAMO Measurements: GRaND contains four separate sensors that measure fast neutrons. The four sensors point towards the plus and minus z-axes and the plus and minus y-axes of the spacecraft, respectively. Each sensor uses the same boron loaded plastic (BLP) scintillator technology that has successfully measured fast neutrons at the Moon [5], Mars [7], and Mercury [12]. During LAMO, the z-axis of the Dawn spacecraft mostly points nadir so that the plus-z BLP sensor provides the primary Vesta fast neutron measurement. The plus- and minus-y sensors will provide secondary and independent measures of fast neutrons. The minus-z BLP sensor provides information about spacecraft background neutrons.

Because Dawn recently entered LAMO, GRaND is only at the beginning of data acquisition and analysis. Even so, all GRaND sensors are clearly detecting neutrons and gamma-rays from Vesta [4]. Initial fast neutron data from the plus-z sensor are shown in Fig. 2, where the fast neutron count rate is plotted versus a Vesta shape-model-corrected solid angle [3]. While the statistical variations are relatively large at this early state of data acquision, there is a clear count rate variation with solid angle. This variation, which shows higher count rates for larger solid angle indicates that the detected fast neutrons are coming from Vesta.

By March, significant progress will be made to the GRaND fast neutron acquisition and analysis. First and most importantly, GRaND will have collected approximately three times more data than is shown in Fig. 2. This will have the main benefit of reducing the statistical uncertainties, which will in turn allow the characterization of Vesta surface composition. Second, as the overall GRaND analysis proceeds, we will gain understanding about how to implement the various Vesta-specific corrections that are required for all planetary gamma-ray/neutron data. Third, we will carry out specific analyses to select fast neutron coincidence parameters for ground-based processing of event data to optimize the fast neutron signal versus background signal. Finally, we will analyze the plus and minus y-axis BP sensors and combine these data with the plus z-axis data to further optimize the overall fast neutron signal coming from Vesta.

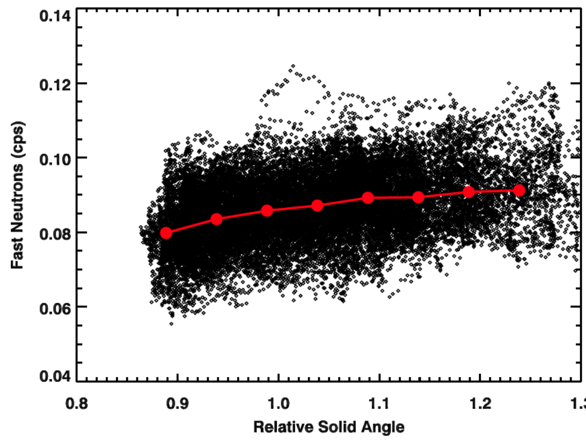

Fig. 2. Fast neutron data from the plus-z BP sensor taken during the first ~20 days of Vesta LAMO versus Vesta shape-model corrected solid angle. The full nadir-pointed data are shown in black and a binned version of the data are shown in red. Both show the trend of higher fast neutron count rate for larger solid angle, which indicates the detected fast neutrons are from Vesta.

Summary: Fast neutrons will provide additional compositional constraints that can be used to address the overall science goals of Dawn's Vesta mission. Initial data from the Vesta LAMO phase show a clear detection of fast neutrons. With increased counting statistics and standard data processing, GRaND fast neutron data will add to our steadily increasing knowledge of Vesta.

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