X-RAY AND GAMMA-RAY SPECTROMETER OBSERVATIONS OF THE ELEMENTAL COMPOSITION OF THE EQUATORIAL REGION OF MERCURY: TESTING FORMATION MODELS.

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Introduction: En route to its 2011-2012 orbit about Mercury, NASA's MESSENGER spacecraft [1] will fly by the planet three times, the first on 14 January 2008, within 200 km of the surface. Although the viewing time will be short during flybys compared with the orbital phase of the mission, modeling suggests that geochemical data can be obtained with sufficient quality to distinguish some plausible models of Mercury's surface composition.

Composition Models: We have generated six model compositions for Mercury (Table 1, Figure 1). Model 1 is derived from the mineralogy obtained from deconvolved mid-infrared spectra of the surface near the flyby footprint and represents a mixture of presumably deep-seated, magnesian, ultramafic, garnet-bearing lithologies with near-surface Na-K-rich basaltic to feldspathic materials [2]. Model 2 represents a single lithology, still magnesian and ultramafic, but with calcic feldspar and no garnet. Models 3 and 4 are variants on 1 and 2, respectively, adding 5 wt.% nanophase iron to represent a space-weathered, FeO-rich lithology. Models 5 and 6 are also variants on 1 and 2, respectively, switching the relative abundances of mafics and feldspar to produce feldspar-rich compositions.

Taken as a whole, these models represent a range of possibilities, including ultramafic compositions (1 and 2), space-weathered FeO-rich compositions (3 and 4), feldspar-rich compositions comparable to the feldspar-rich early crust of the Moon produced by a global magma ocean (5 and 6), volatile-rich compositions that would support formation of Mercury's large core by metal-silicate fractionation prior to accretion (1, 3, and 5), and volatile-poor compositions that might be more indicative of high-temperature impact processes (2, 4, and 6).

Expected Results at the First Mercury Flyby: MESSENGER carries two instruments for directly determining elemental abundances from Mercury's surface, an X-Ray Spectrometer (XRS) and a Gamma-Ray and Neutron Spectrometer (GRNS).

Table 1. Elemental compositions of six models that represent a range of possible compositions for Mercury's upper crust.

	#1	#2	#3	#4	#5	#6
Si	25.5	23.6	24.2	22.4	28.4	22.2
Al	3.6	5.1	3.4	4.9	8.1	13.6
Fe	3.4	3.1	8.3	8.0	1.7	1.1
Mg	15.8	16.7	15.0	15.8	5.6	5.8
Ca	3.4	5.2	3.3	5.0	2.7	10.2
K	1.3	0.0	1.2	0.0	3.7	0.1
Na	1.0	0.3	1.0	0.2	2.8	0.7
Ti	0.1	0.1	0.1	0.1	0.1	0.1
Mn	0.1	0.1	0.1	0.1	0.1	0.1
Cr	0	0.0	0.0	0.0	0.0	0.0
O	45.6	45.5	43.3	43.2	46.5	45.9
Total	99.8	99.7	99.9	99.7	99.7	99.8
Mg/Si	0.62	0.71	0.62	0.70	0.20	0.26
Al/Si	0.14	0.22	0.14	0.21	0.28	0.61
Fe/Si	0.13	0.13	0.34	0.36	0.06	0.05

XRS: The XRS measures fluorescent X-rays emitted from the planet's surface due to excitation by solar X-rays [3]. Because the flyby closest approach is on the planet's night side, the XRS is expected to see sunlit Mercury (and hence detect fluorescence signals) for only a short time (<20 minutes) on the outgoing part of the flyby trajectory. To estimate whether a useful signal will be obtained during the flyby, we used a typical "quiet" (non-flaring) solar spectrum to calculate theoretical X-ray fluorescence spectra [4] for our composition models. The solar spectrum was based on fits to spectra observed by the XRS solar monitor on 1-2 August, 2007, scaled to the flux expected at Mercury's orbit. Model fluorescence spectra were calculated with the assumption that sunlit Mercury fills the XRS 12° field of view for 5 minutes during the flyby and included the detector response, observed detector background, and random statistical noise. Fitting of the spectra indicates that the predicted absolute fluxes of Mg, Al, and Si fluorescent X-rays are sufficient to distinguish an ultramafic from a feldspar-rich composition (2-σ

error ellipses on Fig. 1A). Should a moderate to large solar flare fortuitously occur during the flyby, we would expect to see spectra of much higher quality, including the possible detection of S, K, Ca, and Fe, perhaps allowing us to distinguish Fe-rich models (3 and 4) from Fe-poor models (1, 2, 5, and 6).

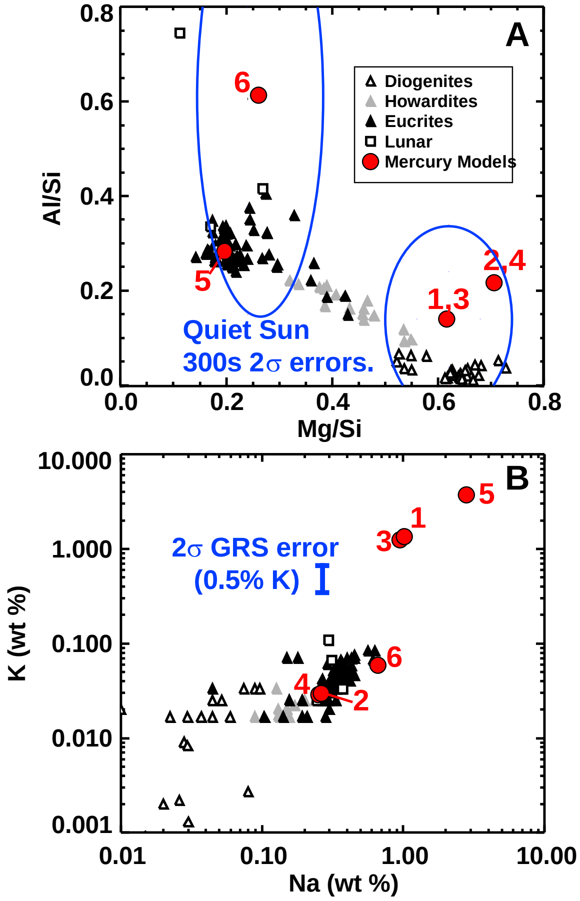

Figure 1. Model compositions compared to achondritic and lunar meteorites (from the database of [5]). Blue ellipses on A are expected 2-σ errors for 5-minute quiet-Sun observations of Mercury model 1 and 6 compositions. Blue error bar on B indicates expected GRS sensitivity for 10-minute integration with 0.5% K (Na will not be detectable).

GRNS: The Gamma-Ray Spectrometer (GRS) sensor on GRNS is a 50 mm-diameter by 50-mm-long high-purity n-type Ge detector surrounded by a charged particle anti-coincidence shield of BC454 boron-loaded plastic [6]. The GRS is sensitive to photons in the energy range 0.1-10 MeV. The total GRS viewing time below 1000 km during the flyby will be no more than ~11 minutes, during which time the spacecraft boresight will be pointing mostly away from nadir, which will severely limit element detection, but the count rate from the gamma-ray line at 1461 keV due to ^{40}K may be sufficient to discriminate between several of the models in Table 1. Potassium is a valuable diagnostic of volatile enrichments or depletions (Fig. 1B). Figure 2 shows a 10-minute Mars Odyssey Gamma-Ray Spectrometer (GRS) spectrum collected over a region of Mars with a high (0.5%) K concentration. The count rate was 5.4 cpm, and the 1–σ uncertainty is 22% [7]. Taking into account the many differences between the two detector systems and observing conditions, the K counting rate at Mercury should be comparable for a similar composition. As indicated in Fig. 1B, even this level of detection for K will distinguish between compositions similar to achondritic and lunar meteorites from those that are more mafic or feldspar rich.

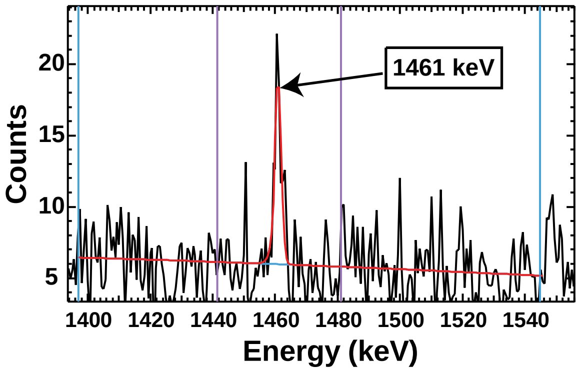

Figure 2. 10-minute Mars Odyssey GRS spectrum collected over a region with 0.5% K.

Conclusions/Predictions: Even given the non-ideal flyby geometry and the short integration times, measurements by the MESSENGER XRS and GRNS should allow discrimination among models for the composition of Mercury's crust (e.g., ultramafic vs. feldspathic, volatile-rich vs. volatile-poor) and, by extension, models for the formation of Mercury (e.g., magma ocean, impact devolatilization). Barring a fortuitously timed solar flare, we can probably not determine whether the crust of Mercury is Fe-rich or Fe-poor until the orbital phase of the mission.

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