THE DISTRIBUTION OF IRON ON THE SURFACE OF MERCURY FROM MESSENGER X-RAY SPECTROMETER MEASUREMENTS. Shoshana Z. Weider (sweider@ciw.edu)[1], Larry R. Nittler[1], Richard D. Starr[2], and Sean C. Solomon[3]. [1]Department of Terrestrial Magnetism, Carnegie Instiution of Washington, Washington, DC 20015, USA. [2]Physics Department, The Catholic University of America, Washington, DC 20064, USA. [3]Lahmont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

Introduction: The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft has been orbiting the innermost planet since March 2011. The onboard X-Ray Spectrometer (XRS) has since been gathering fluorescent X-ray spectra during solar flare periods, from which compositional information for the surface of Mercury has been derived. Mercury's crust is Mg-rich, but Al- and Ca-poor, compared with typical terrestrial and lunar rocks, and it has a high abundance of S contained mainly in sulfide minerals [1,2].

Iron on Mercury: It has long been known that Mercury's high uncompressed density is a result of a high metal-to-silicate ratio. Several hypotheses account for Mercury's unusually large fractional core mass either by accretion from precursor materials that were similarly enriched in metal phases [*e.g.,* 3], or through an early high-temperature event that stripped away much of its silicate portion, such as a giant impact [4] or evaporation in a hot solar nebula [5]. The absence of a 1 µm absorption feature in reflectance spectra of the surface indicates that there is less than ~6 wt% FeO contained within mafic silicates. It had been proposed [6,7] that Fe is instead present as Fe,Ti oxides such as ilmenite, but this idea was ruled out by orbital XRS and Gamma-Ray Spectrometer (GRS) measurements [1,8] that show the surface has low abundances of these elements (<1 wt% Ti; ~1.5 wt% Fe). More recent XRS measurements with better spatial resolution have shown that large expanses of volcanic plains in the northern lowlands and Caloris basin differ, in the concentration of Mg, Al, S, and Ca, from the older terrains that surround them [2]. By mapping the abundance of Fe over much of the surface it is possible to investigate if Fe shows similar, or different, variations.

Estimating Fe with XRS: Fe X-ray fluorescence from Mercury's surface requires energetic incident X-rays that are released from the Sun only during the strongest solar flares. It has therefore taken longer than for the lower-mass elements to acquire sufficient data to confidently estimate the abundance of Fe across the surface. We present data from ~50 solar flare periods from which Fe estimates can be made.

Results: Fe/Si (mass ratio) estimates are obtained through forward modeling [1,2] of the spectra from each of the XRS observations. The data do not show a dependency on flare plasma temperature. However, as shown in Figure 1, the derived Fe/Si ratios were found generally to increase with the phase angle at which the observation was made, albeit with substantial scatter. Increased Fe/Si from measurements made at high phase angles are predicted for non-flat surfaces due to shadowing [*e.g.,* 9]. However, published models of this phase angle effect do not directly apply to the XRS observations. We thus empirically corrected the data by subtracting the best-fit correlation line and renormalizing to give a mean Fe/Si of 0.04 (~1 wt% Fe). Determining the correct offset to use in our correction for phase angle is difficult, and therefore the absolute ratios may not be accurate. However, relative differences between regions are more robust. The offset value we have chosen is consistent with the lowest-phase-angle (<85°) data, which should be least affected by the shadowing. This value is half that reported from GRS measurements [8], but is consistent with the low Fe abundance upper limit given by electron-induced XRF data [10]. The XRS–GRS difference may indicate either that the southern hemisphere has less Fe than the northern regions sampled by GRS, or a systematic uncertainty in one or both of the datasets (*e.g.*, the XRS abundances may be systematically underestimated due to limitations in the fluorescence model we use in our analysis, depending on the chemical form of Fe [11]).

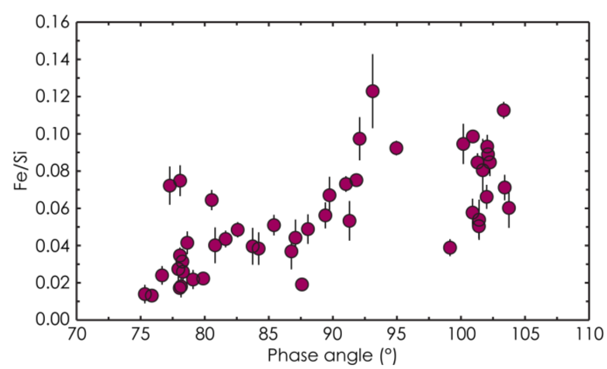

Figure 1. Fe/Si estimates derived from XRS data versus the mean phase angle for each of the ~50 observations. The linear correlation coefficient for these data has a value of 0.74.

A map of Fe/Si constructed from the XRS results, corrected for the phase angle effect, is shown in Figure 2. The spatial resolution varies across the surface, depending on both the spacecraft altitude at the time of observation and integration period, with smaller footprints generally located in the northern hemisphere. We divided the surface into 0.25°×0.25° pixels and assigned to each the average Fe/Si value of all footprints that overlap with it. Only pixels with at least two overlapping footprints are included in Figure 2, resulting in the sparse northern coverage.

Abundance estimates for Ti, Cr, and Mn from several of these flare spectra are in general agreement with previous results [1]. Many of the strongest spectra also indicate the presence of Ni.

Discussion: The map of corrected Fe/Si (Fig. 2) illustrates large-scale variations in the surface Fe abundance of Mercury's southern hemisphere. The large-scale regional variations do not relate to the distribution of smooth plains units [12], but there may be some relation to surface elevation and terrain type. The high-Fe region encompasses a large expanse of high-standing terrain, whereas the neighboring low-Fe region contains a higher proportion of low-lying terrain. There may also be some correlation with spectral parameters from Mercury Atmospheric and Surface Composition Spectrometer (MASCS) data [13].

The absence of a correlation between Fe/Si and Mg/Si indicates that Fe is unlikely to be substituting for Mg within mafic silicates. There are possible Fe/Si–S/Si and Fe/Si–Ca/Si correlations, but these are less apparent than previously noted [14]. The lack of obvious relationships between Fe and the other elements may be a function of observing such large regions, or it could be indicative of native Fe in metallic form, perhaps delivered exogeneously. Such a source may also account for the detectable levels of Ni.

The accurate determination of the abundance of Fe on Mercury's surface improves our understanding of the planet's bulk composition and interior structure, and can be used in the analysis of other MESSENGER datasets [*e.g.,* 15]. Moreover, knowledge of the surface Fe abundance aids in the estimation of the oxygen fugacity during planet formation, an important constraint on the partitioning behaviour of several elements during global differentiation [*e.g.,* 16,17].

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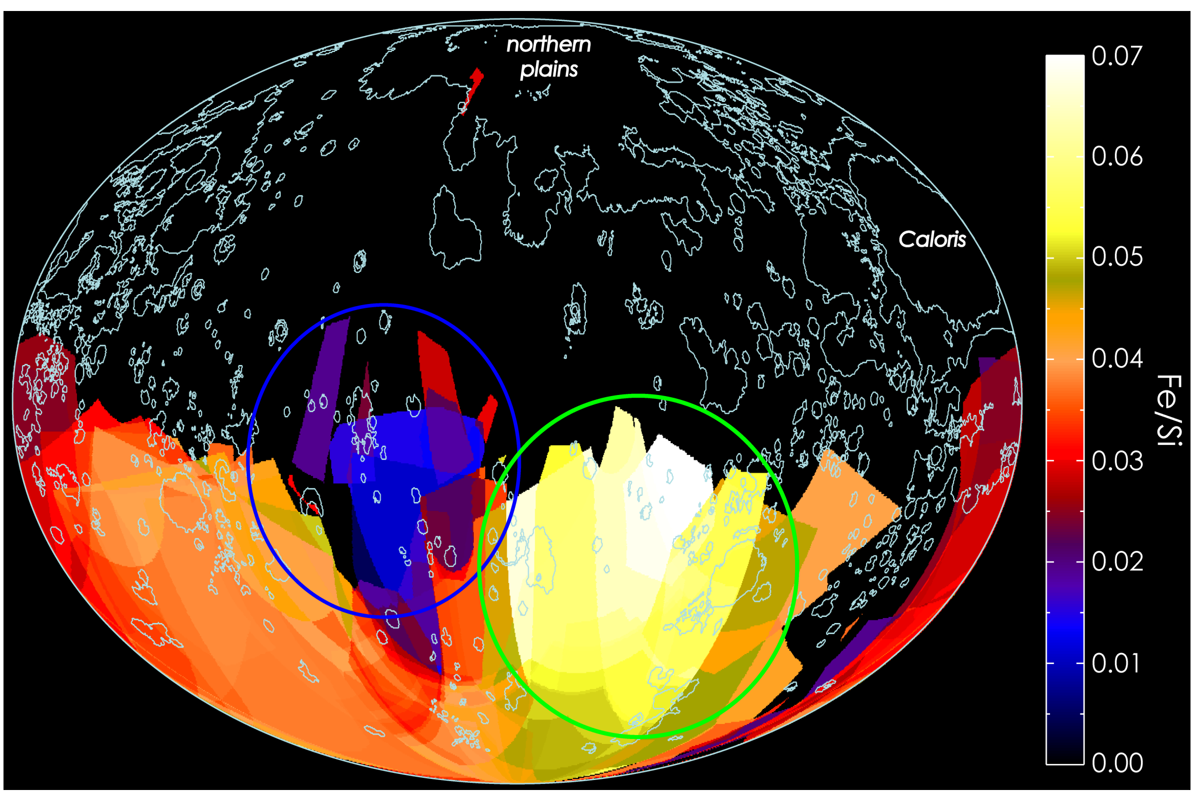

Figure 2. Map of Fe/Si, corrected for phase angle, on the surface of Mercury (the Mollweide projection is centered on 0° longitude) derived from ~50 XRS measurements. Smooth plains deposits [12] are outlined in cyan. The two circles denote regions of relatively high (green) and low (blue) Fe contents.