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Mercury's Surface Composition: Early Results from the MESSENGER X-Ray Spectrometer

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Abstract

X-Ray Spectrometer (XRS) data acquired during both solar flare and quiescent solar conditions indicate that Mercury's surface is significantly richer in Mg and poorer in Al and Ca than both lunar crustal rocks and terrestrial basalts. The derived Mg/Si, Al/Si, and Ca/Si ratios lie within the range of terrestrial ultramafic rocks. Analysis of flare spectra also indicate low total concentrations of Ti (<1 wt. %) and Fe (<~5 wt. %) and a surprisingly high S abundance (~3 wt. %) in surface materials on Mercury.

1. Introduction

The MESSENGER spacecraft was launched in August 2004. Following a nearly seven-year cruise, MESSENGER entered into Mercury orbit on 18 March 2011, becoming the first spacecraft to orbit Mercury and the first mission to the innermost planet in our solar system since the Mariner 10 flybys of the mid 1970s [1]. The XRS began observations on 23 March 2011 and has observed X-ray fluorescence from the surface of the planet during both "quiet" Sun and flaring conditions whenever a sunlit portion of Mercury has been within the XRS field of view. XRS can detect the characteristic X-rays of Mg, Al, and Si even during quiet-Sun conditions, but solar flares are required to produce measureable signals from the higher-Z elements S, Ca, Ti, and Fe [2]. The XRS is sensitive to material within ~100 μm of the planetary surface.

2. XRS Observations

Late in 2010, the Sun recovered from one of the deepest solar minima of the last 100 years and is now exhibiting X-ray emissions 1 to 2 orders of magnitude greater than in 2008 and 2009, just in time for XRS orbital observations. An example of an early XRS measurement during flare conditions is shown in Figure 1. Emissions from Mg, Al, Si, S, Ca, and Fe are present. Line energies are shown by the vertical dashed lines. The spectra in Figure 1 were accumulated over 450 s, and background has been subtracted. The measurement (sum of spectra from 3 planet-facing detectors) is indicated by the light gray lines. Fits to the data and the impact of varying S, Ti, and Fe are indicated by the solid and dashed black lines.

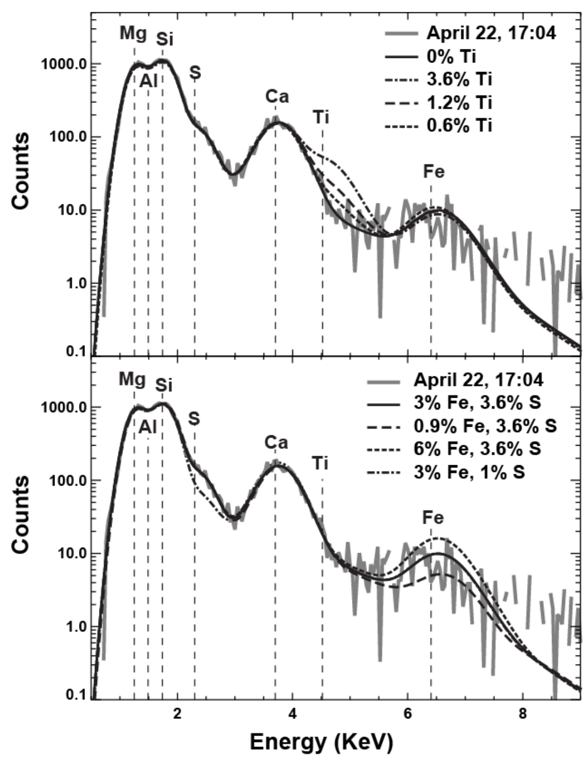

Figure 1: XRS measurement of Mercury surface X-ray fluorescence during a flare on 22 April 2011.

3. Discussion

One of the more important questions underlying our study of terrestrial planet formation is the origin of Mercury's unusually high density and metal/silicate ratio [3]. One possible explanation, due mostly to Wetherill [4] and Benz et al. [5], is that a large impact, occurring after global differentiation, ripped away Mercury's earliest crust and much of its mantle. XRS measurements of the Mg/Si, Al/Si, and Ca/Si elemental ratios indicate a relatively low abundance of plagioclase feldspar, perhaps consistent with this model. Other models, which emphasize Mercury's close proximity to the Sun, suggest that it condensed at very high temperatures and formed from highly reduced material similar to enstatite chondrites [3, 6, 7]. Interestingly, melting experiments conducted on enstatite chondrite powders [7] produced a composition with Mg/Si, Al/Si, Ca/Si, and S/Si elemental ratios consistent with those measured by the MESSENGER XRS.

The effect of varying the S, Ti, and Fe abundances on fits to XRS spectral data is shown in Fig. 1. The plot highlights the robustness of the fits and their sensitivity to these elements. The high S abundance is reproduced in nearly all such XRS measurements and is consistent with the enstatite chondrite model [7]. Fe and Ti abundance are low, though even at ~3%, the Fe abundance is higher than for the enstatite chondrite model. The low values for Fe and Ti, which like those for S are seen in multiple measurements, would appear to be inconsistent with the suggestion of high surface abundances of ilmenite [8-10], and also suggest that these elements are not primarily responsible for the thermal neutron absorption observed during MESSENGER's Mercury flybys [11].

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