

ELEMENTAL COMPOSITION OF 433 EROS: NEW CALIBRATION OF THE NEAR-SHOEMAKER XRS DATA.

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Introduction: We present relative elemental abundances for six elements (Mg, Al, Si, S, Ca, Fe) in the surface layer of 433 Eros, derived from a new analysis of the solar-induced fluorescence measured by the NEAR-Shoemaker X-ray Spectrometer (XRS). XRS-derived elemental abundances have been presented before [1,2]. However, calibration of XRS data depends critically on knowledge of the incident solar spectrum, which varies greatly on time scales of seconds to minutes. Unfortunately, the gas solar monitor carried by NEAR was inadequately calibrated prior to launch. The previously published XRS results were based partly on broadband measurements by the Earth-orbiting GOES-8 (Geostationary Operational Environmental Satellites) X-ray detectors and partly on a preliminary solar monitor calibration carried out by the present authors. The new solar monitor calibration is based on a more recent set of physical models of the solar spectrum at various temperatures, an improved fitting procedure, analysis of a large number of flight spectra, and comparison with concurrent data from the GOES X-ray detectors. In addition, the new analysis includes data from three solar flares not considered in earlier papers.

Characterizing the Solar X-ray Spectra: Because of the limited energy resolution of the gas solar monitor, we could not derive the solar spectrum from our data alone. Instead, we relied on theoretical models of the solar X-ray spectrum. Isothermal models of the solar X-ray spectrum were published by Mewe *et al.* (1985) [3]. A more recent set of models, generated by the “CHIANTI” code [4,5] is now available. Updated versions of CHIANTI-generated spectra (CHIANTI v. 5.0 pre-release) were obtained by the author from K. Phillips and E. Landi (personal communication, 2004). The flares observed by NEAR’s gas solar monitor were modelled with a two-temperature fit, since in general solar flares are multi-thermal. The detector response to isothermal spectra at many temperatures was modelled and then combinations of isothermal spectra were tested to find the best fits to the solar monitor data. The “CHIANTI” models usually produce a very good fit to the data at energies below about 2.5 keV, whereas above 5 keV the Mewe *et al.* models match the data more successfully. At any given temperature, the CHIANTI code generally produces more flux in the 6 keV solar emission lines and less in the 8 keV emission lines than the Mewe *et al.* model. The majority of the flux in both of these complexes is emitted by highly-ionized Fe in the solar corona.

Two sets of solar spectral models were used in this analysis. The first was a composite model in which, at each temperature, the solar spectrum was generated by the updated CHIANTI code below 6 keV and by the Mewe *et al.* code above 6 keV. The second used the CHIANTI code throughout the 1–10 keV energy range of the detector. Fits to the gas solar monitor output using the CHIANTI-only models have consis-

tently higher χ^2 values than those using the composite model, but have the advantage of theoretical consistency across the entire spectrum.

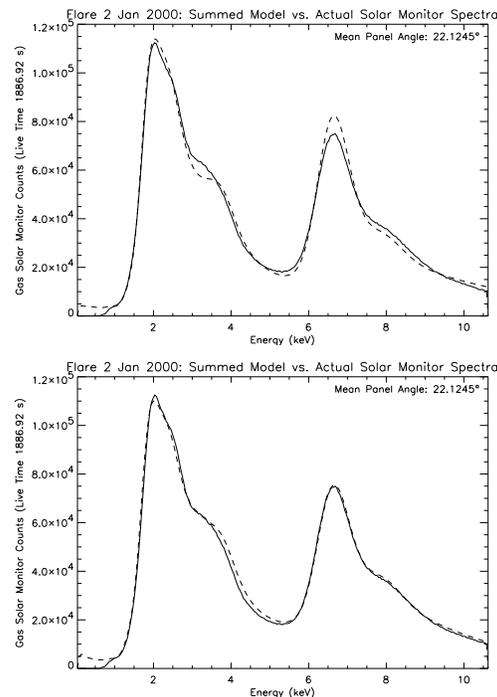


Figure 1: Actual and Modelled Gas Solar Monitor Output. Solid lines are the sum of 41 gas solar monitor spectra from the 2 January 2001 solar flare; dashed lines are the sum of the 41 two-temperature models using as input either CHIANTI theoretical solar spectra (top) or the “composite” CHIANTI + Mewe *et al.* model (bottom).

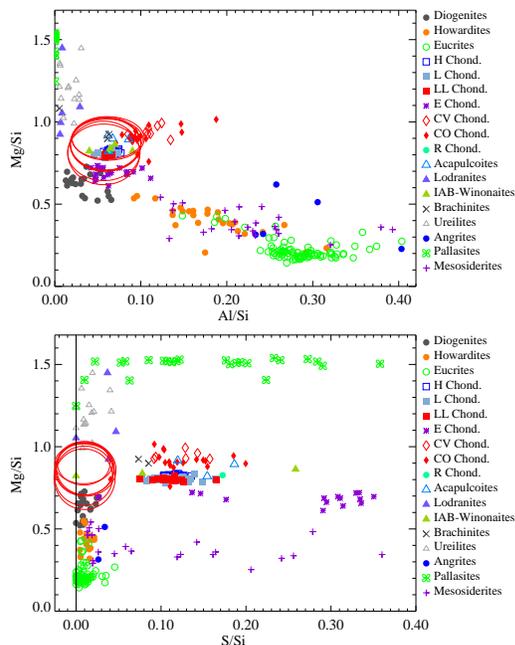
Post-launch calibration of the NEAR solar monitor: Also at issue is the effect of the graded filter [6] on the sensitivity of the gas solar monitor as a function of energy and solar incidence angle. Due to inadequate pre-launch calibration, uncertainties in the thicknesses of the various filter layers and the sizes of the pinholes in the Delrin and Be layers propagate into substantial systematic uncertainties in the solar spectrum and, therefore, in the geochemical interpretation of the asteroid fluorescence measurements. We have addressed this problem by applying various graded-filter models to a large number (160) of solar monitor flare spectra, solving for the solar spectrum with either the composite or the CHIANTI-only spectral models, and, when applicable, applying the derived spectra to the transfer functions [7] of the two GOES-8 channels and com-

paring the results with the actual GOES-8 data from the same times. Many possible graded-filter configurations performed poorly and were eliminated. Seven models—four (Models 1–4) with the composite spectra and three (Models 5–7) with the revised CHIANTI-coronal spectra—have been chosen either on the basis of good chi-squared values or close matches to the GOES channel ratios to be applied to the analysis of the fluorescence data.

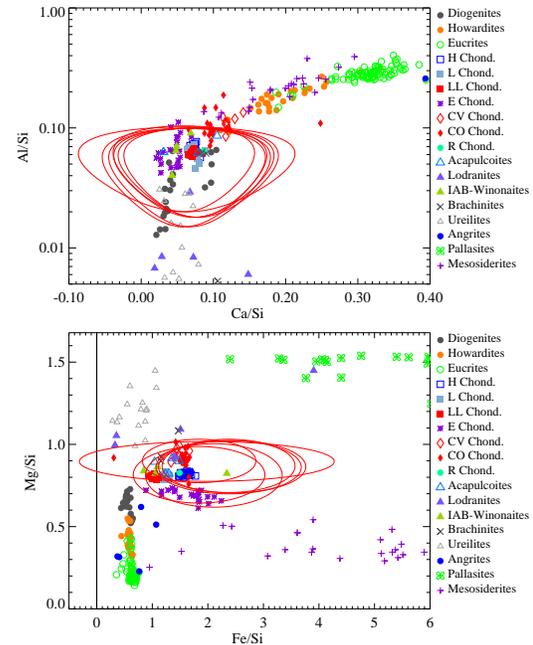
Geochemical Results: Fluorescence data from eight solar flares were analyzed using Models 1–7. The resulting eight-flare averages have been plotted as Figure 2. Each ellipse represents the 1- σ uncertainty in the eight-flare average for one solar model. Thus, the remaining systematic uncertainties in the composition of Eros are represented by the differences among the ellipses.

The compositions presented here are essentially similar to the “Best Eros” values published in 2001 [1], but are based on better estimates of the incident solar spectra. We now therefore have a much better understanding of how our results are and are not vulnerable to the systematic uncertainties in the solar calibration.

In all seven of the solar models chosen for this study, the averaged Mg/Si, Al/Si, and Ca/Si ratios are consistent with an ordinary chondritic composition. The new Fe/Si composition is slightly higher than the 2001 value, although it is still within 1- σ of many ordinary chondrites. The major result that the surface S/Si of Eros is sub-chondritic has proven robust under the new calibration.



Figures 2a and 2b: XRS elemental ratios for 433 Eros derived using solar models 1–7. Each error ellipse represents the average of the same eight-flare fluorescence data as analyzed with a different solar model. Meteorite compositions [7] are plotted for context.



Figures 2c and 2d: XRS elemental ratios for 433 Eros derived using solar models 1–7.

The simplest explanation for the observed composition as a whole is that the bulk composition of 433 Eros is primitive and that the observed departures from chondritic S/Si and Fe/Si are caused by surface effects. Because of the volatility of sulfur, it can readily be mobilized by “space weathering” processes such as impact volatilization and sputtering, leading to its depletion in the surface layer.

The NEAR GRS (gamma-ray spectrometer)- derived Fe/Si ratio of 0.8 ± 0.3 [9] is considerably lower than the XRS derived Fe/Si. The GRS samples to depths of tens of centimeters, whereas the X-rays only sample to hundreds of microns. This suggests that the elevated Fe/Si is a surface phenomenon. At present it is unclear whether the observed Fe/Si may have been inflated by phase-angle effects [10] or whether the Fe in the surface layer may in fact have been enhanced by size sorting in the regolith (the “Brazil-nut” effect [11]).

References: [1] Nittler L.R. *et al.* (2001) *Meteoritics & Planet. Sci.* 36, 1673-1695. [2] Trombka J.I. *et al.* (2000) *Science* 289, 2101-2104. [3] Mewe *et al.* (1985) *Astron. Astrophys. Suppl.* 62, 197-254. [4] Dere, K.P. *et al.* (1997) *A&AS* 125, 149-173. [5] Young, P.R. *et al.* (2003) *ApJSS* 144, 135-152. [6] Clark, P.E. *et al.* (1995) *LPS XXVI*, pp. 253-254. [7] Schwartz, R. (1998), NASA Solar Data Analysis Center. [8] Nittler, L.R. *et al.* (2004). *Antarctic Meteorite Research* 17, 233-253. [9] Evans, L. G. *et al.* (2001). *Meteoritics & Planet. Sci.* 36, 1639-1660. [10] Okada, T. (2004). *LPS XXXV*, abstract 1927. [11] Hong, D. C. *et al.* (2001). *Phys. Rev. Lett.*, 86, 3423