OBSERVATIONS OF SOLAR WIND NI AND FE

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ABSTRACT

We report the first measurements of solar wind Ni/Fe elemental and Ni isotopic ratios. The data were obtained from the SOHO/CELIAS/MTOF sensor in the typical interstream solar wind. We compare our value with the meteoritic ratio, which is believed to be a reliable reference for the solar system and for the outer convective zone, since neither element is volatile and no meteoritic fractionation is expected. Similarly, meteoritic and terrestrial isotopic nickel abundances agree and should be a reliable reference for the solar isotopic composition. We find, in support of this expectation, that the solar wind elemental Ni/Fe ratio and the isotopic composition of solar wind nickel are in good agreement with the meteoritic benchmark, giving further evidence for the faithful representation of low-FIP elemental abundances and for the absence of substantial isotopic fractionation effects for heavy elements in the solar wind.

1. INTRODUCTION

Observations of rare elements and isotopes in the solar wind are important because they help determine how neutral atoms in the relatively cool photosphere become the highly ionized atoms in the corona and then ultimately the supersonic plasma we call the solar wind. The results will also help establish the isotopic composition of the primordial solar nebula.

The good agreements of photospheric and meteoritic abundances [e.g., *Asplund et al*., 2005] for a wide range of refractory and moderately volatile elements are consistent with a common origin of solar and planetary matter. The Sun is considered to contain a largely unfractionated sample of matter from the protosolar nebula. The solar wind composition is expected to be that of the solar outer convective zone, differing only as a result of possible fractionation processes.

In this paper we present measurements of the Fe/Ni elemental ratio and also the Ni isotopic distribution. Elemental composition is subject to the well-known fractionation process ordered by the first ionization potential (FIP), reflecting the separation of neutrals and ions in the upper chromosphere. Fe and Ni are not expected to be affected by this fractionation since they are both low-FIP elements (7.9 eV and 7.6 eV, respectively). Isotopic composition is not subject to this fractionation process.

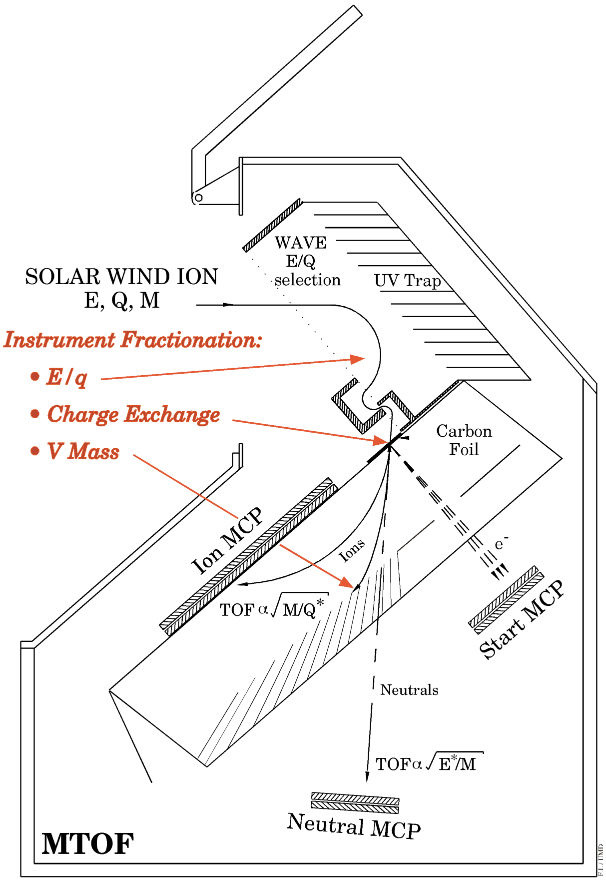

Figure 1. CELIAS MTOF Schematic

2. INSTRUMENTATION

The Mass Time-of-Flight Spectrometer (MTOF) is part of the Charge, Element, Isotope Analysis System (CELIAS) Investigation on the Solar Heliospheric Observatory (SOHO) spacecraft. MTOF has unprecedented mass resolution and collection power for solar wind composition studies, and can identify rare elements and isotopes that were previously not resolvable from more abundant neighboring species, or were not previously observable at all. The Proton Monitor (PM) is an auxiliary unit designed to measure the solar wind proton bulk speed, density and thermal speed [*Ipavich et al.*, 1998]. Both MTOF and the PM are housed within a common structure that also contains the low voltage power converter, the high voltage power supplies, the analog electronics, and the digital electronics.

The MTOF sensor is illustrated in Fig. 1. Solar wind ions enter through an energy/charge filter, the Wide-Angle, Variable Energy/charge (WAVE) deflection system. The WAVE has a very large bandwidth (about a factor of 4 vs. typically 5% in traditional solar wind instruments), allowing the entire solar wind energy/charge range to be covered in just a few voltage steps. The ions then pass through a thin carbon foil, leaving them with a charge state $q*$, independent of their charge state in the solar wind. They then enter a region where a linear electric field deflects ions with $q* > 0$ to the Ion microchannel plate. For an ion of mass M, the time of flight in this region is $\propto \sqrt{(M/q)}$. Importantly, an ion's time-of-flight through this region is *independent* of its initial energy or angle. Sub-nanosecond TOF measurements then translate into mass resolutions of a fraction of an AMU. The MTOF sensor is further described in *Ipavich et al.*, (2001).

3. OBSERVATIONS

Fig. 2 shows a mass spectrum obtained from MTOF during an uneventful 3-day period during which the solar wind speed was approximately 400 km/s. The counts displayed are uncorrected for instrument efficiencies. The un-colored peaks represent elements

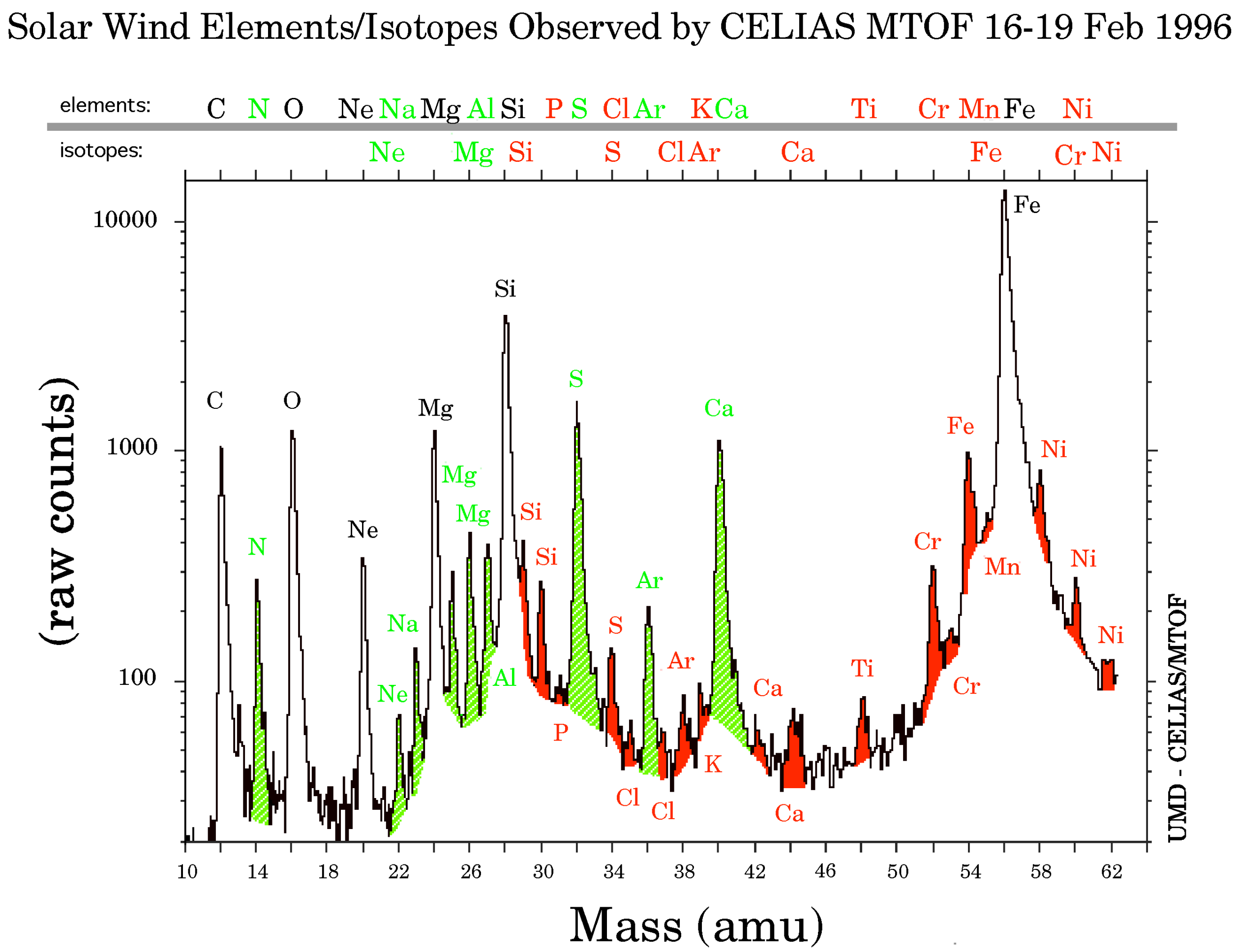

Figure 2. Solar wind elements and isotopes observed by MTOF during a 3-day period in Feb 1996.

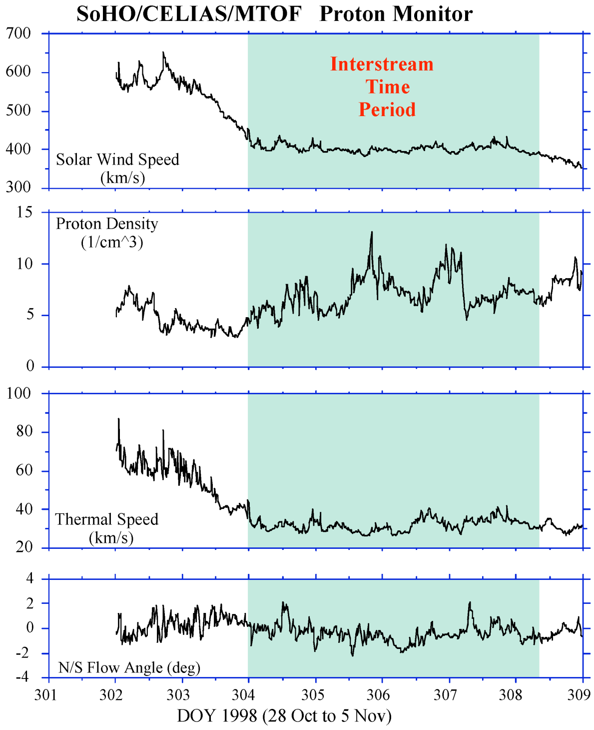

Figure 3. Solar wind parameters during the second analyzed time period.

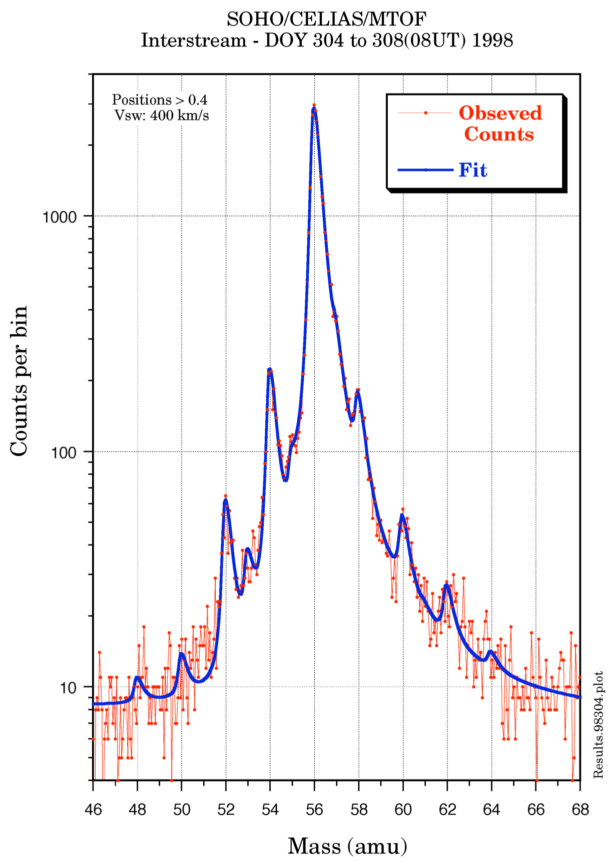

Figure 4. Mass spectrum integrated over the shaded time interval indicated in Fig. 3.

commonly observed by in-situ solar wind experiments; the elements and isotopes for which MTOF has provided the first in situ spacecraft solar wind observations are colored in red; and the elements and isotopes that are shaded green have been observed, but not routinely, by solar wind experiments.

Solar wind parameters during another nondescript, interstream time period are displayed in Fig. 3. The shaded region indicates the time interval during which the mass spectrum shown in Fig. 4 was accumulated.

4. RESULTS

The mass spectra for the two time periods were fit using a maximum likelihood technique using a 24-parameter model function as described in *Ipavich et al*. (2001). A smooth background was subtracted from the resulting fits to reveal the uncorrected integral count for each desired mass peak. These raw values were then corrected for instrument efficiency effects by relying on a comprehensive instrument model computer program. This program, based on calibration data, accounts for such effects as transmission through the deflection analyzer, the fraction of each ion species that emerges from the carbon foil with charge +1, and ion ray-tracing through the mass spectrometer. The efficiency correction for the Fe/Ni elemental ratio was typically about 30%, and for the Ni isotopes about 5%. The overall derived uncertainties include the effects of counting statistics as well as systematic uncertainty (for example, the solar wind speed is assumed to have a 5% error).

The results for the Ni/Fe elemental abundance ratio for the 2 analyzed time periods are listed in Table 1. The quantity "SW combined" represents the weighted average of the 2 solar wind samples. We derived the elemental ratio from the efficiency-corrected abundances for the dominant isotopes Fe^{56} and Ni^{58}, corrected for the presence of other isotopes by using

Table 1. Ni/Fe Elemental Ratios

Ni/Fe Ratios		
	Raw Value	Efficiency-Corrected
SW d47-50, 1996	0.041	0.055 ± 0.004
SW d304-308, 1998	0.042	0.053 ± 0.005
SW combined		**0.054 ± 0.004**
Meteoritic[(a)]		**0.055 ± 0.005**
Photospheric[(a)]		**0.060 ± 0.009**
SEPs[(b)]		**0.048 ± 0.005**
[(a)] *Asplund et al*., 2005		
[(b)] *Reames*, 1998		

measured terrestrial isotopic values for these elements. Table 1 indicates that the solar wind Fe/Ni ratio is in excellent agreement with meteoritic, photospheric and Solar Energetic particle (SEP) values. There is no evidence of relative fractionation in any of these four samples of solar system material. The Ni/Fe ratios are presented graphically in Fig. 5.

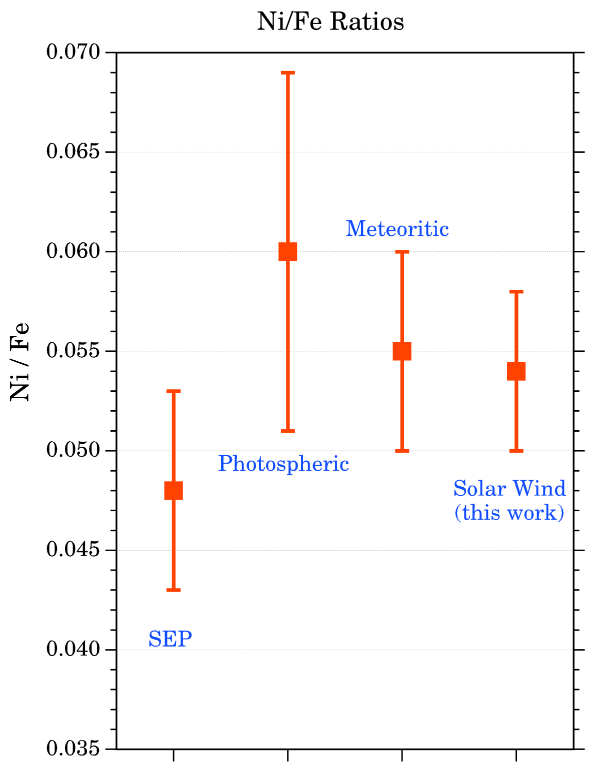

Figure 5. Ni/Fe elemental ratios observed in different samples of solar system material.

The isotopic distribution of Ni^{58}, Ni^{60} and Ni^{62} are listed in Table 2. "SW combined" again represents the weighted average of the 2 solar wind samples. As expected there is no evidence of fractionation of the Ni isotopes in the solar wind as compared to terrestrial values.

Table 2. Ni Isotopic Distribution

	Ni Isotopes		
	Ni^{58}	Ni^{60}	Ni^{62}
SW d47-50, 1996	0.70±0.03	0.25±0.03	0.05±0.02
SW d304-308, 1998	0.72±0.04	0.21±0.04	0.07±0.04
SW combined	**0.71±0.03**	**0.24±0.03**	**0.05±0.02**
Terrestrial	**0.695**	**0.268**	**0.037**

ACKNOWLEDGMENTS

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