Detection of Pickup- and Sputter Ions by Experiment SMS on the WIND-S/C After a Mercury Conjunction

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Abstract

Planet Mercury was located about 43° west of the Earth-Sun line at $\sim$ 0.46 AU distance from the Sun on 20–22 April 1998. A proton flare appeared at the Sun on 20 April (W 90°, S 47°, 9:38–11:19 UT) and Mercury was hit by energetic protons and α-particles which released probably pickup and sputter ions from the planetary surface. The WIND/SC, located in the libration point L1 in April 1998, was connected via the interplanetary magnetic field with Mercury. The SMS-experiment detected in the energy/charge ranges 0.5–9.5 and 6.5–225 keV/e singly charged heavy ions above the solar cosmic ray background which we interprete partly as Mercury ions. However a contribution of pickup ions from the dust located near the Sun cannot be excluded.

1 Introduction:

A remote sensing method is described which allows to collect information on the surface composition of planet Mercury. A very special interplanetary condition was necessary for such a measurement: Mercury had an inferior conjunction on 6 April 1998. About 2 weeks later on 20 April appeared an energetic particle flare at the Sun (W 90° S 43°) and energetic solar protons and α-particles reached the surface of planet Mercury. They produced pickup und sputter ions which escaped from the planet and gained then energy from the pickup process and probably also in the interplanetary space from a small shock. The detection of pickup ions has been used earlier as a method to study the composition of the inerstellar medium (Möbius et al., 1985; Gloeckler et al., 1993; Geiss et al., 1994) and of the lunar surface (Hilchenbach et al., 1991; Kirsch et al., 1998; Mall et al., 1998). Grünwaldt et al. (1997) detected for the first time C and O-ions from planet Venus during an inferior conjunction of the planet.

2 Instrumentation:

For our study measurements of the SMS experiment (S = Solar Wind Ion Composition Sensor [SWICS], M = high resolution sensor MASS, S = Suprathermal Ion Compososition Sensor [STICS]) as described by Gloeckler et al. (1995) are used. Especially the double coincidences of the STICS sensor (E/e = 6.5–225 kev/e) are important for our study because the energies of singly charged heavy ions are insufficient for triple coincidences (E/e $>$ 30–225 keV/e). Thus the full mass resolution of the STICS sensor cannot be used. However a special program has been developed for the data analysis which considers the energy loss of singly charged heavy ions in the carbon foil of the STICS-sensor (Cierpka et al., 1998). The SWICS sensor (0.5–30 keV/e) would have been the ideal sensor. But due to a technical defect it cannot resolve the higher ion masses. The MASS sensor delivers high resolution ion measurements however only in the E/e range 0.5–9.5 keV/e.

3 Method of Detection:

The X-ray and solar proton flare on 20 April 1998 at W 90° and S 43° (9:38 UT) was measured by the GOES-9-satellite (Solar Geophysical Data 1998), as well as by other experiments on WIND (Reames et al., 1998) and GEOTAIL. Protons were accelerated up to energies $>$ 110 MeV and are therefore able to hit the surface of Mercury. The particle event was also characterised by high Fe/O , S/O and Si/O ratios. The expected pickup and sputter ions are singly charged and can therefore be distinguished from the multiply charged solar wind ions. Galvin (1997) and Gloeckler et al. (1999) have shown that solar wind ions have mostly mass/charge ratios < 10. Only in rare cases low charged Fe-ions can appear between 10 and 20 amu/charge. A further possibility to recognise pickup ions at solar wind energies is to compare their composition with the standard composition of the solar wind as compiled e.g., by Chotoo (1998), see also Reames et al. (1998). Compared to the oxygen content of the slow solar wind other elements have the relative abundance: C = 0.72, N = 0.129, Ne = 0.17, Mg = 0.16, Si = 0.19, S = 0.05, Fe = 0.12 and Cl $\sim$ 0.24, K $\sim$ 0.55, Ca $\sim$ 10.6, Ti $\sim$ 0.34. Our present knowledges of planet Mercury are based on the Mariner 10 (e.g., Eraker & Simpson, 1986) mission which had altogether 3 encounters with the planet and on spectroscopic observations from the Earth (Potter & Morgan, 1986; Sprague et al., 1990). High intensity spikes of electrons up to 600 keV were detected during the encounter of Mariner 10 with planet Mercury as well as an internal magnetic field of about 100 nT (Eraker & Simpson, 1986). Recently Grande (1997) published an actual overview on the magnetosphere of Mercury. The appoximate range for substorm like particle acceleration reaches up to $\sim$ 8 Mercury radii. The subsolar distance of the magnetopause is at $\sim$ 1.6 RM. It is presently not known whether an enhanced solar wind speed can push the magnetopause down to the planetary surface and generate pickup ions from the surface since a counter magnetic field could be induced. But one can assume that the 10–100 MeV protons and α-particles of the solar particle event reached the whole sunlit hemisphere and generated pickup and sputter ions. Measurements of the sputtering yields obtained e.g., by Johnson et al. (1984), Johnson (1996), Limburg (1998) in the energy range < 1 MeV revealed that 10–100 % of the primary particle generate sputter ions. For a quantitative understanding of the sputtering process model calculations are necessary which should consider the flux and energy spectra of the solar particles. The sputtering process must be studied experimentally for various target materials and proton energies up to > 100 MeV. It is expected that Mercury and the Earth moon have a very similar surface and exospheric composition. A. Stern (preprint 1997) has compiled for Mercury the already identified elements: H, He, Na, K. Upper limits were found for O and Ar. It was also found that the Mercury/Moon ratio for Na is $\sim$ 600 and that for K $\sim$ 30. Identified are the following lunar ions: C, N, O, Ne, Na, Mg, Al, Si, and P (Mall et al., 1998).

4 Observations of Mercury ions:

Fig. 1 shows an overview picture of ion measurements with STICS (2–40 amu/e), together with solar wind (courtesy K.W. Ogilvie et al.) and magnetic field mesaurements (courtesy R.P. Lepping et al.) from 1998 doy 106–115. An unusual accumulation of singly charged heavy ions can be seen on doy 110–112 which is not caused by high speed solar wind streams or high magnetic field magnitudes. Since the heavy ions are associated with the solar particle event we interprete them as pickup ions from Mercury. Fig. 2 depicts for the most important doy 111 (21 April 1998) the measured M/q ratios. One sees on a high background rate, caused by the solar particle event: enhanced fluxes of C, N, O, Fe^{3+}, Ne, NaMg , AlSi, P, S, and Cl ions. The Fe^{3+} ions result most likely from the solar particle event which had a high Fe/O ratio, (Reames et al., 1998). Fig. 2 shows also that the carbon content is higher than that of oxygen. The ions NaMg and AlSi appear as a double peak and are not resolved by our instrument. The detected He cannot be distinguished from interstellar He pickup ions and is therefore excluded from further discussion. In Fig. 3 the time interval doy 110–112 is shown, however selected for the velocity interval $1.2 < vion/vsw < 2.1$ which is the pickup ion velocity above the solar wind velocity. Almost the same ions can be recognised: He, C, N, O, Fe3+, NaMg, Si, P, S, Cl. It can also be stated that the Carbon content is somewhat higher than the oxygen content. Measurements of the MASS sensor were obtained in the E/e range 0.5–9.5 keV/e on doy 110, 1998. This energy/charge range is suitable to detect solar wind ions as well as low energy pickup ions. The ions C, N, O, NaMg, Si, P, S, Cl, Ar (or K, Ca), Ti, and Fe were detected in the above mentioned energy/charge range. Carbon has again a higher abundance than oxygen (not shown as figure).

5 Discussion:

A very special interplanetary condition allowed us to detect pickup und sputter ions from planet Mercury. Beside the already known ions (H, He, Na, K) WIND/STICS found: C, N, O, Ne, Na, Mg, Si, P, S, Cl and

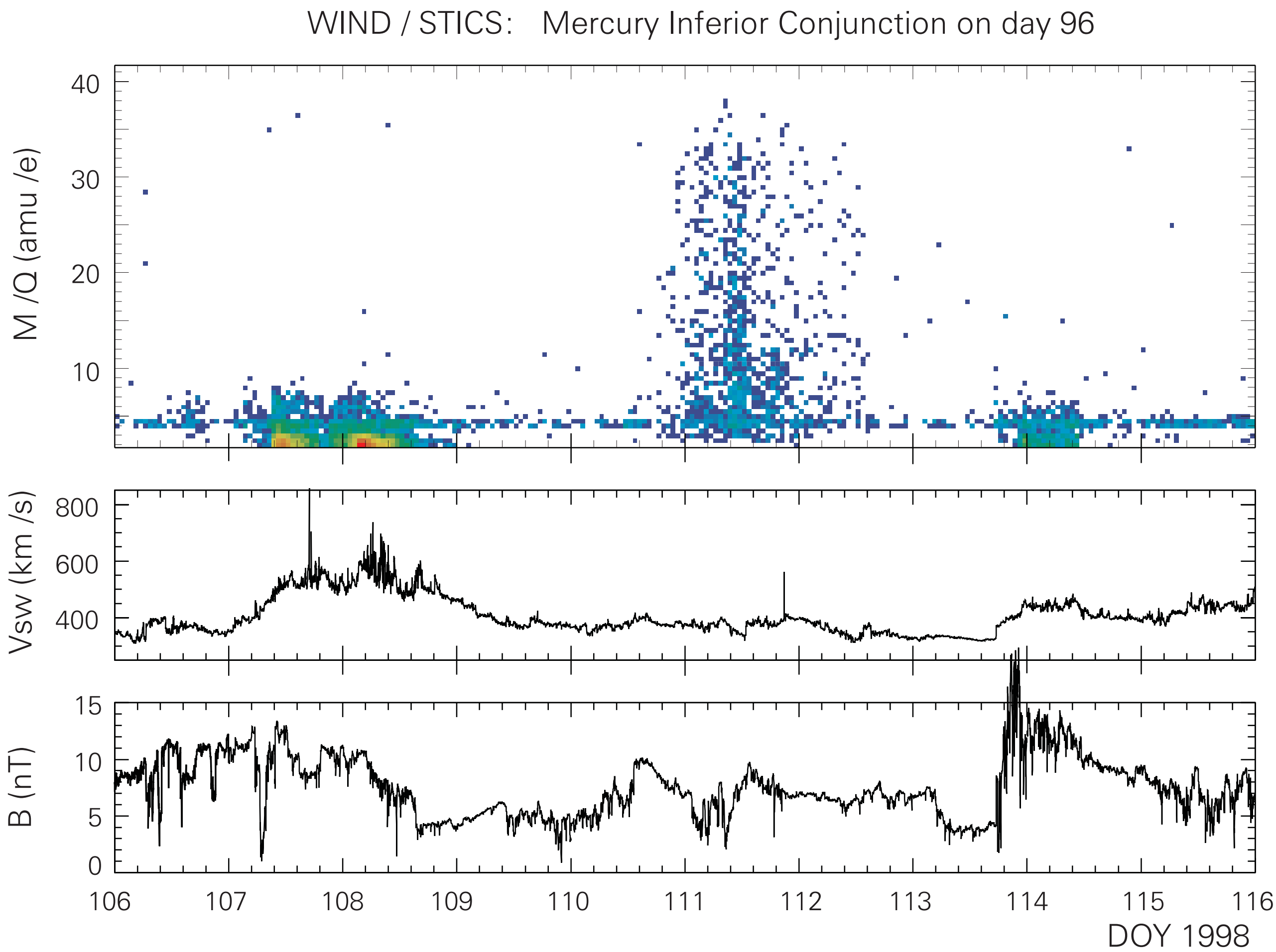

Figure 1: Overview picture. Heavy and singly charged: ions appear on doy 110-112

WIND/MASS: C, N, O, Ne, Na, Mg, Si, P, S, Cl, Ar, Ti and Fe. He ions were always present but they cannot be distinguished from interstellar He-pickup ions which were also studied by Chalov and Fahr (1999). Fe^{3+} which was seen by STICS is most likely of solar flare origin and Fe detected by MASS is a constituent of the solar wind. Surprising is the high Carbon abundance compared with oxygen. We assume here that dust located near the Sun was sputtered by solar protons and α-particles so that an overabundance of carbon and probably other elements was produced. We consider however Na, P and Cl as typical Mercury ions since they are rare in the solar wind. Mall et al. (1998) have shown that oxygen is the most frequent lunar pickup ion. At Mercury are the most frequent ions NaMg, Si, P and and probably Cl. It cannot be decided whether carbon stems from Mercury or from the interstellar dust cloud surrounding the Sun.

6 Conclusions:

Pickup- and sputter ions from planet Mercury were most likely detected by the experiment SMS on WIND. However a contribution of pickup ions from dust located near the Sun cannot be excluded.

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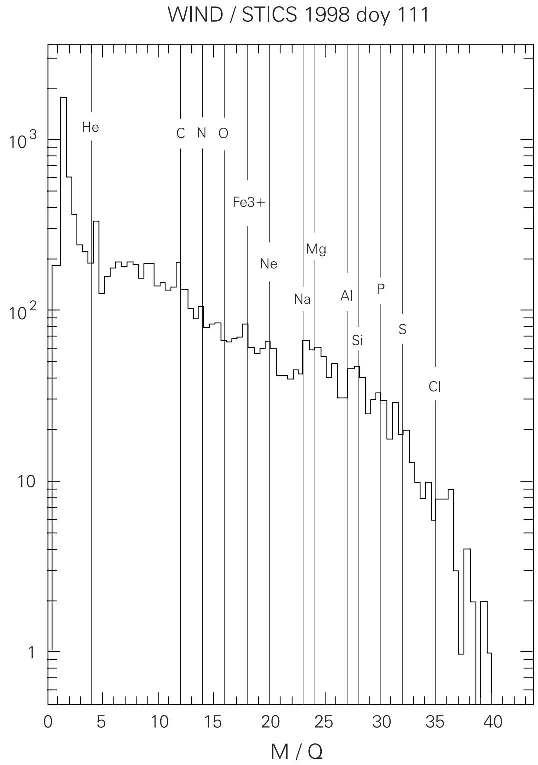

Figure 2: Double coincidences of STICS (E/e = 6.5–225 keV/e).

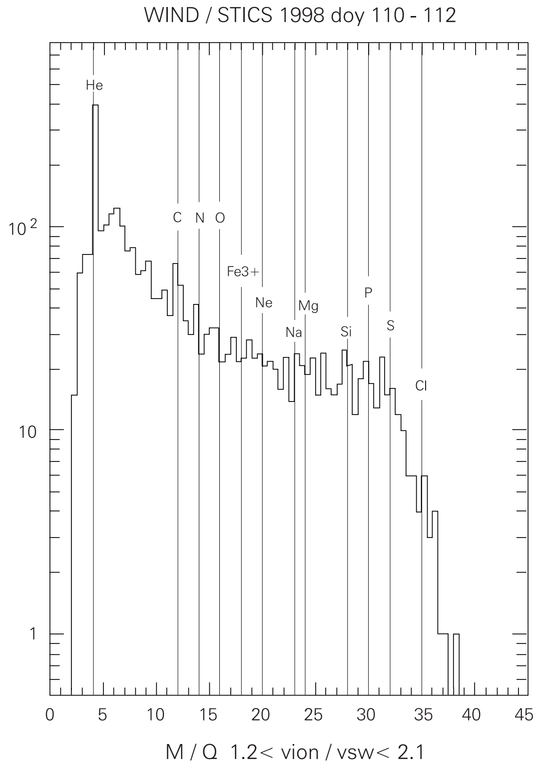

Figure 3: Double coincidences of STICS for pickup ions

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