Consideration on Oxygen isotopic composition recorded on the lunar surface based on the KAGUYA observation of terrestrial oxygen. K. Terada[1], S. Yokota[1] and Y. Kawai[1], [1]Graduate school of Science, Osaka University. 1-1 Machikaneyama-cho, Toyonaka 560-0043, JAPAN (terada@ess.sci.osaka-u.ac.jp).

Introduction: It is well known that the rocky celestial bodies such as Earth, Moon, Mars (SNC meteorites), Vesta (based on the HED meteorites) and Itokawa have own oxygen isotope composition, which is expressed by the line of which inclination is about 0.5 (so-called, mass-dependent fractionation line). On the other hand, those of lunar regolith obviously deviate from the fractionation line, showing mass-independently fractionated either negatively[1] or positively[2]. Hashizume and Chaussidon [1] reported the ^{16}O-rich component ($\Delta^{17}O = \delta^{17}O - 0.52 \times \delta^{18}O < -20 \pm 4$ ‰) of which concentration is 1-3 wt.%. Observed ^{16}O-rich components, which mostly exist at the depth deeper than 200 nm up to 2000 nm from the sample surface. Whereas, Ireland et al.[2, 3] reported the ^{16}O-poor component with $\Delta^{17}O = +26 \pm 4$ ‰. Most puzzling nature of ^{16}O-poor component is its high oxygen concentration of ~8 wt.% at the shallower depth (around tens of nm), which is 5-10 times over abundant compared with the expected solar wind concentrations[3].

Now, we realize that the lunar mass-independently fractionated oxygen isotope can be interpreted as three components: isotopically normal lunar-intrinsic oxygen, which is identical to that of Earth ($\Delta^{17}O \sim 0$) [4]; ^{16}O-rich Solar Wind origin oxygen and unknown ^{16}O-poor component [5]. Here, it is interesting to note that the stratospheric ozone (O_3) is mass-independently fractionated and greatly enriched in ^{18}O and ^{17}O depending on the altitude (up to 400 permil at 32 km) [6] which are chemically produced when O_3 is formed from molecular oxygen [7]. Although the possibility of terrestrial nitrogen and noble gases in lunar soil has been discussed based on their isotopic composition [8,9], complicated oxygen isotope fractionation in lunar metal (particularly the provenance of the ^{16}O-poor component) remains a large enigma. In order to confirm the hypothesis of "Earth Wind", we have investigated the plasma data obtained by Japanese spacecraft Kaguya.

Kaguya observation: The lunar orbiter Kaguya was launched on 14 September 2007 and had a nominal observation of 1 year at an altitude of 100 km. The Magnetic field and Plasma experiment - Plasma energy Angle and Composition experiment (MAP-PACE) on the Kaguya spacecraft performed the first direct ion measurements of 3-dimensional energy and mass information[9]. In this study [10], we used the data of MAP-PACE available in the Kaguya Data Archive (http://l2db.selene.darts.isas.jaxa.jp/).

The Moon and the Japanese lunar orbiter Kaguya were occasionally captured by the plasma sheet for tens of minutes to a few hours per month in 2008. When the Moon moved in the central magnetosphere on 21 April, Kaguya measured plasma sheet ions with an energy of several keV during the periods of 0:50-1:10 and 8:00-16:00 and slightly detected cold lobe ions in the remaining period. Figure-1 illustrates the geometrical setting of the Sun, Earth, Moon.

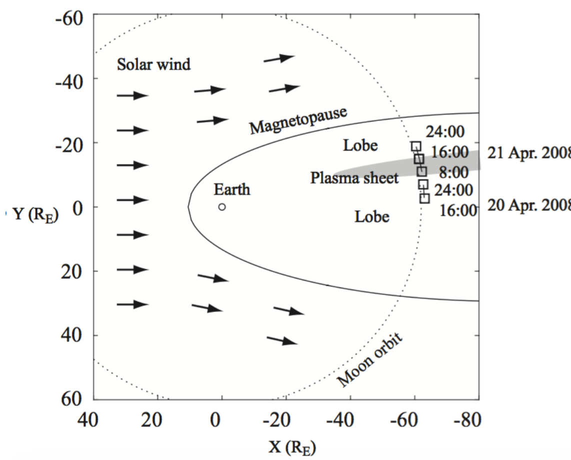

Fig.1 Geometrical setting of the Sun, Earth and Moon

Because only the IMA was equipped with a mass analyser, the energy spectra of moonward ions for all species and anti-moonward ions for H^+ and O^+ were obtained. The anti-moonward H^+ energy spectra (IMA) are comparatively similar to those of moonward ions (IEA), particularly in the plasma sheet, whose hot and isotropic ions entered both ion sensors. The low-energy signatures below ~1 keV (IMA), which repeatedly appeared in the dayside region in the anti-moonward O^+ spectra, were attributed to the ions of lunar origin [11] which were produced by the photoionization of exospheric particles and/or the ion emission from the surface and accelerated by the electrical potential difference between the lunar surface and the spacecraft. Such a potential difference causes the cutoff energy to be approximately 1 keV in the energy distribution [11,12]. Higher-energy O^+ (1-10 keV) ions were not detected when the Moon was outside the magnetosphere [11], but they were measured during almost the entire period of the plasma sheet encounters in this study. These O^+ ions are generally considered magnetospheric ions that escaped from the Earth's ionosphere [13]. The average abundance ratio of O^+/H^+ for the period of 8:00-16:00 was 2.4%, which is consistent with previous observations [13, 15-17] and one order higher than that of the Solar Wind [18]. In addition, the calculated density and net flux of the magnetospheric O^+ were 1.2 x 10^{-3} cm^{-3} and 2.6 x 10^4 $cm^{-2}sec^{-1}$, respectively, which are consistent with the previous GEOTAIL observation of 2.1 x 10^4 ions $cm^{-2}sec^{-1}$ at approximately 75-150 R_E [13]. Thus, we conclude that observed 1-10 keV O^+ during the plasma sheet originated from the Earth ionosphere, and the possibility of Solar Wind origin is excluded based on the valence and energy distribution. In this study, terrestrial nitrogen ions were not observed, possibly because of the low abundance ratio of N^+/O^+ (for example, 0.05-0.1 for the ionosphere [19] and the outflow from the ionosphere [20] and 0.05 for the outflow from the polar magnetosphere [14]). Figure 2 shows the obtained energy spectra of O^+ before, during and after the plasma sheet.

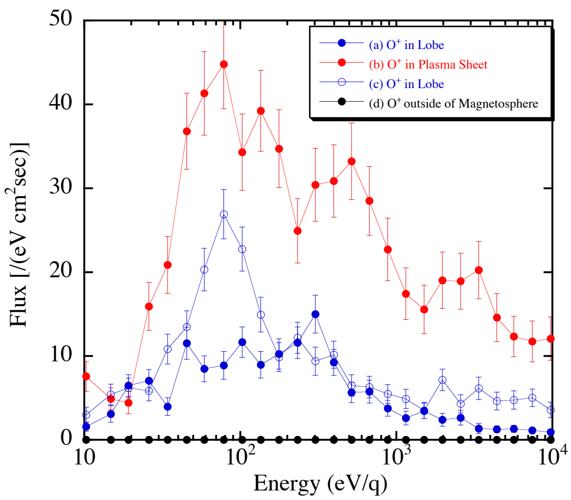

Fig.2 Energy spectra of O^+ ions observed by Kaguya

The importance of our new finding is the valence (+1) and energy (1-10 keV) of oxygen ions, which appear only when the Moon and Kaguya cross the plasma sheet. Such an energy range of the Earth Wind corresponds to the penetration depth of several tens of microns for metal grain according to SRIM [21] (e.g., approximately 30-40 nm for 10 keV and/or 3-4 nm for 1 keV), which is consistent with the observation of high-concentration ^{16}O-poor components at the shallow depth in the lunar regolith (~8 wt.%; $\Delta^{17}O$= +26 ± 4‰ and +33 ± 3‰).

This finding introduces a new paradigm that the entire lunar surface can be contaminated with biogenic terrestrial oxygen, which has been produced via photosynthesis for over a few billion years (e.g., 4 x 10^{36} O^+ ions for 2.4 billion years after the Great Oxygenation Event [22]). Here, our hypothesis does not exclude the possibility that the Earth Wind originated from oxygen molecules in the Earth's atmosphere, whose isotopic composition is "normal". Indeed, most lunar metals (more than 30 grains from 38 grains) show "normal" isotopic compositions, and only two metal grains show meaningful ^{16}O-poor signatures [3], although the normal isotopic composition of lunar metal is interpreted with the possibility that an unresolved small silicate grain sits in the analysed area.

For better understanding, we will require the oxygen isotope measurement by a high-sensitive and high-mass resolution mass spectrometer such as a miniaturized multi-turn TOF mass spectrometer [23], which has been designed for the future exploration in the Solar power Sail OKEANOS mission to a Jupiter Trojan asteroid [24].

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