Development on non-destructive muonic X-ray analysis: Appication to Earth and Planetary Science

K. TERADA[1], A. SATO[1], K. NINOMIYA[1], Y. KAWASHIMA[1], K. SHIMOMURA[1, 2],
D. Tomono[1], G. YOSHIDA[1], Y. KAWAI[1], T. OSAWA[3] and S. TACHIBANA[4]

[1]Osaka University, [2]High Energy Accelerator Research Organization.
[3]Japan Atomic Energy Agency and [4]Hokkaido University

The muon is a lepton with a mass of 105.7 MeV/c^2, approximately 200 times heavier than the electron. So far, electron-induced characteristic X-ray analysis has been widely used to determine chemical compositions of materials in Earth and Planetary Science. In recent years, analysis of characteristic X-rays from muonic atoms, in which a muon is captured, has attracted attention because both a muon beam and a muon-induced characteristic X-ray have high transmission abilities, of which energies are about 200 times higher (e.g., muonic carbon-Kα is 75keV, whereas electron-induced carbon-Kα is 0.3 keV). It is known that muonic X-ray analysis has great advantages in several ways; (1) non-destructive elemental analysis from light to heavy elements, (2) depth profile analysis, (3) isotopic measurement for heavy elements and (4) investigation of chemical condition (redox-state). Such a non-destructive muonic X-ray analysis has a great potential to characterize precious extraterrestrial samples returned by spacecrafts such as Hayabusa2 and OSIRIS-REx in 2020's.

Following our successful detection of muonic X-ray spectra from carbonaceous chondrites, Murchison and Allende with intense pulsed Muon beam at J-PARC [1], we have developed on muonic X-ray analysis at the MuSIC (MuSIC; MUon Science Innovative Channel at Osaka University, [2, 3]), and obtained the fundamental data for quantitative analysis of planetary materials [4]. Using one of the world-leading intense direct current muon beam source, we successfully detected characteristic muonic X-rays of Mg, Si, Fe, O, S and C from Jbilet Winselwan CM chondrite, of which carbon content is about 2 wt%, and the obtained elemental abundance pattern was consistent with that of CM chondrites. We also checked Muon irradiation damage of pellets of mixed organic chemical reagents (alanine, glucose, paraformaldehyde, phenanthrene, and stearic acid) after 3–12 hour exposure to check the irradiation damage, and confirmed that they do not show any systematic changes with either the exposure time or the depth, and are not different from those of non-exposed samples within the variation of initial reagent mixtures. We also performed the muonic X-ray analysis of terrestrial PbS (Galena) for Pb isotopes measurement and iron meteorite to check the feasibility of chemical condition (redox-state) measurement. At the symposium, we will report on our recent progress of muonic X-ray analysis and discuss on a future prospect for applications for earth and planetary science.

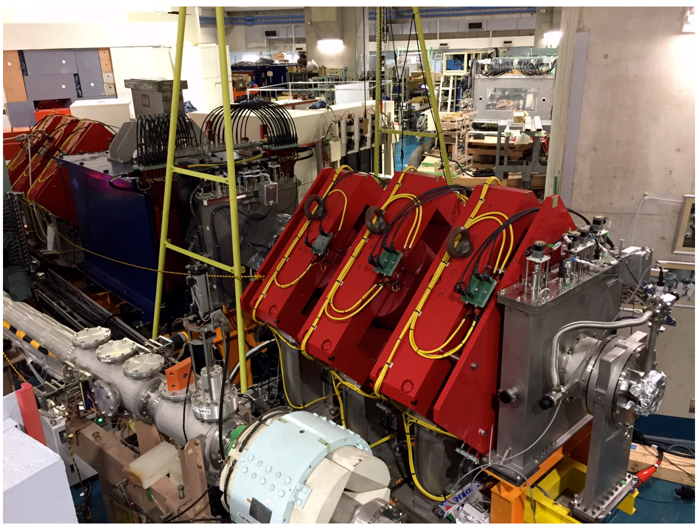

Figure 1: Direct-current Muon beam line at MuSIC, Osaka University.

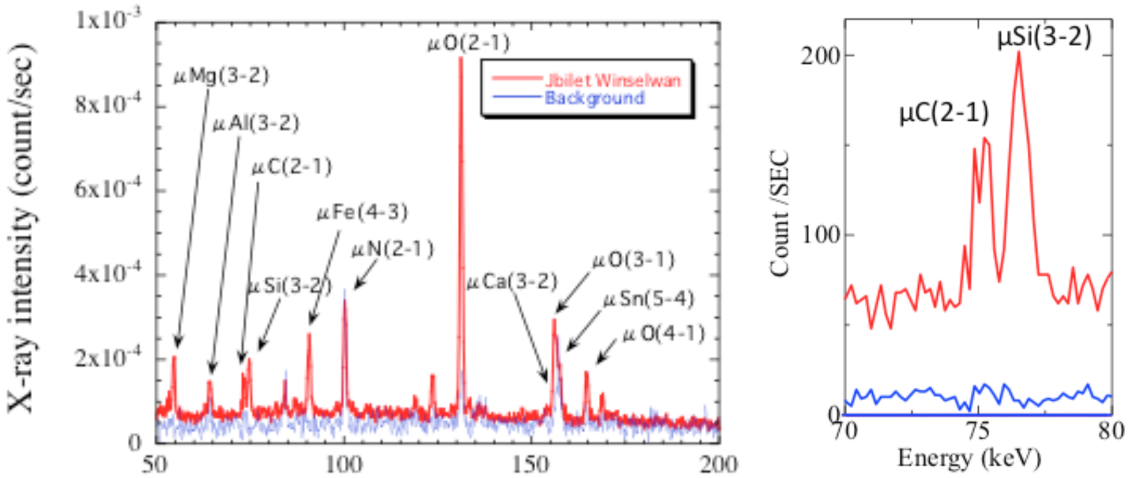

Figure 2: Muonic X-ray spectra of Jbilet Winselwan CM2 chondrite.

References

[1] Terada, K. *et al.* 2014. *Sci. Rep.* **4**, 5072; DOI:10.1038/srep05072 **[2]** Hino, Y. *et al.* 2014. *Nuclear Physics B (Proc. Suppl.)* **253-255**, 206-207. [3] Cook, S. *et al.* 2017. *Physical Review Accelerators and Beams* **20**, 030101.