REANALYSIS OF POSSIBLE DEGRADATED XRS AND REMOTE X-RAY SPECTROSCOPY IN THE FUTURE MISSIONS.

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Planetary remote X-ray fluorescence spectroscopy could provide major elemental composition precisely, when adopting an X-ray detector with high energy resolution. But there are some problems happened in the previous lunar missions. Degradation of detector performance, instability of spacecraft environments, and uncertainty of solar X-ray monitoring are among the critical topics on this problem, and we propose here a potential solution by showing the new concept of XRS instrument using a standard sample.

Introduction: X-ray map of airless body like the Moon or asteroids is an essential data for investigating planetary evolution such as crustal formation, volcanism, and interior structure. X-ray map shows regional variation of Mg-Al-Si composition ratios and Mg-number (mole ratio of Mg/(Mg+Fe) in silicate). As was proven during the Apollo 15 and 16 missions [1], major elements are quantitatively determined through X-ray fluorescence spectroscopy from orbit. Lunar X-rays are sufficiently excited by irradiation of solar X-rays. In the last decade, X-ray fluorescence spectroscopy of the Moon has been planned in Smart-1, Kaguya, Chang'E-1, Chandrayaan-1 missions. Major elemental composition of lunar surface should have been determined and classified region to region, but little progress has been made due to problems of instrument design or performances, troubles in spacecraft, and historically quiescent solar activity during the solar minimum period. Precise major elemental map on the Moon, asteroids, and other planets are therefore still lacking.

Possible Degradation and re-analysis of XRS: Our XRS might have suffered from degradation of CCD by irradiation of trapped protons when passing through the terrestrial radiation belt. We cautiously treated the possible degradation for its energy calibration and energy resolution, and reanalyzed the data. In Hayabusa case, our analysis was done by fitting the data with flexible value of energy and energy resolution at each fluorescence line so that no substantial change of results might be necessary [2].

While in Kaguya case, significant degradation has happened and in comparison with the results of proton radiation test we carried on afterwards it is found difficult to perform quantitative elemental analysis. One reason of this trouble is the lack of radiation shield because of the improper radiation test level at the critical design review, which is more than one order of magnitude lower than the realistic level.

Next Plans for X-ray Spectroscopy: Next remote lunar XRF experiments are now planned with the similar instrumentation in Chang'E-2 and Chandrayaan-2. Solar X-ray monitors are not a favorite type in its design and perhaps in its performance. Its narrow field of view cannot cover solar X-rays continuously. In future missions like SELENE2 or other kind of missions such as a low-cost small sized satellite mission to orbit the Moon more appropriate XRF experiments should be planned.

XRS Detector: We will propose the next CCD-based X-ray spectrometer for future planetary orbiters. In Japan, we have many heritages in CCD-based X-ray devices in MAXI (all sky survey of X-ray astronomy), Hayabusa (asteroid Itokawa), and Kaguya (Moon). CCD can provide information on energy and position of incident X-ray photon.

XRS used in Apollo, NEAR-Shoemaker to asteroid 433 Eros, or Messenger to Mercury is based on conventional proportional counters with balanced filter method. Although their experiments have been successful, the accuracy is not far from satisfactory due to their low energy resolution. XRS mounted on Chang'E-1 and Chang'E-2 is based on PIN photodiode arrays, which does not work well due to their thermal design to use peltier coolers to keep the detector at low temperature.

Another potential one will be a position sensitive pixel array CMOS detector, which is being developed in the industry. CMOS detector is considered to have similar energy resolution and detection efficiency but consumes less power to drive the detector and works well even at higher temperature, so that it will be a candidate in future space missions.

Position Sensitive Observation: Two-dimensional position sensitivity is another advantage of using CCD. In Kaguya mission, XRS does not use its function, but the position on CCD could cover different footprint of the lunar surface if the X-ray window is smaller than the detection area, just the principle of pin-hole camera. Here we will use the position to determine the surface footprint area from where X-ray photon comes. For example, the instrument has wide field of view (±45°) but 10° effective angular resolution could be achieved in cross-track direction. The new XRS composes of planetary X-ray detector, solar X-ray monitor, as well as electronics. Planetary X-ray detector will have eight CCD chips in 2 x 4 positions. X-ray window of 1 cm x 5 cm will get X-rays from the lunar surface in ±45°x ±15° region.

Solar X-ray Monitor: In Hayabusa and Kaguya missions, the solar X-ray monitor with a standard plate to compare X-rays both from the surface of planetary bodies and from the plate. The method is so successful and the solar X-ray monitor for the next mission will also have a glass-plate standard sample for XRF calibration. If possible the design of two kinds of standard sample plate with two detectors is more robust for any surface composition and any troubles to happen.

Lessons Learned from the Past Missions: One important point of lessons learned is to shield radiation during the cruise of terrestrial radiation belts to avoid damage of detectors, by which the detectors on SMART-1 and Kaguya showed severe degradation of energy resolution. The door is required to close during the cruise and open after arrival. Another point is to calibrate energy using the radioisotope (such as Fe^{55} source) or a small X-ray generator. Since the X-ray detector must experience some degradation of efficiency (a few to several percent) during several year-long mission. Onboard analysis to construct energy histogram is also necessary because the photon counts changes several orders of magnitude time to time due to change of solar activity. Onboard analysis works well on Hayabusa, Kaguya, and Chnadrayaan-1.

Target Design of XRS for the Next Lunar Missions: The instrument including a CCD-array based XRS for lunar X-ray observation and the CCD-based solar X-Ray monitor with standard samples as well as electronics box is the favorite XRS for the next missions. A typical design is considered that the total mass is less than 10 kg and power is less than 25 W. The necessary duration of mapping the Moon will be at least two or six mouths depending on the solar activity. The lunar orbiter circling the Moon will map the surface elemental composition by moving distance during integration time in along-track direction and by angular resolution of the position of CCD in cross-track direction, which will cover the surface effectively.

References:

[1] Adler, I. et al. *Science* **177**, 256- (1972).

[2] Arai, T., et al., Earth Planet Space, **60**, 21-31, 2008.

Table 1 Expected performances for XRS

Detector CCD:	1’ x 1’, 1k x 1k pixels
Energy res.:	<150 eV @Mn-K
Temperature	<-40 C:
Cooling:	radiator + peltier cooler
FOV:	±15deg x ±45 deg (TBD)
Spatial Res.:	25 km x 25 km @100km for 16sec
	50 km x 50km @200km for 32sec
Total Mass:	10 kg
Total Power:	20 W

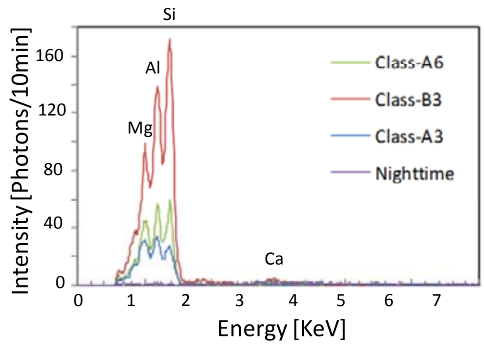

Figure 1. X-ray spectra by Kaguya SOL-C off the standard sample during three different levels of flare times.

Figure 2. Kaguya SOL-BC on the mechanical test. SOL-C is part of this component with a standard sample.

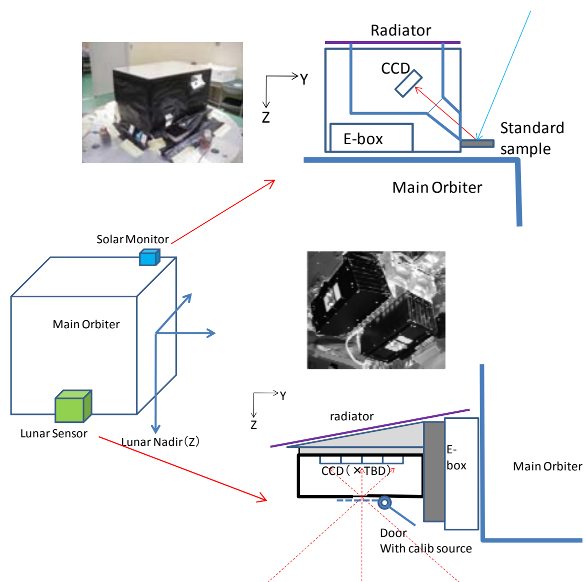

Figure 3 Cartoon of XRS design. Concept of Kaguya SOL-C and MAXI type design with Kaguya type radiator are mixed to compose the appropriate design.