Search of Water Ice in the Lunar Polar Regions

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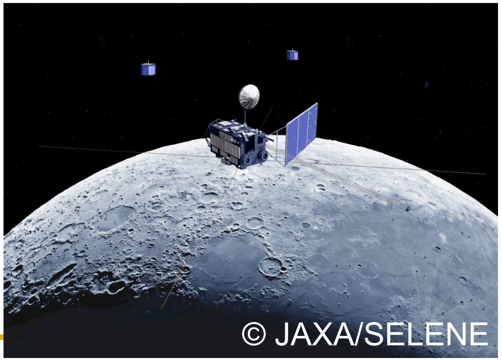
Introduction

- Search of water ice in the Moon is important for utilizing materials for human activity in the future.
- The possible existence of water has been suggested on the Moon.
- Conventional observations: radio observation, neutron spectrometer, γ rays with low energy resolution
  - Clementine: The floor of one crater is covered with frosts from 2.4 to 21%
  - Lunar Prospector: 100~150 ppm hydrogen is suggested in both poles
- SELENE (KAGUYA)
  - Launched in September 2007
  - Onboard Gamma-ray Spectrometer



Motivation

- Now, the observation of SELENE (KAGUYA) GRS is going!
  - Water ice in the Moon is detected by H and Si capture γ ray.
    - If water ice exists in the surface, γ ray intensities of major elements are changed as well as H intensity.

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    - The variation of H and Si intensities is possible to constrain water contents and distributions.
  - For detecting H and Si γ rays, Doppler effect and a energy resolution of the GRS must be considered.

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- <u>Therefore, Geant4 is used for calculating these factors.</u>

Water Distribution: Calculation Methods

Geant4.8.0.p01

- Models
  - QGSP_BERT_HP
  - G4NDL3.9 (modified)
- Incident particle : GCR proton
  - Energy spectrum at solar average
  - Energy range : 100 MeV ~ 100 GeV
- Target : lunar surface model

Energy spectrum of GCR proton
(solar average)

Distribution of
Neutron Capture reaction

Soil composition
Partial cross section

Estimation of g-ray intensities at the surface

Variation of H and Si γ-ray intensities

⇒ constrain water content and distribution?

Water Distribution: Models of Lunar Surface

Ferroan anorthosite (FAN):
Lunar highland sample from the Apollo missions

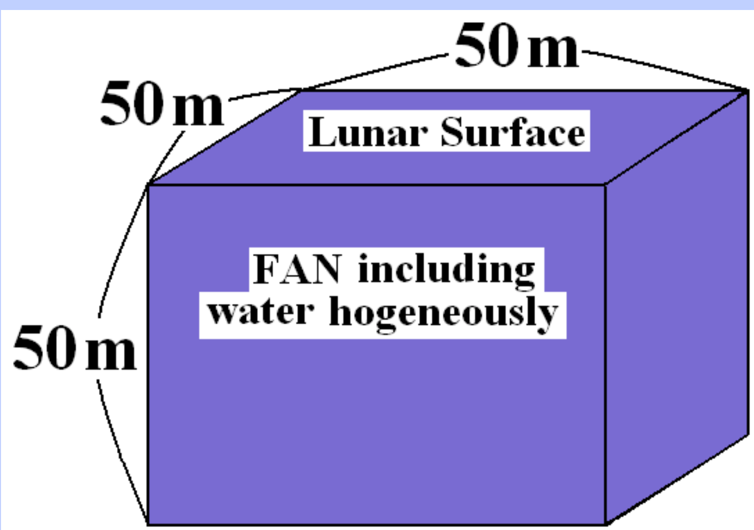
Composition of FAN [wt%]

Na_2O	MgO	Al_2O	SiO_2	CaO	FeO
0.2	3.6	30.3	44.5	17.7	3.7

Simplified lunar surface suggested by LP team

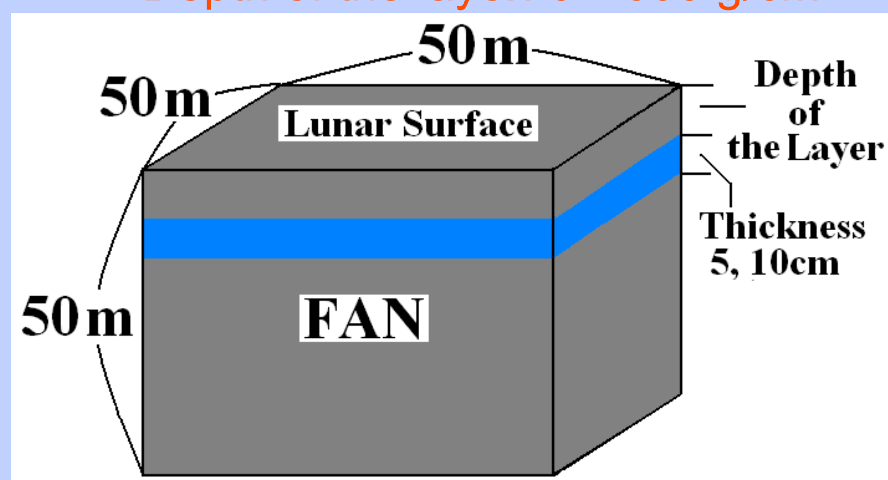
Homogenous Model (HM)

Ratio of composition: constant
water contents: 0~50 wt%



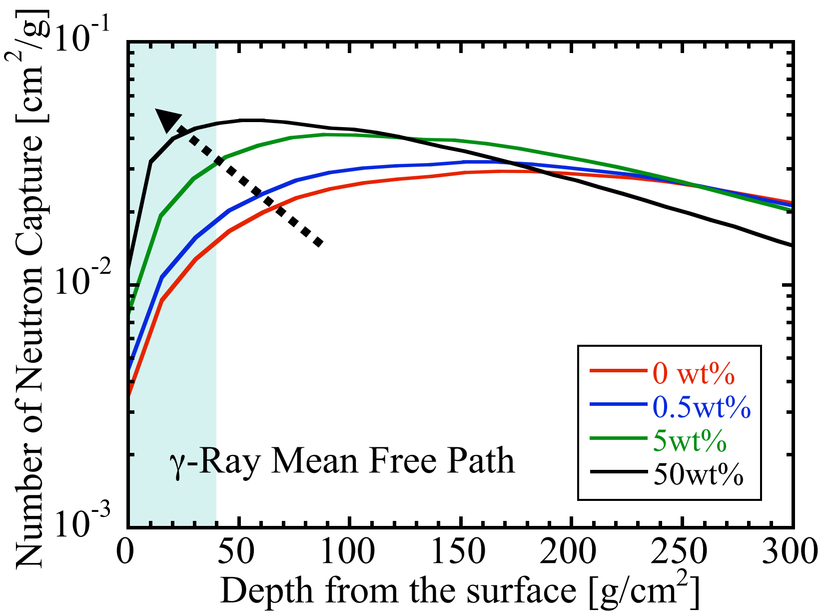
Layered Model (LM)

Pure water layer (1.0 g/cm^3) exists in the dry FAN
Layer thickness: 5, 10cm
Depth of the layer: 0～600 g/cm^2

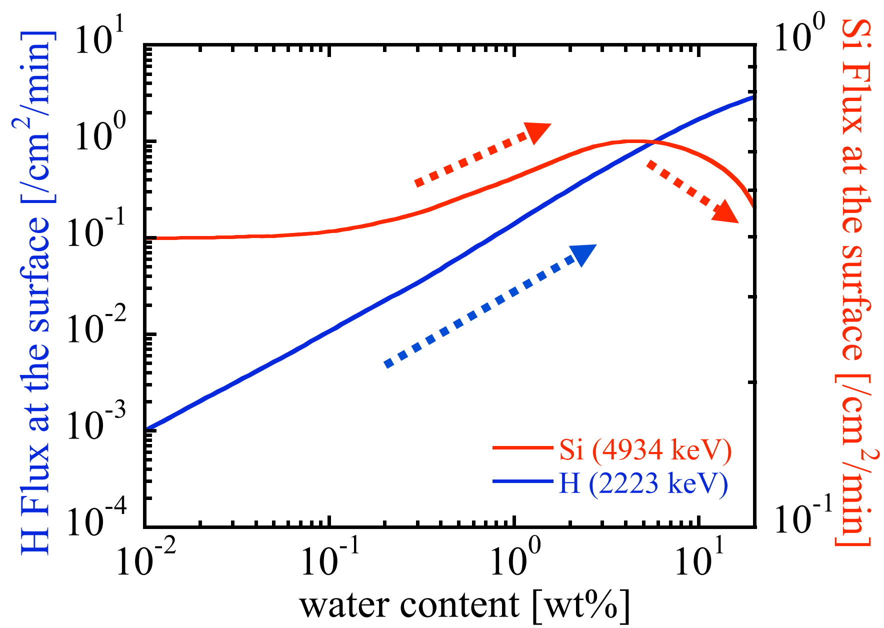


Water Distribution: Results (Homogenous Model)

Neutron Capture Reaction



H, Si γ ray intensity



Water Content ↗ → Neutron Capture ↗

→ Si: 4934 keV increase (<10 wt%)

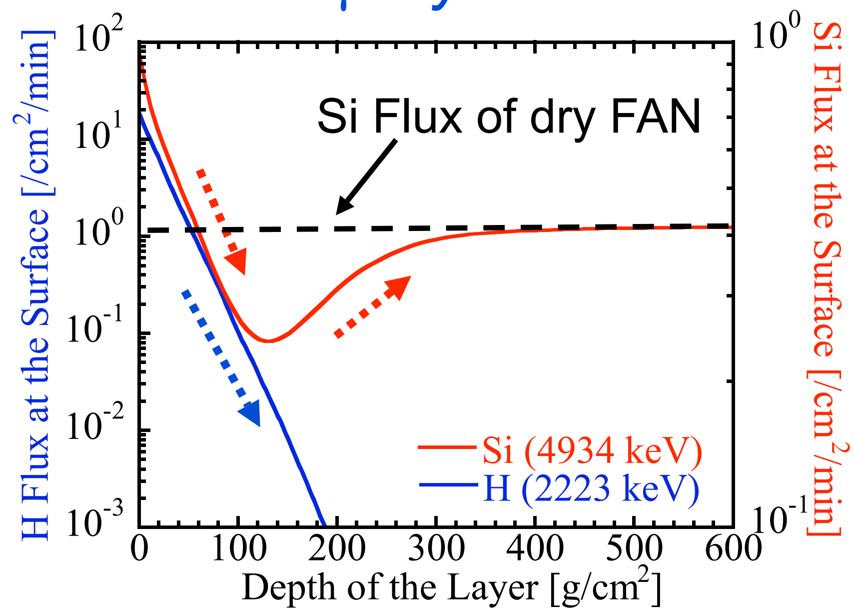
→ H: 2223 keV increase

Water Distribution: Results (Layered Model)

(Layer thickness: 10 cm)

Neutron Capture

H and Si γ ray intensities



The number of neutron capture reactions is especially increased in the water layer.

As the layer became deeper,

1) Si flux decreased (depth < 120 g/cm²) and increased to one of dry FAN (depth > 120 g/cm²).
2) H flux decreased because attenuation effect of γ ray became stronger.

Water Distribution: Discussion

- A concentration of Si is thought to vary slightly in the polar regions.

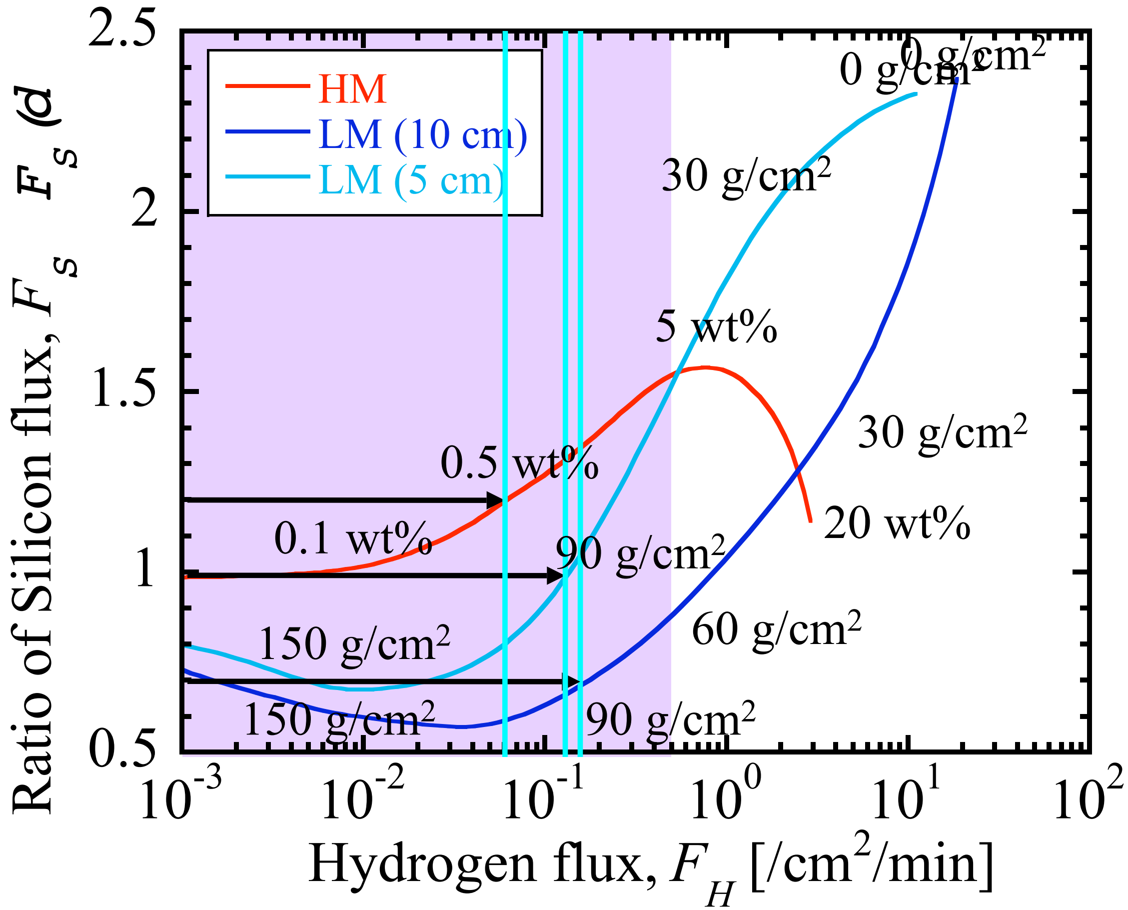
- Comparison of H γ-ray intensity with Si γ-ray intensity (normalized to the dry case)
  - A relation of H and Si intensities is not same for other distribution model.

    → F_{Si}: HM > LM (F_H < 0.4)

- Estimation H and Si γ ray intensities

- Water content and distribution are able to be constrained.

γ-ray intensities of H, Si



Doppler Broadening: Introduction

- The discussion so far is considered by line γ rays.

- But, in the actual observation, γ rays are detected as broad line because of Doppler broadening and a energy resolution of the detector.

- Doppler broadening
  - For nucleus decayed in very short time (> tens of p sec), a energy of emitted γ rays is changed by Doppler effect because of its velocity.

- A energy resolution of the detector
  - The GRS has a energy resolution of 3 keV at 1.33 MeV (at the ground test).
  - A energy resolution is represented for Full Width at Half Maximum (FWHM).

- Therefore, the effects of Doppler broadening and the energy resolution are considered for search of water ice in the Moon.

Doppler Broadening: Methods and Results

- Geant4 was used for the calculation of neutron velocities.
- Conditions: same for water distribution (homogenous model)
- Procedures
  - Neutron Flux at 30 g/cm^2

    ↓
  - Distribution of neutron velocities

    ↓
  - Distribution of recoil Al velocities

    ↓
  - Al line width broadened by Doppler effect

- Calculated Full Width of Half Maximum (FWHM) of Al (2211keV): 17 keV

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- Al γ ray of 2211 keV interfere H γ ray (2223 keV) strongly!

Al line γ ray

broadened

Doppler broadening of Al

↔ FWHM: 17 keV

Doppler Broadening: Discussion

- Fig (top): H and Al γ-ray spectrum (considered Doppler effect)
  - Calculated from Homogenous Model
- Fig (bottom): H and Al γ-ray spectrum considered Doppler effect and the energy resolution
  - Each line is broadened for the effect of energy resolution 3 keV @ 1.33 MeV

Al and H γ ray broadened by only Doppler effect

broadened by the energy resolution

- FWHM of Al: 19 keV
- H line is strongly interfered by Al line
- In the case of water content is 0.1 wt% , a peak of H line is not detected distinctly.

Summary

- γ-ray intensities of H and Si are changed dependent on water contents and water distribution.
- If sufficient water exists, the change of H and Si γ ray intensities are able to be observed.
- H and Si γ ray are able to constrain water contents and distributions in principle.

- But, in an actual observation of water ice, Doppler broadening and the energy resolution must be considered.
- By the effects of Doppler broadening and the energy resolution, Al line of 2211 keV is widely broadened (FWHM: 19 keV). H line is also broadened by the energy resolution.
- Therefore, the peak of H line is not detected distinctly for the case of 0.1 wt% because of interference of Al line.
- More simulations by Geant4 are needed for search of water ice in the Moon by the GRS.