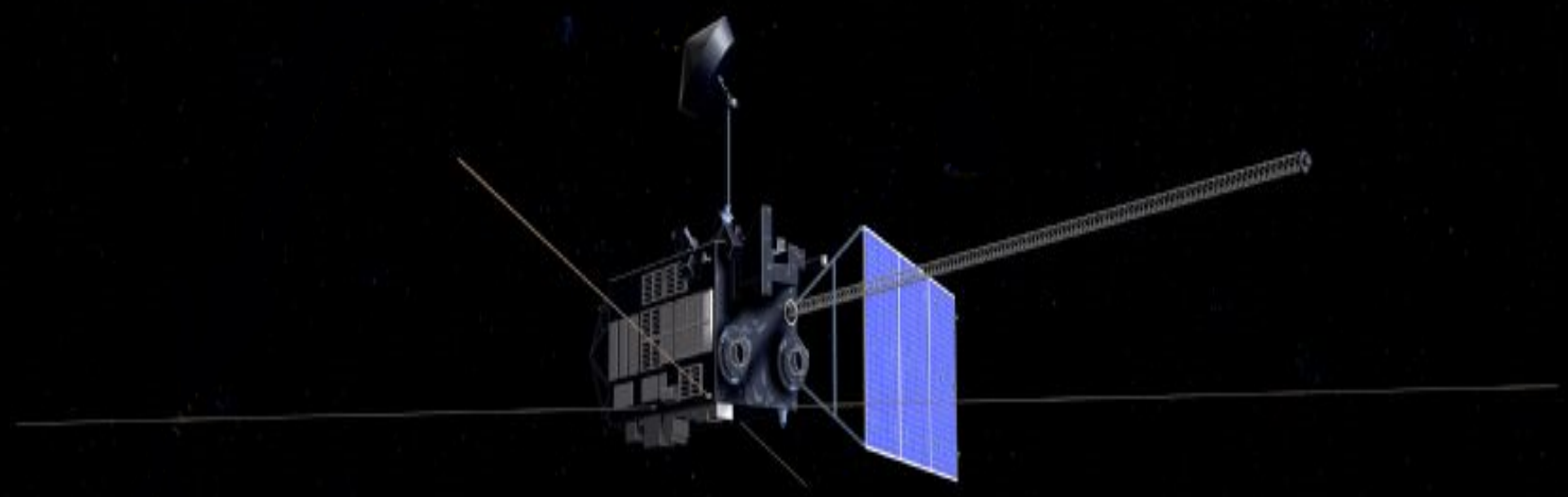
Introduction to elemental distribution of Si and other major elements on the lunar surface observed by Kaguya GRS



K. J. Kim[1,2], H. Nagaoka[3], N. Hasebe[3], D. Hamara[4], R. Elphic[2], J. A. P. Rodriguez[2], S. Kobayashi[5], N. Yamashita[6], Y. Karouji[7], M. Hareyama[8], H. Kusano[3], Y. Sakuramoto[3]

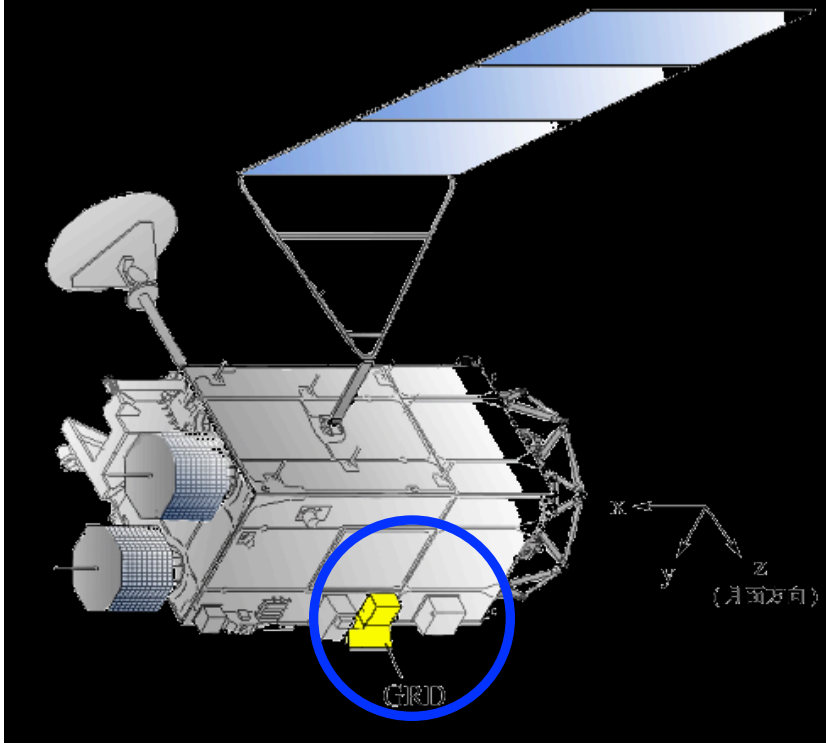
[1]Planetary Geology Dept., Korea Institute of Geosciences & Mineral Resources, Dajeon, South Korea, [2]NASA Ames Research Center, Moffett Field, CA94035, USA, [3]Research Institute for Science and Engineering, Waseda University, Tokyo, Japan, [4]Lunar and Planetary Laboratory, University of Arizona, Tuscon, AZ85721, USA, [5]National Institute of Radiological Sciences, Japan, [6]Planetary Science Institute, Tucson, AZ85719, USA, [7]Japan Aerospace Exploration Agency, Kanagawa,

Kaguya Gamma-Ray Spectrometer

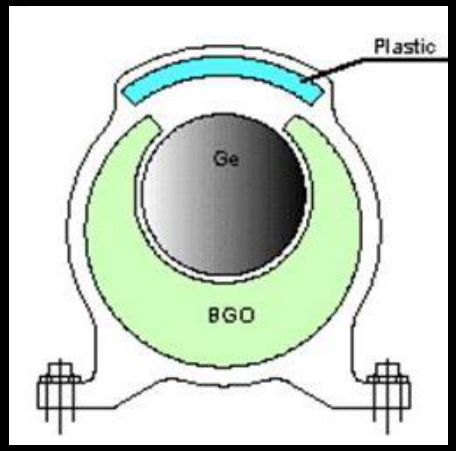
Hasebe et al. 2009 (JPSJ)

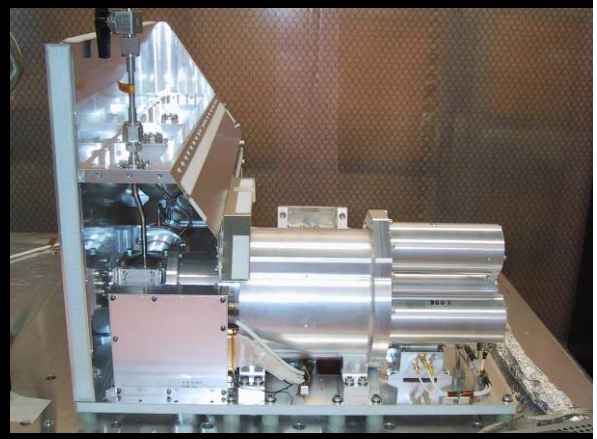
- Main Detector
  - HP-Ge(Eurisys Measures)
- Anti-Coincidence Detector
  - Plastic Scintillator(BICRON)
  - BGO (BICRON)

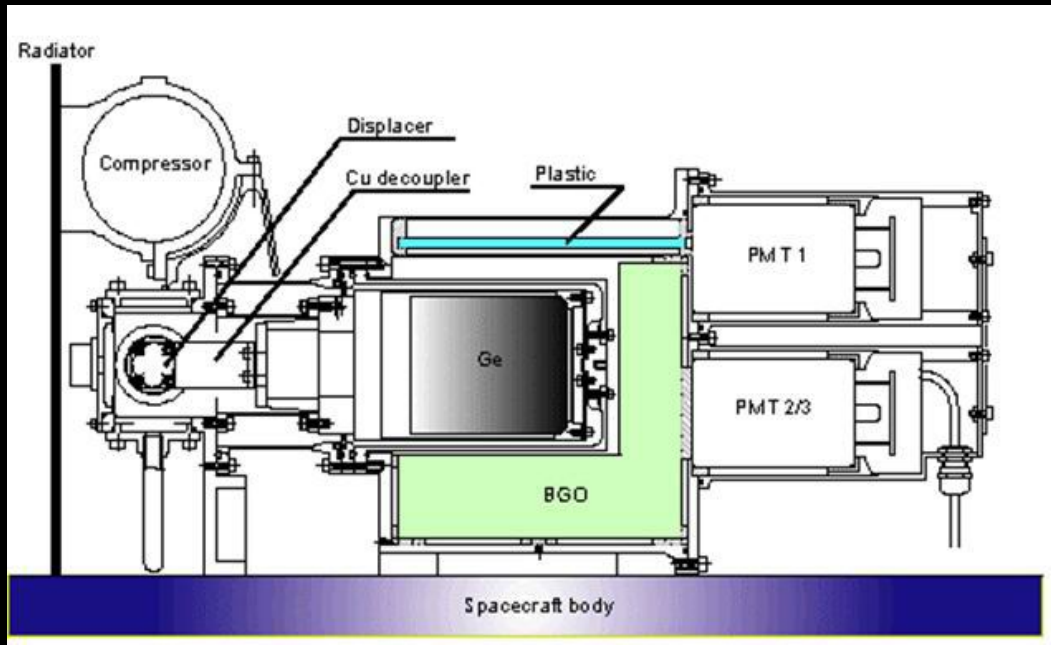
- Objective: Global mapping of K, U, Th, O, Mg, Al, Si, Ca, Ti, Fe, and H



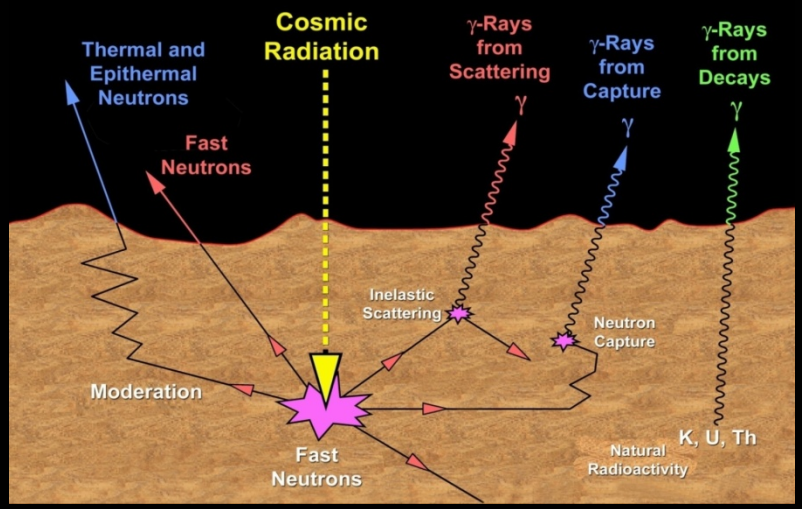
KAGUYA GRS with high energy resolution







Gamma-ray spectra



Hasebe et al. 2009 (JPSP)

Source of Gamma-Ray by Neutron

- Cosmic Ray Induced Gamma-Rays from Major Elements -

Major γ-rays induced by secondary neutrons, Reedy (1967)

Source	Energy (MeV)	Flux (γ/cm^{2}min)
^{28}Si(n,nγ) ^{28}Si	1.779	3.22
^{56}Fe(n,nγ) ^{56}Fe	0.847	1.15
^{24}Mg(n,nγ) ^{24}Mg	1.369	0.73
^{27}Al(n,γ) ^{28}Al	7.724	0.17
^{28}Si(n,γ) ^{29}Si	4.934	0.34
^{40}Ca(n,nγ) ^{40}Ca	3.737	0.35
^{40}Ca(n,γ) ^{41}Ca	6.420	0.24
^{48}Ti(n,γ) ^{49}Ti	6.762	0.41
^{56}Fe(n,γ) ^{56}Fe	7.631	0.60

Abundance: O=43.5, Mg=4, Al=11, Si=20, S=0.7, Ca=10, Ti=1.4, Fe=9

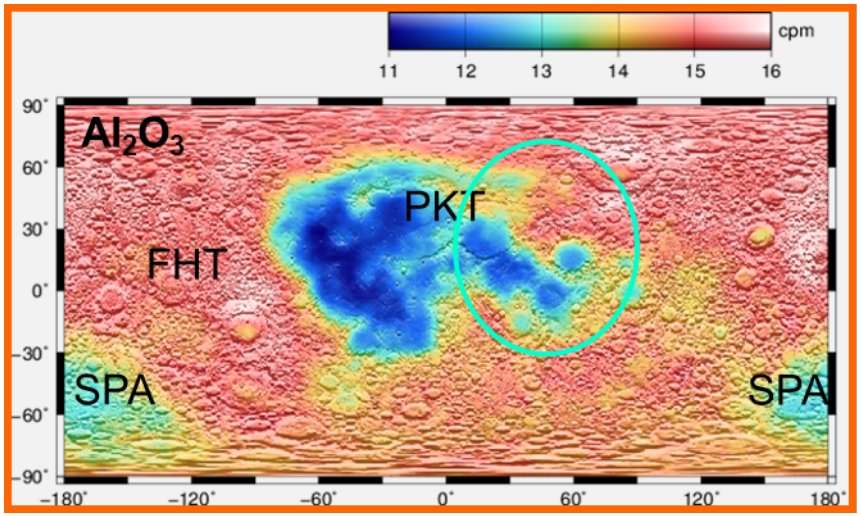
Gamma-ray data processing procedure to make elemental maps

- Step 1 : Peak analysis of GRS data (cpm)
- Step 2 : Altitude correction
- Step 3 : Neutron density correction
  (thermal or fast neutron density)
- Step 4 : Normalization to Apollo data

Ca, Al

Three rock compositions of the Moon

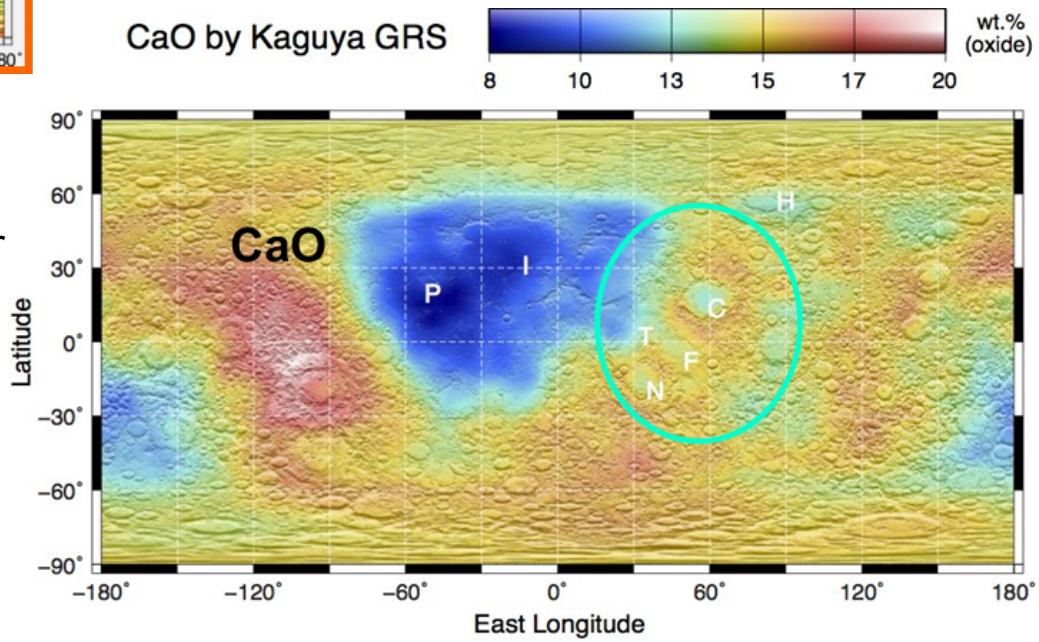
1)Feldspathic highland material including plagioclase (high Al_2O_3, low FeO)
2)Basaltic compositions of Fe-bearing minerals (high Fe, low Al_2O_3), and
3)KREEP material.
Al and Fe compositions tell us those materials.



Major difference b/w Ca and Al is abundance in the eastern maria in nearside.

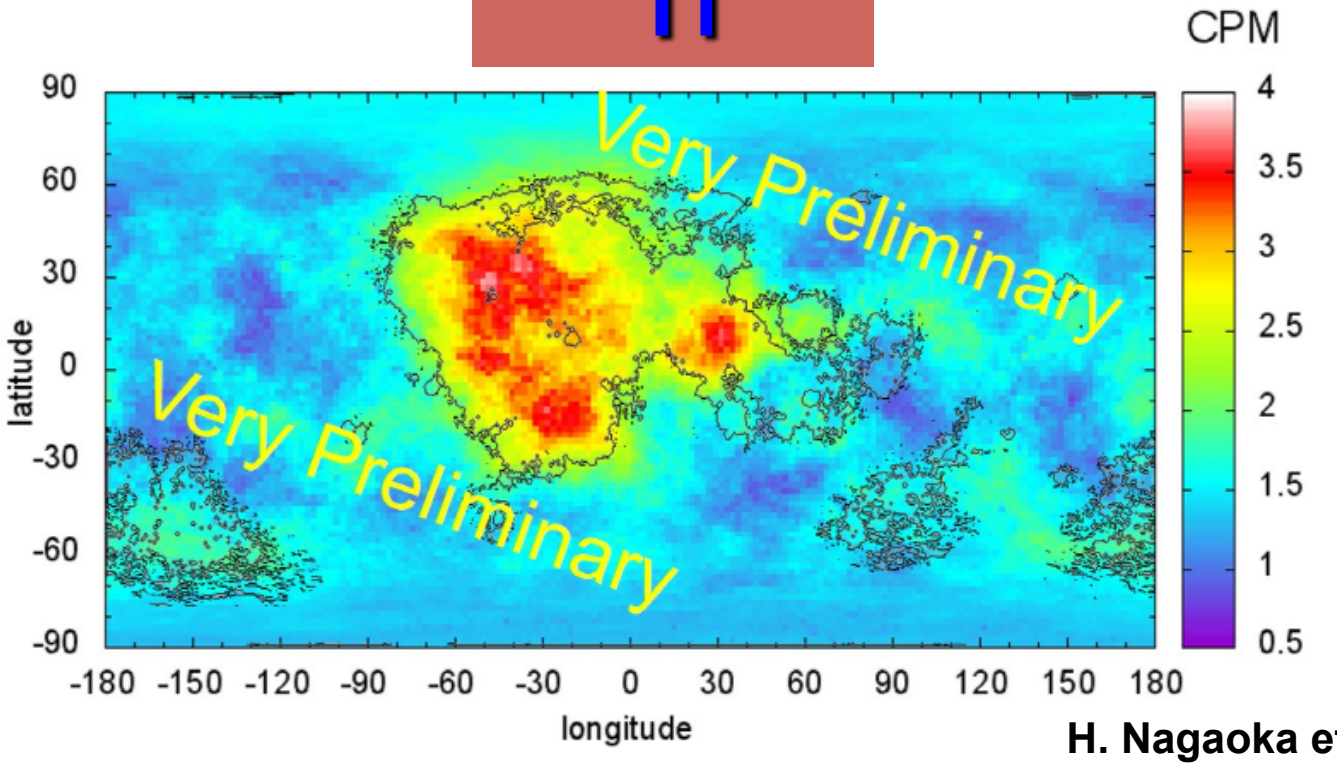
East Maria :
- rich in Ca rich pyroxene

West Maria :
- rich in olivine, orthopyroxene, and/or low-Ca-clinopyroxene



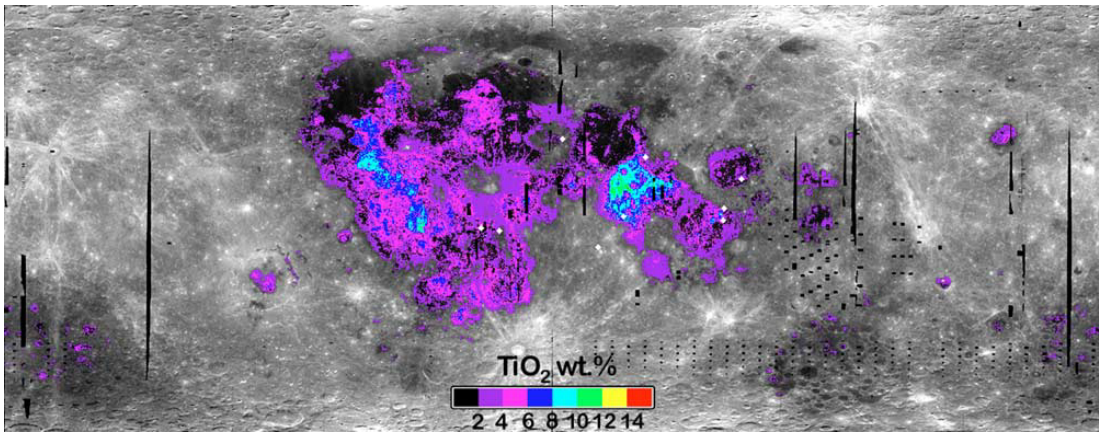
Yamashita et al. 2012 (EPSL)

Ti



H. Nagaoka et al. current

Clementine TiO_2 map of the Moon

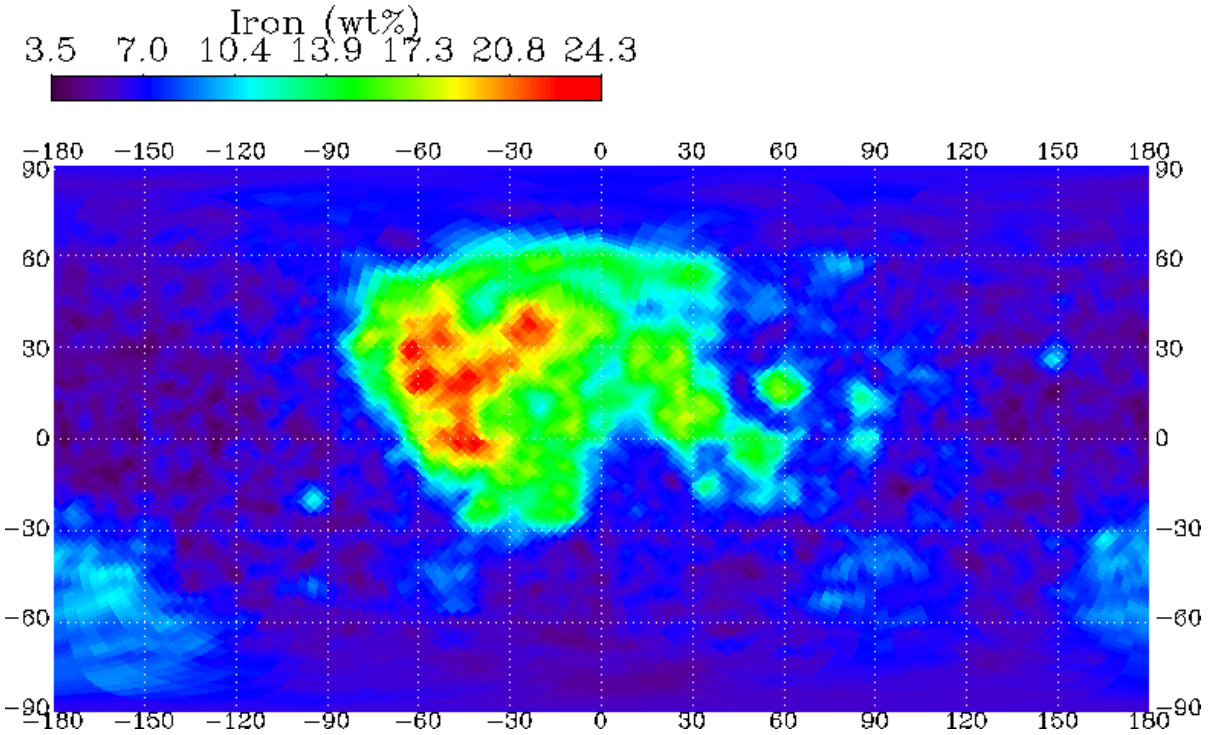


Gillis and Jolliff 2003, JGR

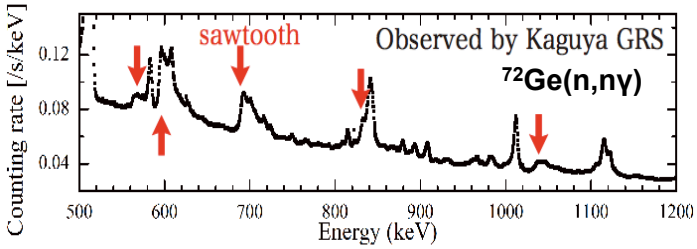
Fe

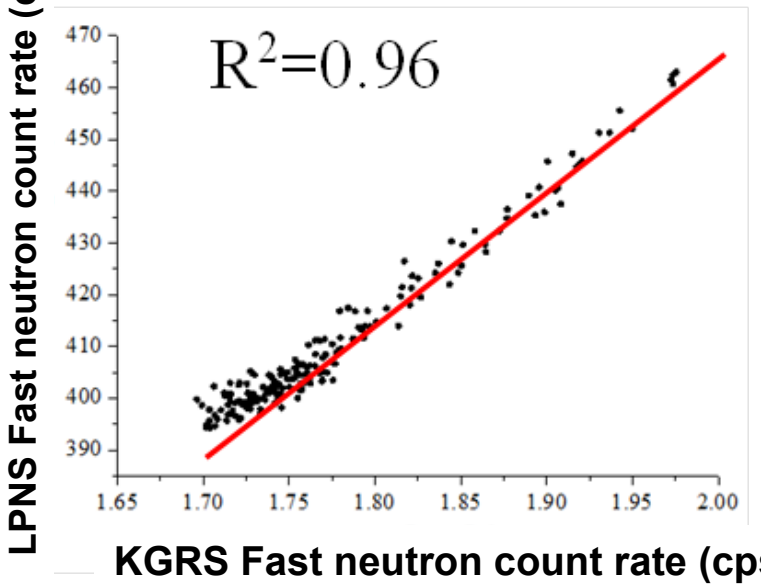
^{56}Fe(n,γ) ^{56}Fe 7.631 MeV : Neutron capture

^{56}Fe(n,nγ) ^{56}Fe 0.847 MeV: Fast neutron



Results of Sawtooth Peak Analysis
Intensity Distrib. of Fast Neutron



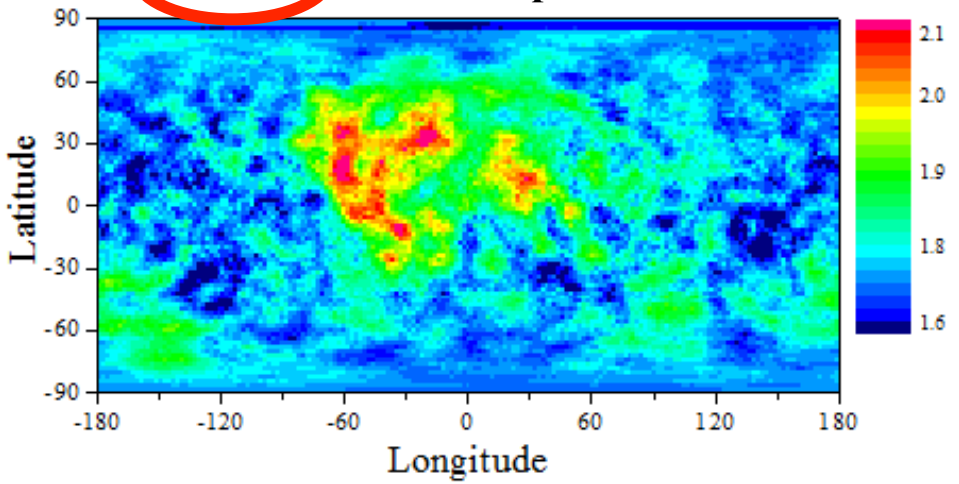


Good correlation between KGRS and LPNS

Extended the lower limit by KGRS

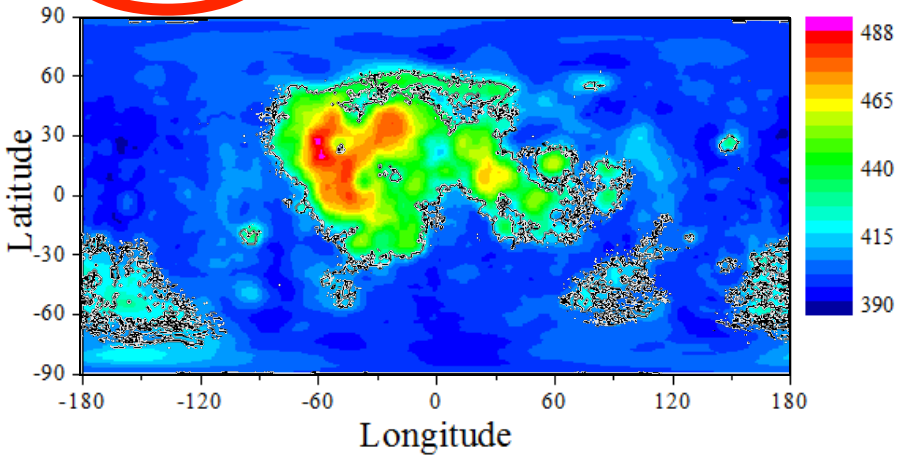
High Neutron Flux in Maria
Low Neutron Flux in Highlands
→ consistent with LPNS Results

KGRS: Global Map of Fast Neutrons



The global distribution of fast neutron has been revealed, for the first time, by the sawtooth-peak analysis for gamma-ray spectrum observed by KGRS.

LPNS: Global Map of Fast Neutrons

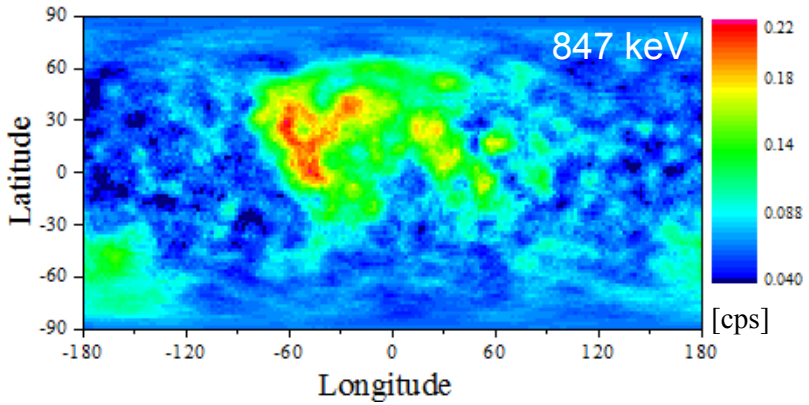


Hasebe et al. current

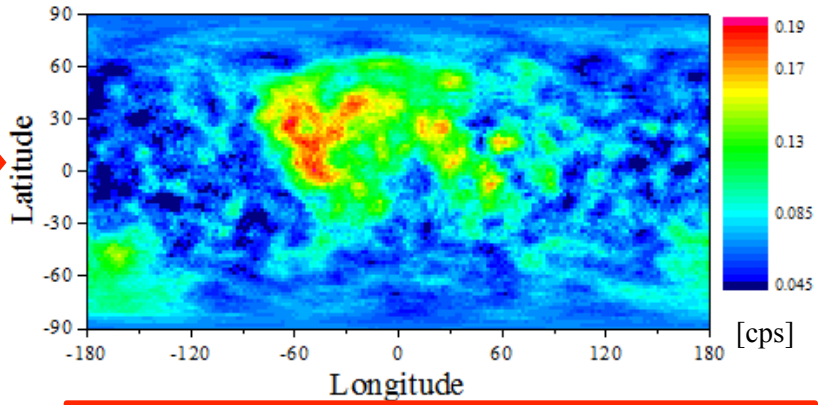
Maurice et al., 2000

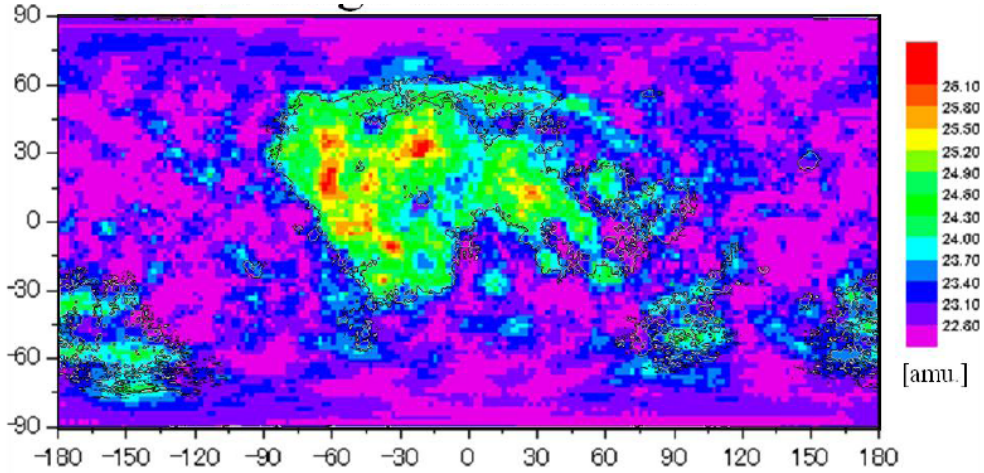
Neutron Correction to Derive Abundances of Major Elements

Fe-count rate map
before neutron correction



Fe-count rate map
after neutron correction





Average atomic mass obtained by KGRS

Neutron measurement cannot identify individual elements. But neutron spectroscopy indirectly provides specific information of elements.

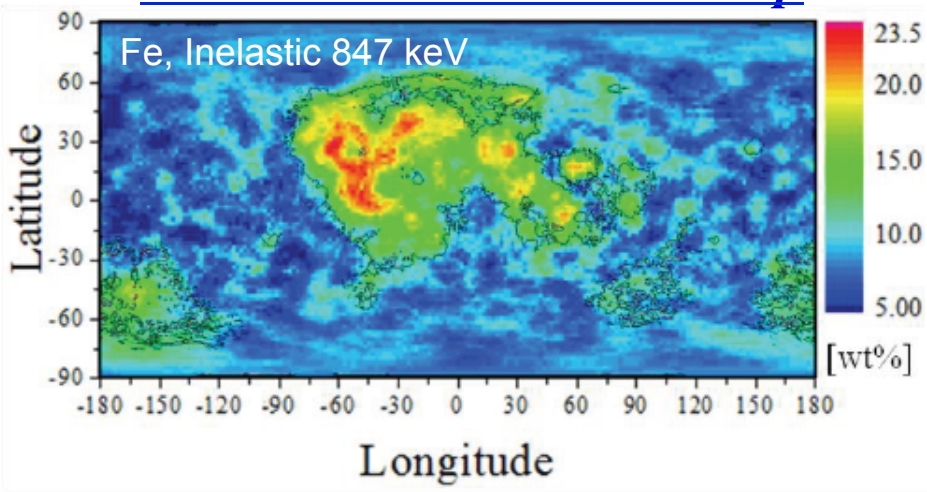
Neutron correction:
Fe(n,nγ) (cnt. rate)
divided by
Fast Neutron（rel. flux）

- **Good agreement with LPGRS**
- **KGRS provides clear distribution with low-FeO abundance when compared with LP data.**
  →This work provides higher precision in the low regions than that by LP

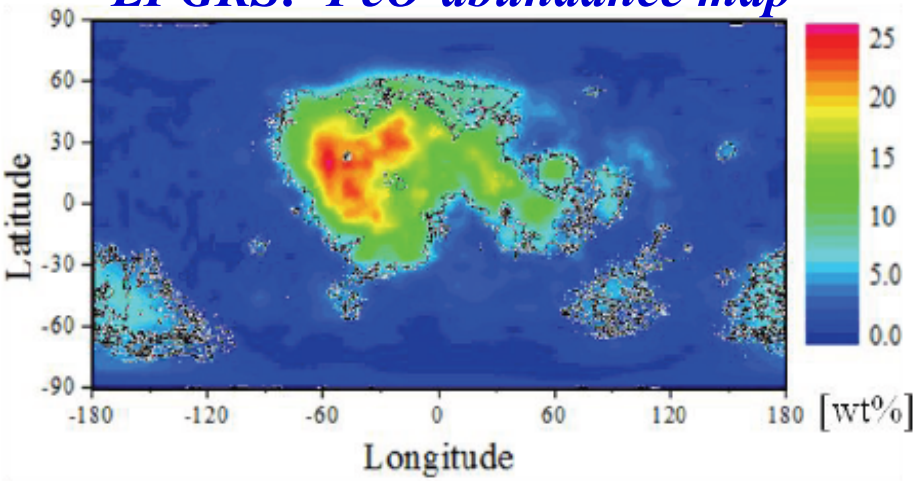
Neutron Correction to Derive Chemical Abundance of Major Elements

Neutron measurement cannot identify individual elements. But neutron spectroscopy indirectly provides information of elements.

KGRS: FeO-abundance map



LPGRS: FeO-abundance map



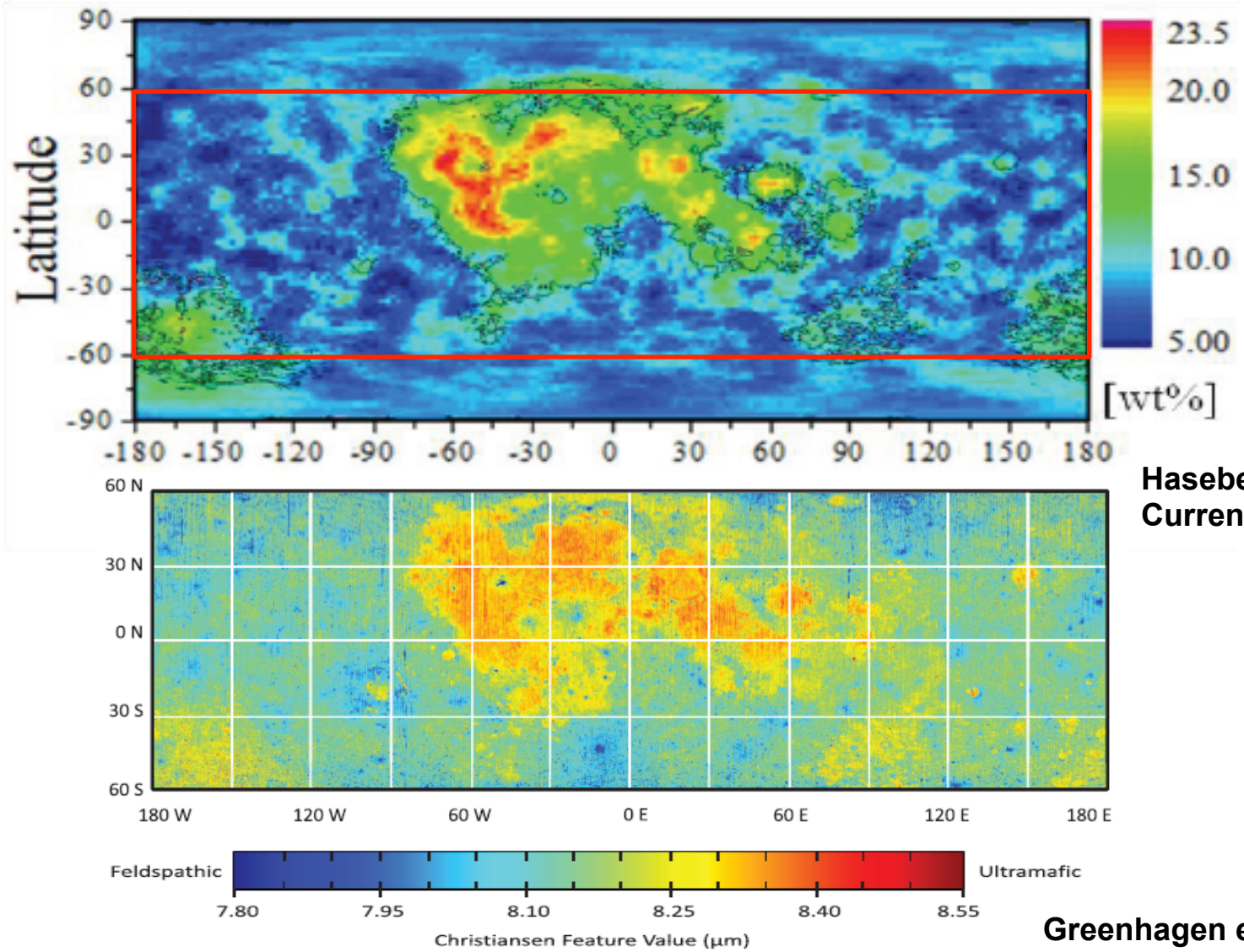
FeO-abundance maps are generated after the intensity correction of neutron.

- **Good agreement with LPGRS**
- **KGRS provides clear distribution with low-FeO abundance, when compared with LP data.**

→This work may provide higher precision in low FeO regions than LP GRS.

Hasebe et al. current

KGRS Fe vs Diviner Mineralogical Map



Hasebe et al. Current

Greenhagen et al., 2010

Si Elemental Analysis

Si analysis investigation

1. H. Nagaoka. WU
2. K. Kim. LPL/KIGAM
   * IGOR PRO analysis
   * Aquarius analysis
3. R. Elphic, NASA/ARC
   * Diviner data analysis

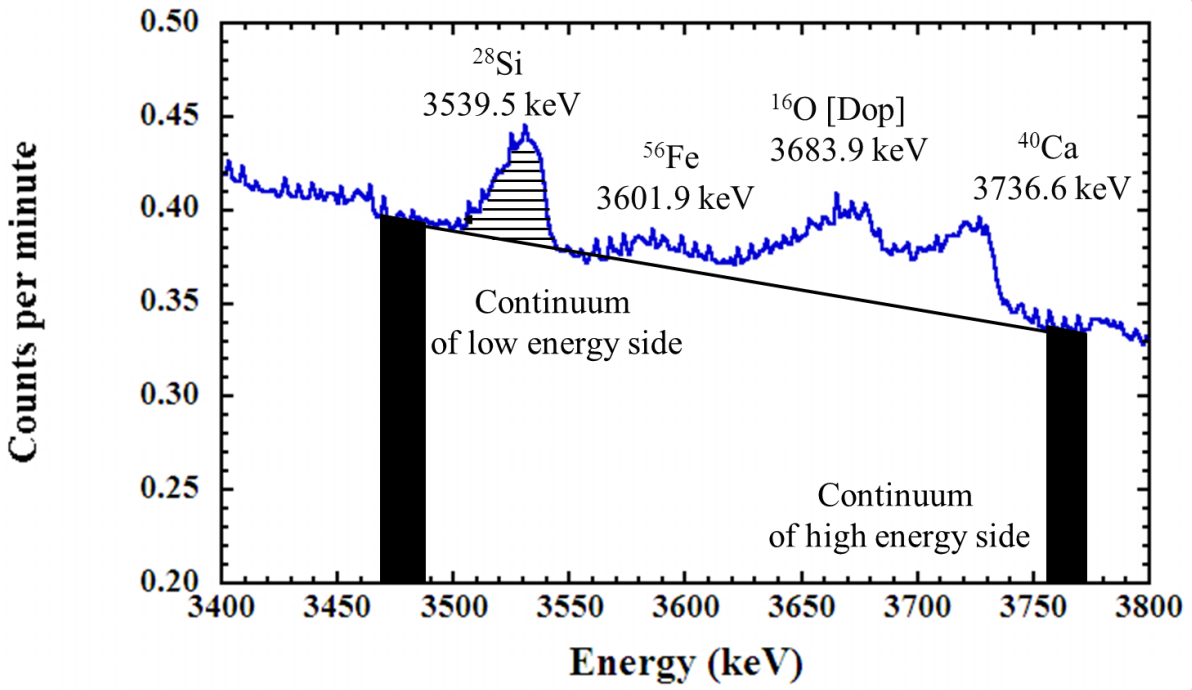
Data: Kaguya GRS data, Period3

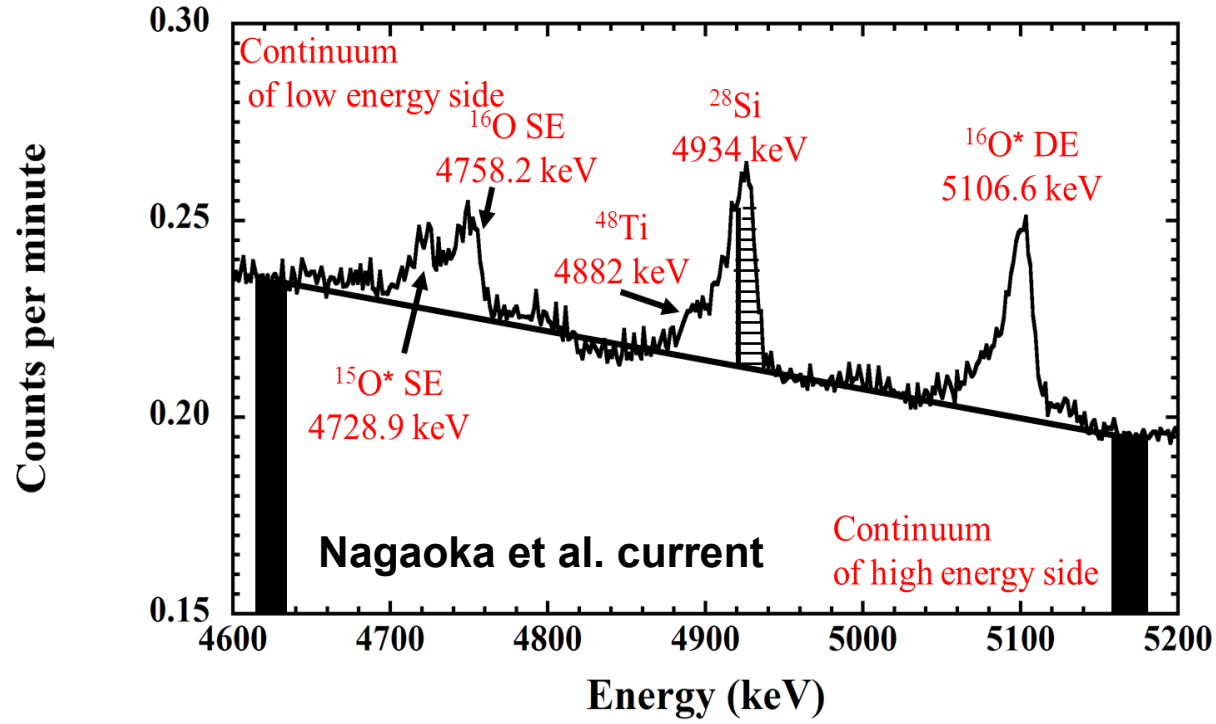
Peaks:

3539.5 keV(Si (n, γ)

4934 keV (Si (n, γ)

1778 keV (Si (n, nγ)



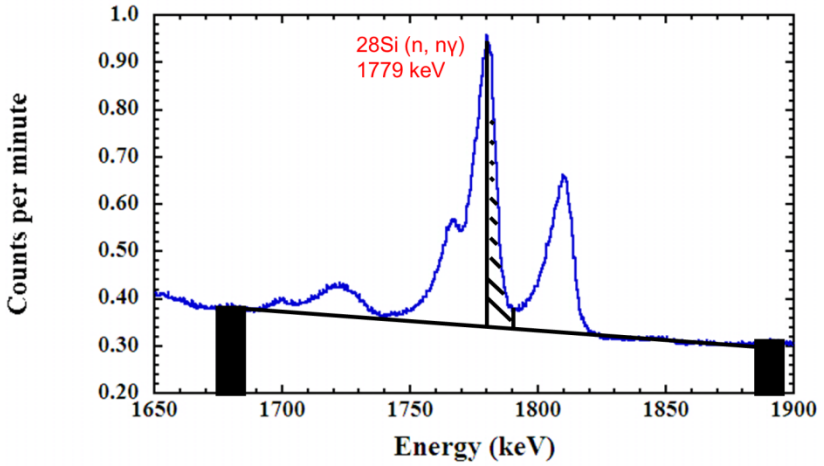


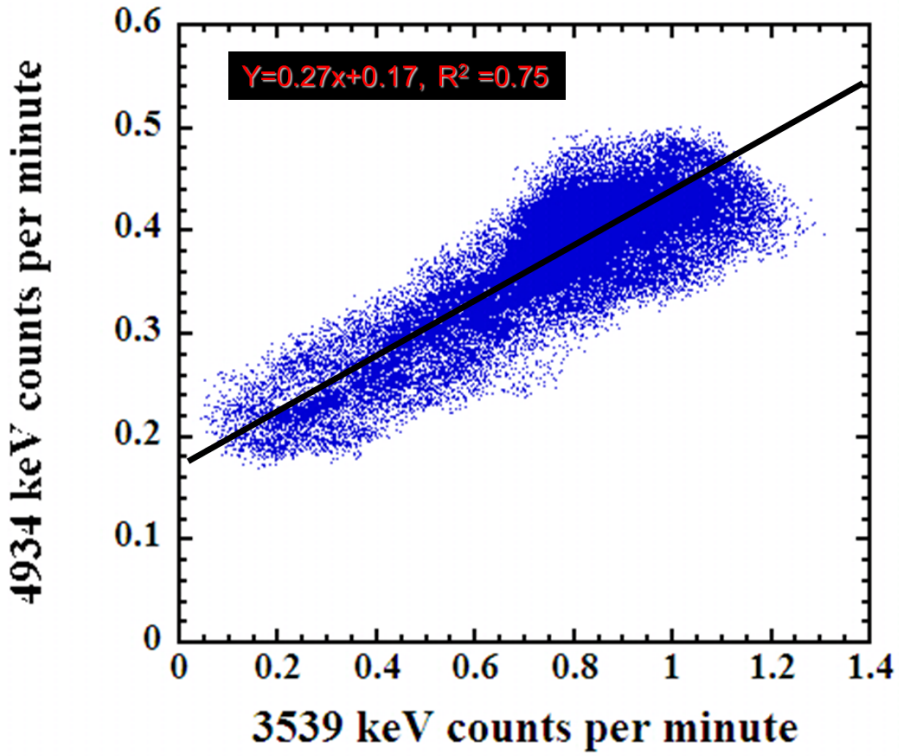
Si gamma-ray peak correlations

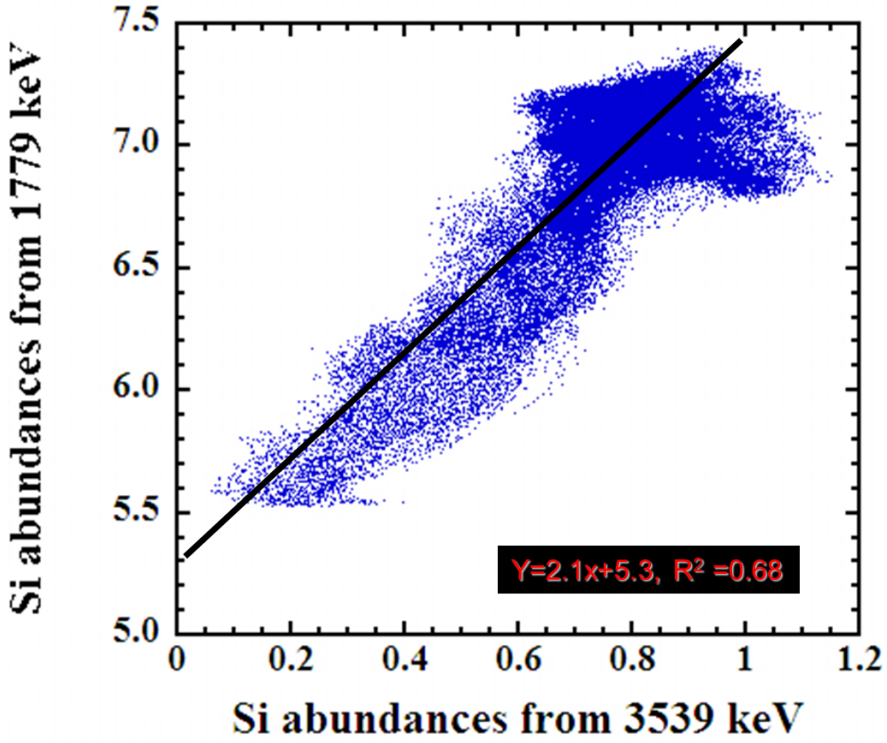
-4934 keV ^{28}Si (n, γ)

-3539 keV ^{28}Si (n, γ)

-1779 keV ^{28}Si (n, nγ)





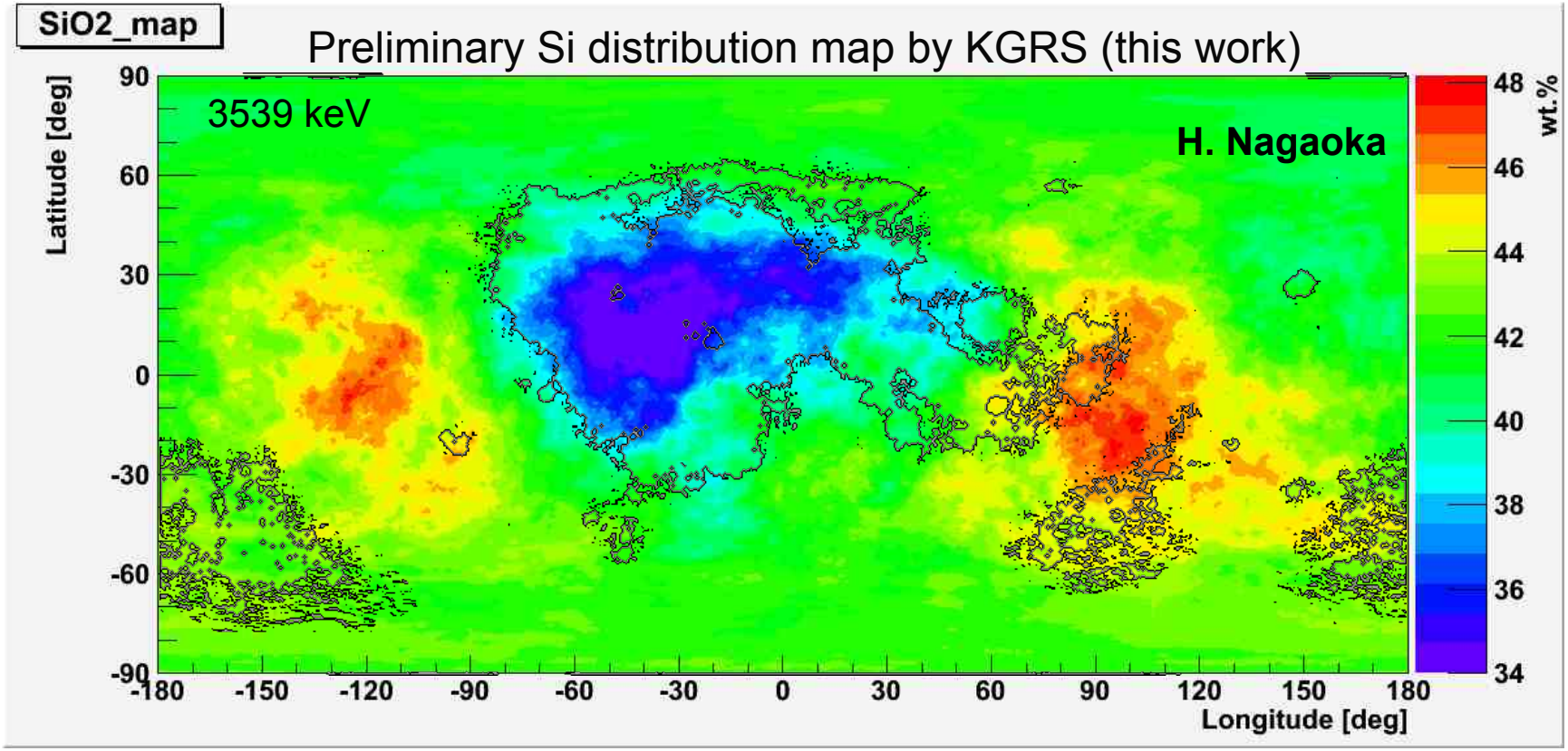


Nagaoka et al. current

Si Distribution Map by KGRS

LP Si concentration data (PDS data) were used for calibration of Si by KGRS

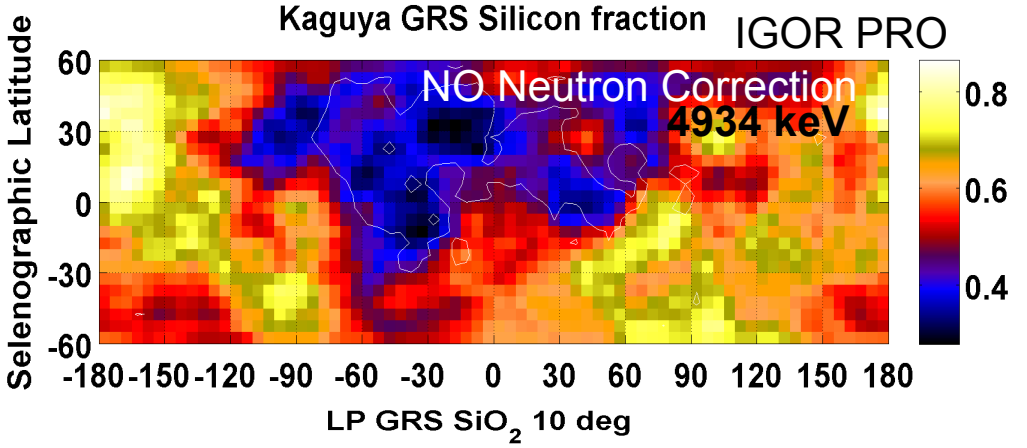
Si distribution Map by LP-GRS (Prettyman et al., 2006)

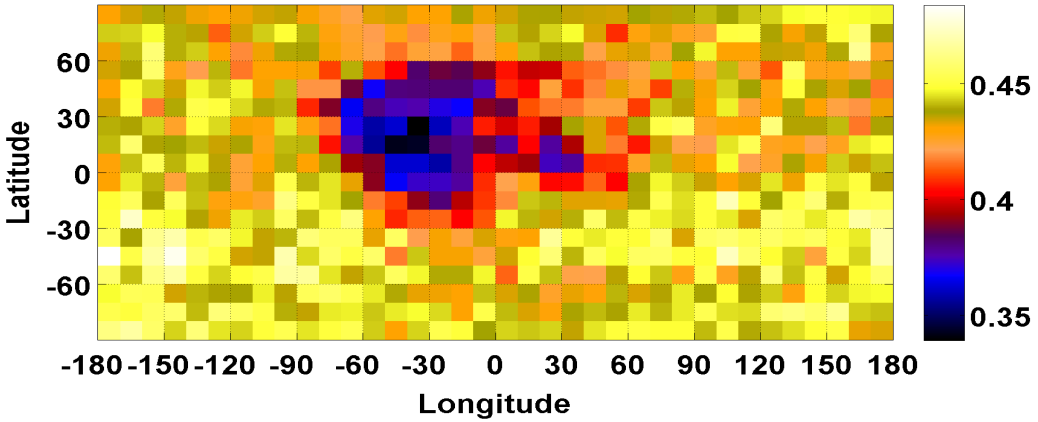


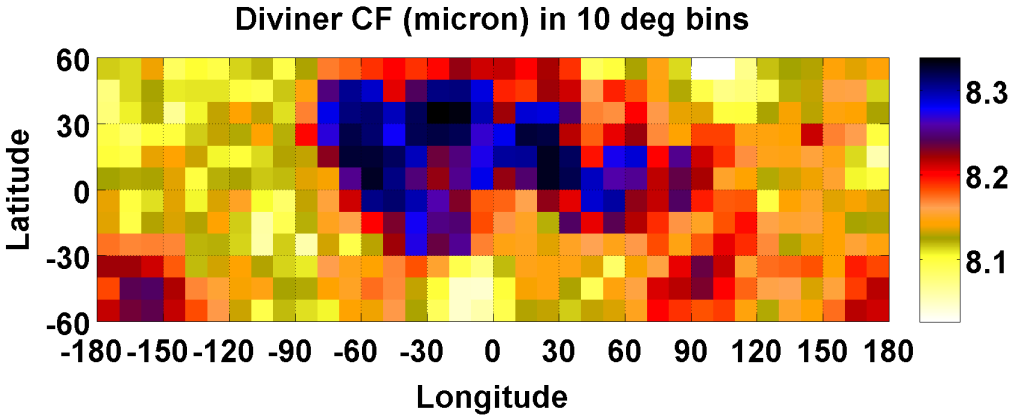
Neutron correction was applied to the net counting rates using Lunar Prospector (LP) thermal neutron data [The Planetary Data System, Maurice et al., 2004].

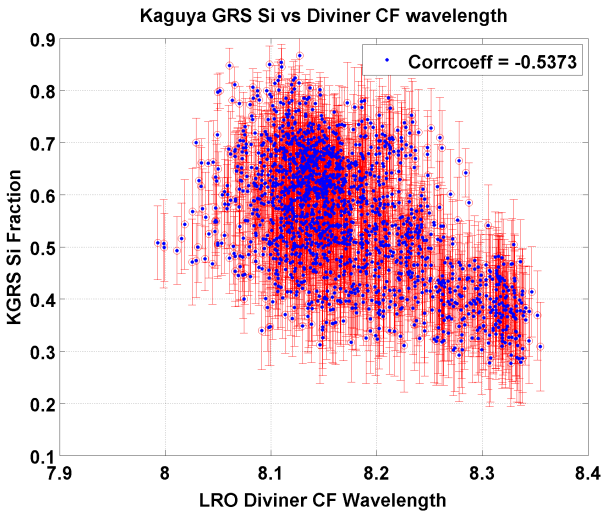
Nagaoka et al. current

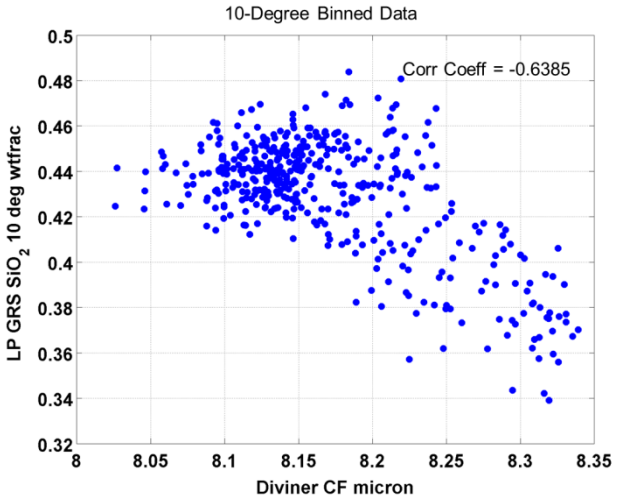
Correlation of Si & mineralogical map (Kaguya, LPGRS, LRO)











Elphic et al.

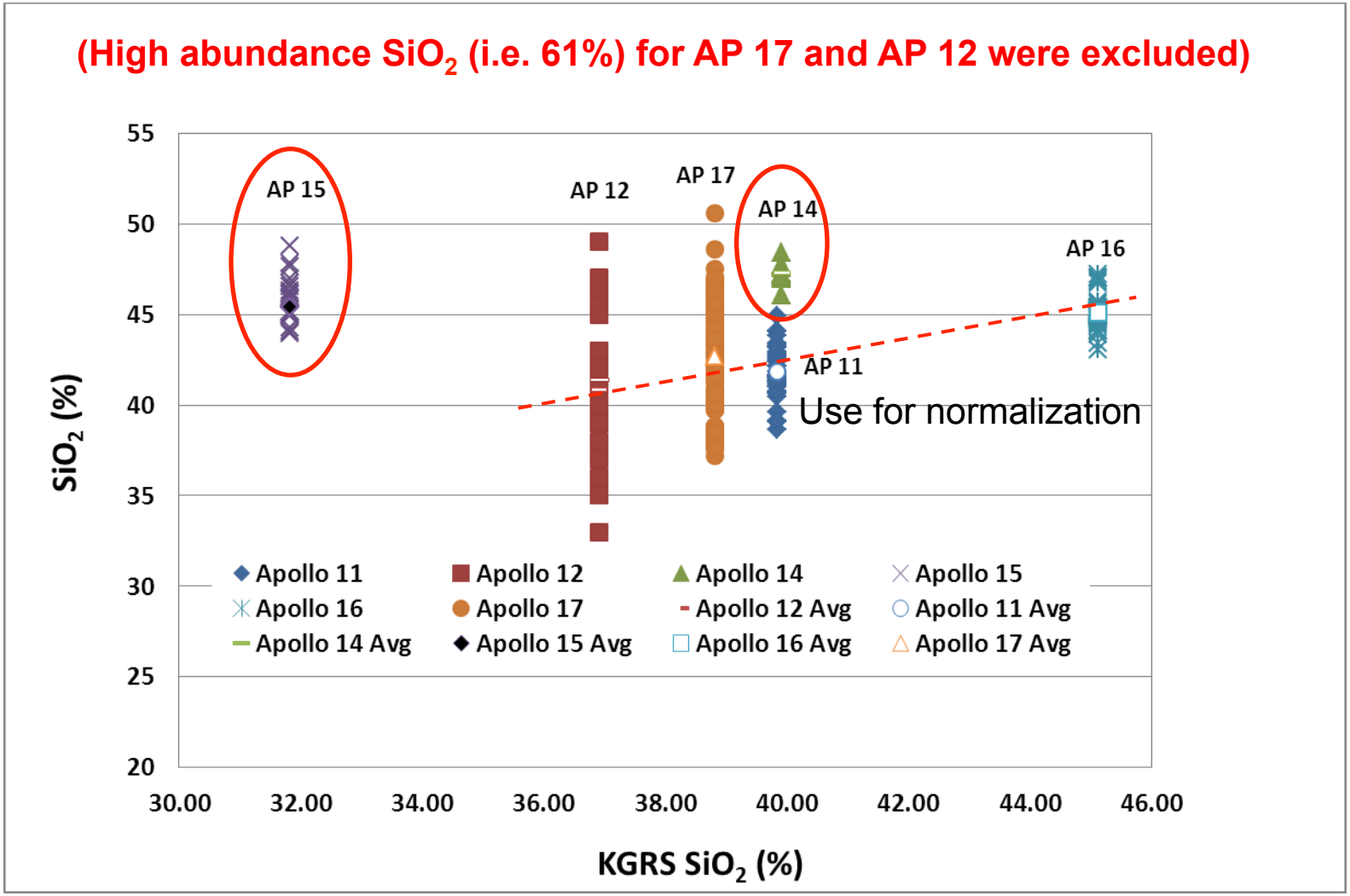
Normalization of Si abundance using Apollo reference data

Lunar Source Book P. 609			KAGUYA Orbit Data	
	Lat	Lon	Lat	Lon
11	0.7◦N	24.3˚E	0.7	24.3
12	3.2◦S	23.4˚W	-3.2	336.6
14	3.7◦S	17.5˚W	-3.7	342.5
15	26.1◦N	3.7˚E	26.1	3.7
16	**9◦S**	**15.5˚E**	**-9**	**15.5**
17	20.2◦N	30.8˚E	20.2	30.8

GRS DATA					
Lat	Lon	GRS (cpm)	Sigma (cpm)	Norm. Si (%)	Norm. SiO_2(%)
0.75	24.25	0.454	0.079	18.52	**39.84**
-3.25	336.75	0.421	0.085	17.16	**36.92**
-3.75	342.75	0.455	0.085	18.56	**39.92**
26.25	3.75	0.363	0.081	14.80	**31.83**
-9.25	15.75	0.514	0.079	20.98	**45.12**
20.25	30.75	0.442	0.079	18.04	**38.81**

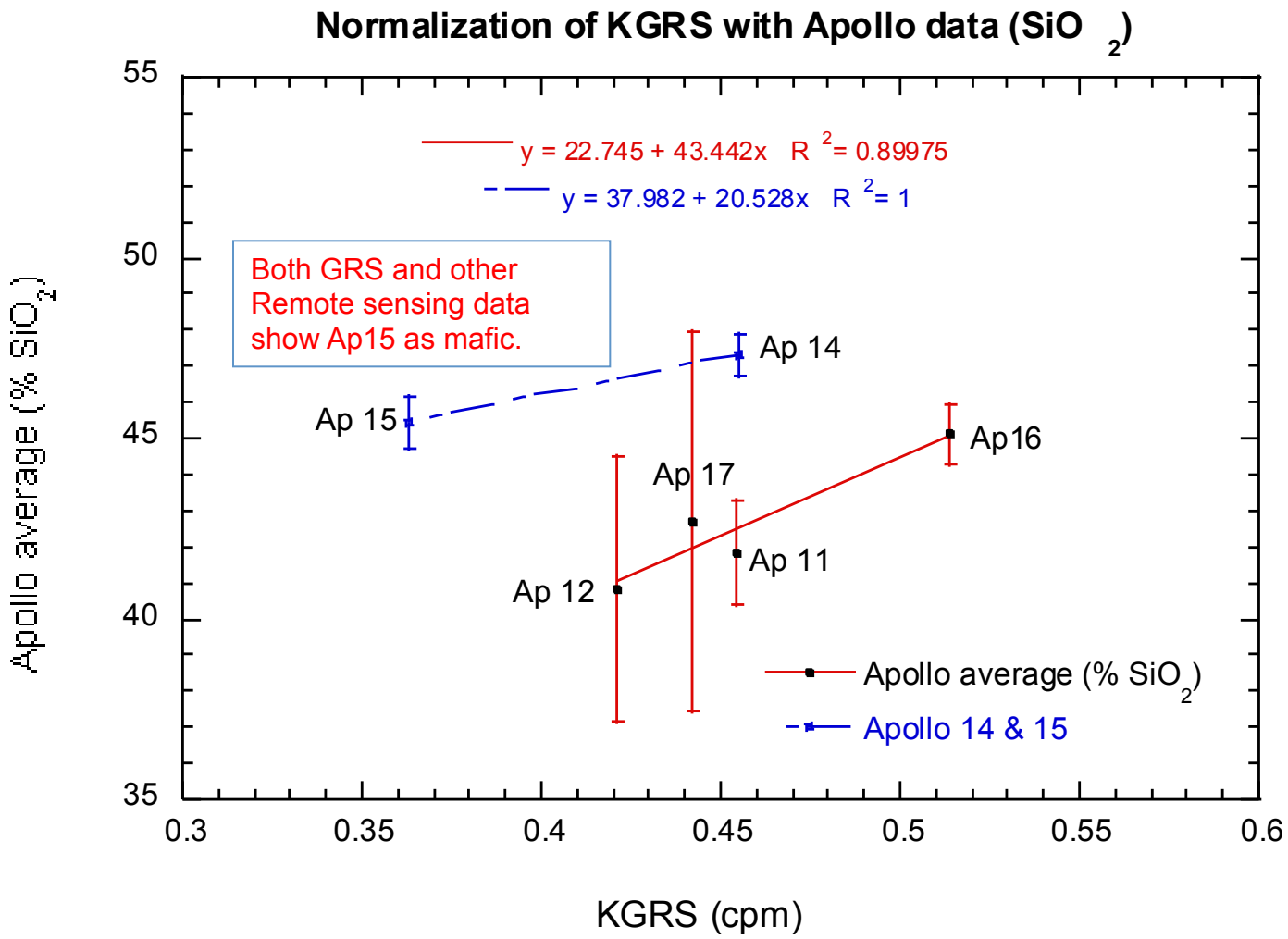
Kim et al. current

SiO_2 abundances Apollo Return Sample DATA

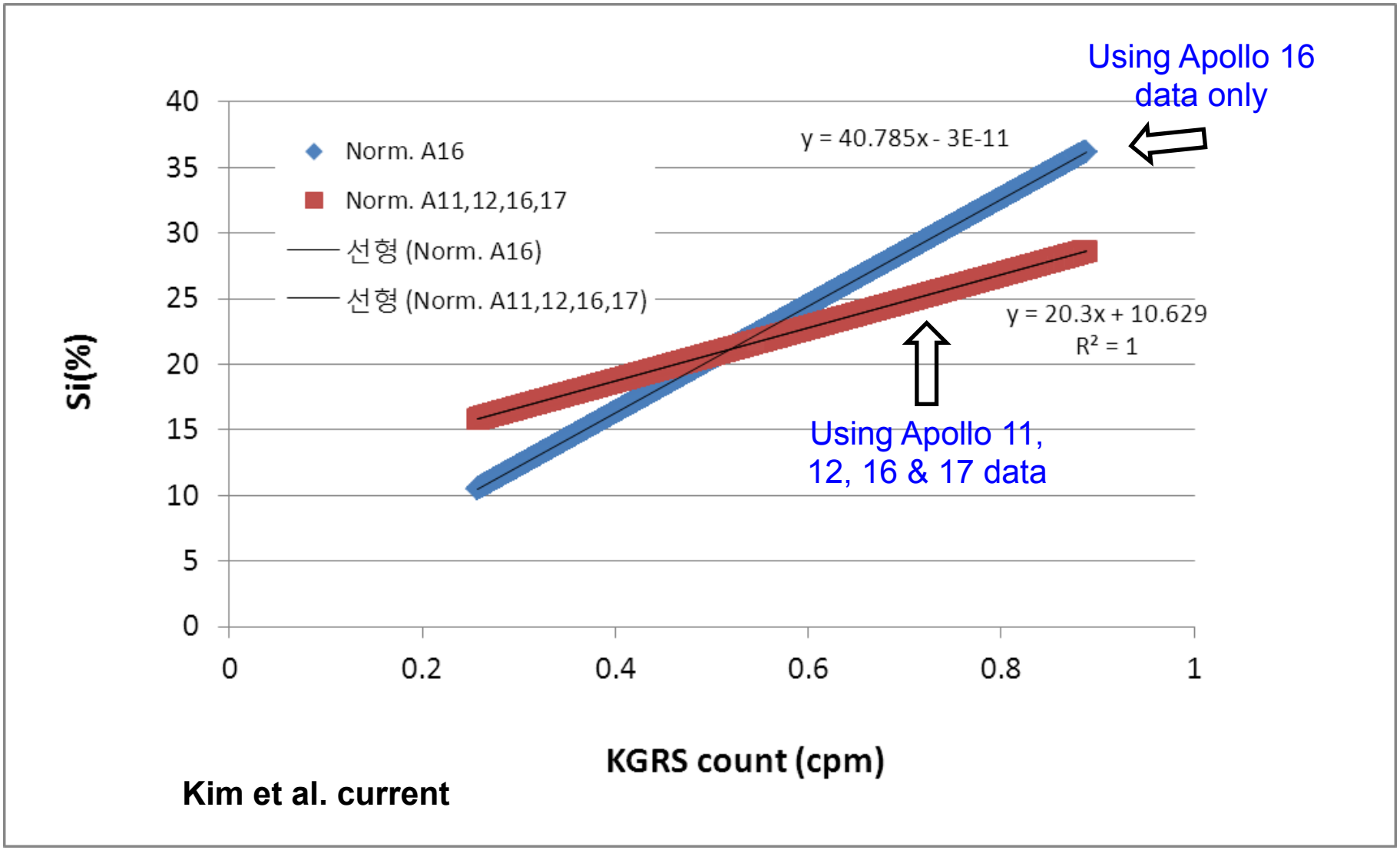


Kim et al. current

KGRS data points for six Apollo sites were read from the altitude and neutron corrected Si map (smoothed.)

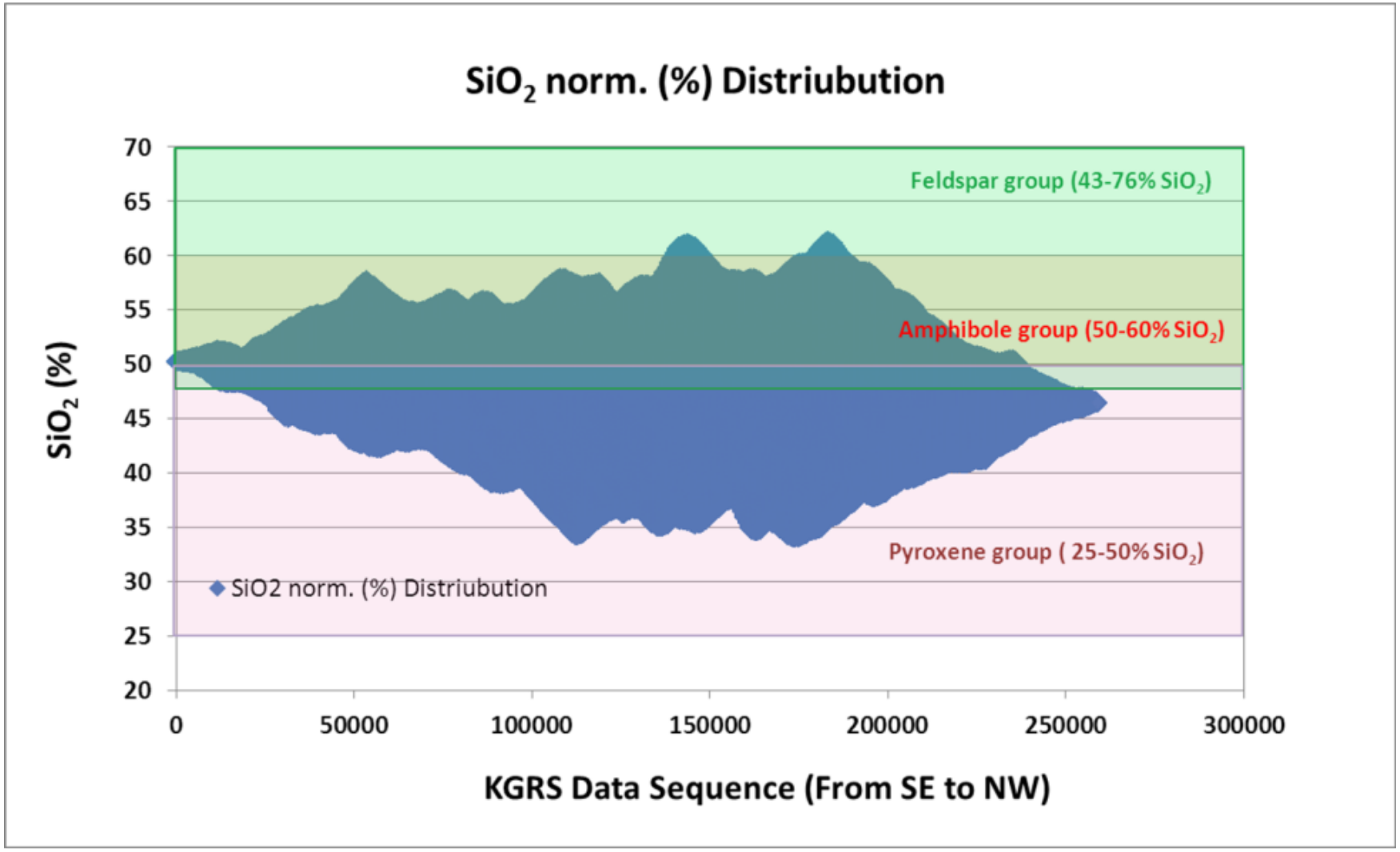


Normalization of Si abundance using Apollo reference data



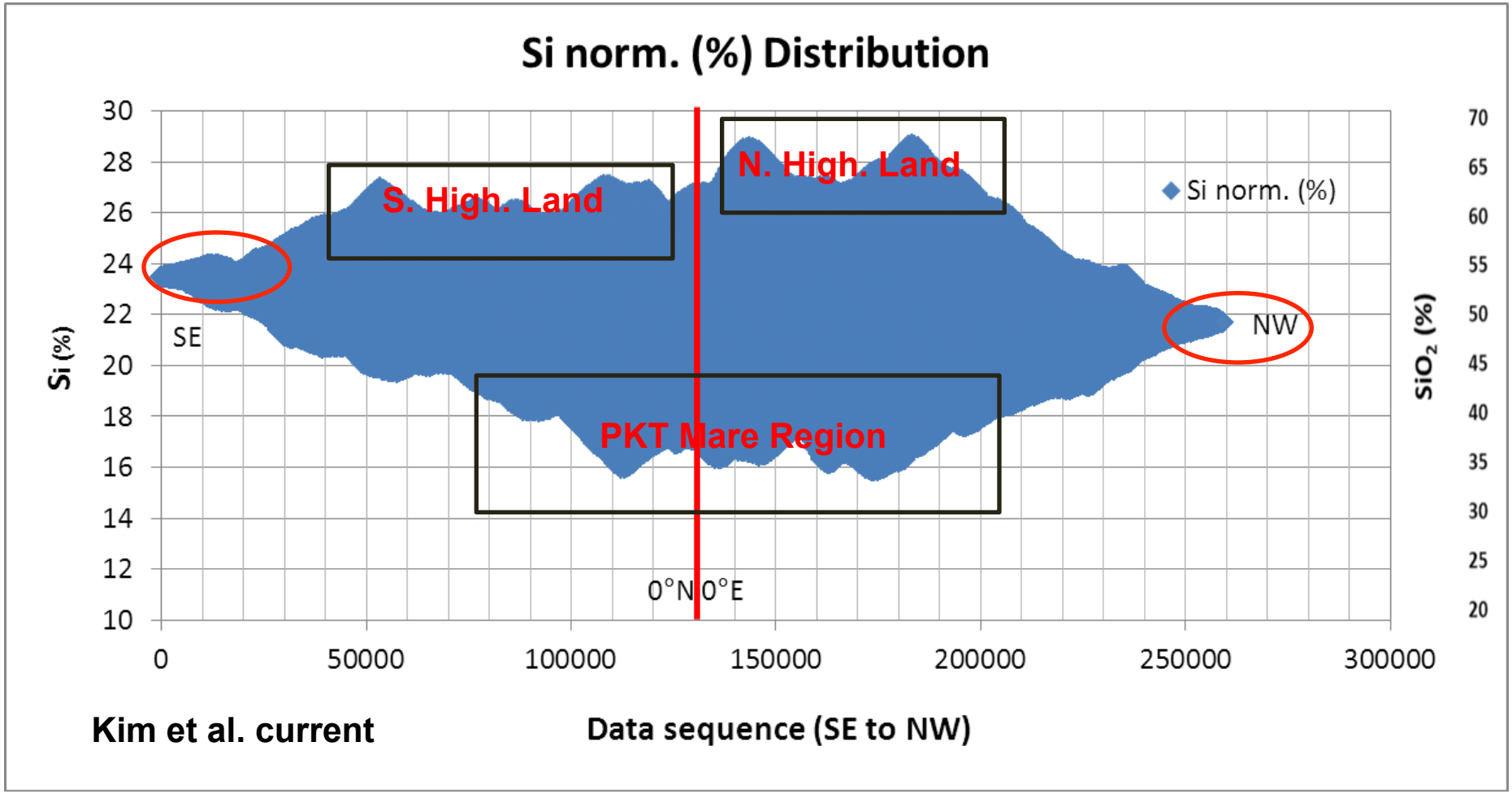
Mineralogical Groups containing Si (Earth) and normalized SiO_2 content of KGRS data

Feldspar group: 43-76% SiO_2
Amphibole group: 50-60% SiO_2
Pyroxene group: 25-50 % SiO_2



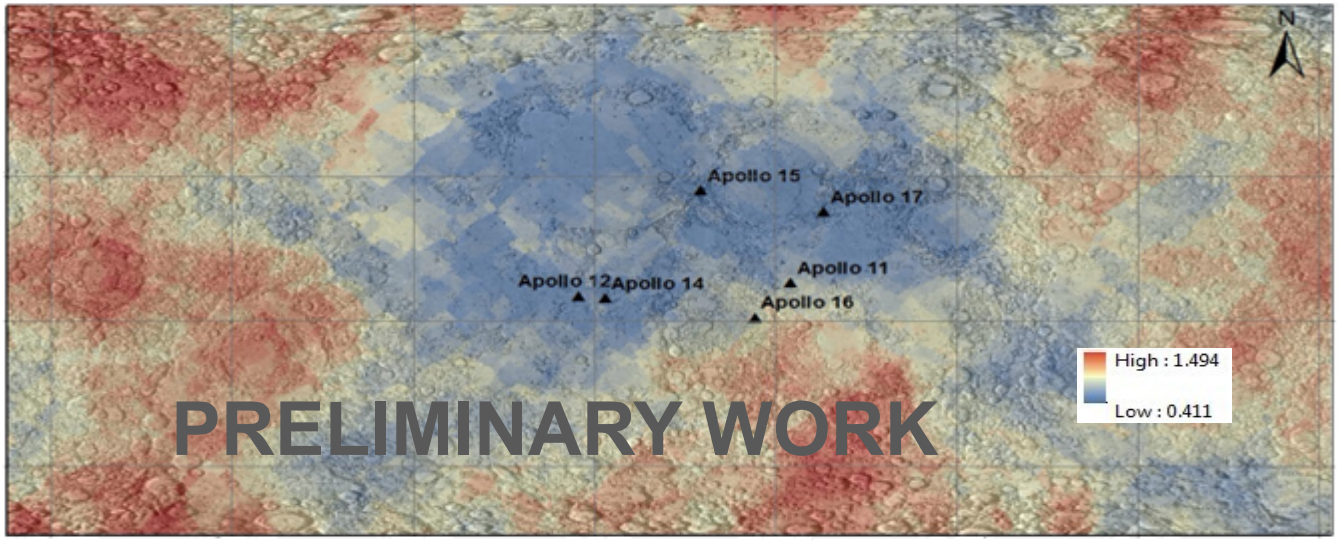
Analysis of Si Distribution & Possible Mineralogical Group by GRS data

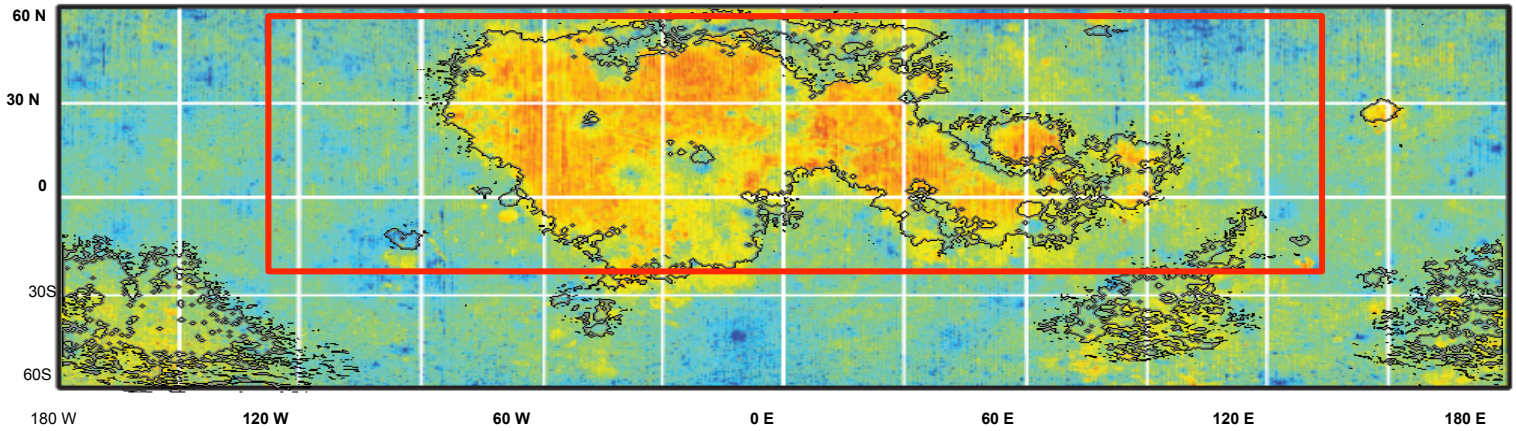
PKT Mare Region: Pyroxene Group (SiO_2 25-50%)
S & N High Land: Feldspathic Group (SiO_2 43-76%)
Amphibole Group (SiO_2 50-60%)

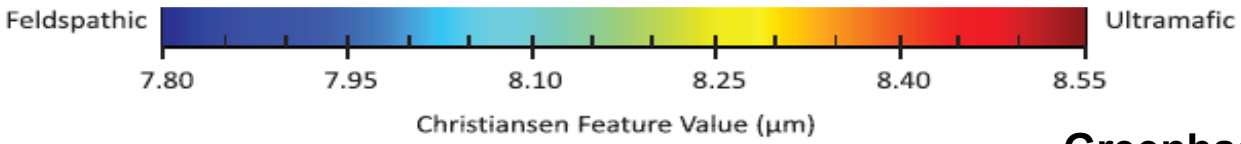


4934 keV Si line, 10 degree map,

Aquarius Program







Greenhagen et al., 2010

Summary

- Normalized Si abundance by KGRS data ranged from ~15 to 27% Si.
- The lowest and highest SiO_2 abundance correspond to mineral groups like pyroxene group (PKT region) and feldspar group (Northern highlands), respectively.
- When the Si map of KGRS data is compared with the LRO/Diviner mineralogical map, a reasonable agreement in understanding of the dichotomy between lunar mafic and feldspathic regions of the moon is confirmed.
- Diviner data show detailed mineralogical variation at the very top surface, but quantification of Si is difficult while GRS data show the quantification of Si for at least several tens of cm depth.
- Major elemental maps of Al and Ca (published).
- Major elemental maps Fe and Ti (under investigation) agree with previously published maps.