PEER REVIEW REPORT

PLANETARY RESEARCH

This peer review report contains the editor decisions, reviews, and author rebuttals for each round of peer review. The peer review rounds are ordered chronologically, and the final acceptance decision is not included.

The published manuscript can be found on the journal website: https://planetary-research.org.

TITLE

The SiO_2 abundance on the surfaces of the Moon and Mercury

AUTHORS

C. Renggli et al.

DOI

https://doi.org/10.53480/bf74m226

EDITOR DECISION
round 1

Dear Christian Renggli,

I would like to thank you for submitting your manuscript "The SiO_2 abundance on the surfaces of the Moon and Mercury" (#226) to Planetary Research. Since you have the very first submission, they may be bugs in the treatment. For the moment, the process is running very well and we will do our best to keep it running smoothly.

I have now received the reviews and associate editor assessment of your submission, which are included at the bottom of this email. Based on my evaluation of your submission, your manuscript should in principle be suitable for publication after revision.

Please provide us with a point-by-point response to all comments and identify what changes you have made to the revised manuscript. In addition to the rebuttal, we ask that you also provide a document that tracks all changes that have been made to your manuscript since its initial submission.

When you have completed your revisions, you can upload the revised manuscript, your response and a tracked changes document from your submission dashboard.

As a reminder, letter manuscripts must contain fewer than 4500 words in the combined abstract, main text and captions, and may contain up to three figures or tables. Following the main text, the manuscript may include a methods section that is no more than 3000 words in length. Please ensure that these limits are fulfilled.

If you have any questions about the recommendations in your review, or if you are unsure how to respond or proceed, please do not hesitate to contact me from your submission dashboard.

Sincerely,

Frédéric Schmidt

Associate editor recommendation

Thank you for submitting your manuscript entitled "The SiO2 abundance on the surfaces of the Moon and Mercury" [Submission Id: 226] to the journal Planetary Research. I have received 2 reviews of your manuscript, which are included below and/or attached. As you can see, the reviews indicate that major revisions are needed before we can consider proceeding with your paper. I am therefore returning the paper to you so that you can make the necessary changes.
Please note that reviewer 2 points out that the relationship between spectral Christiansen Feature and SiO2 content is much more complicated that what shown in the paper. You need to address this issue carefully in the revisions.

Sincerely,

Le Qiao

The following comments were received from the reviewers.

Reviewer 1:
Recommendation: Revisions Required With Review

All pre-existing data used in the manuscript are publicly available and sufficient information is provided so that they can be found and accessed.

Yes

All significant data products generated as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI).

Yes

All significant numerical codes developed as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI or SWHID).

Yes

All pre-existing software used as part of the study are acknowledged, and sufficient information is provided to find, access, and understand the software. If the software is restricted, the conditions under which it can be accessed are publicly available.

Yes

If you answered no to any of the above questions, please provide supporting information.

I am uploading an annotated version of the manuscript.

No

Comments for the authors

This work presents a calibration of the relationship between the mid-infrared Christiansen Feature and SiO2 abundance. The most prominent highlight of this study lies in supplementing measured sample data to enrich the model, that has not been achieved in previous SiO2 inversion studies. The accuracy of the inversion model has been significantly improved. Meanwhile, the derived SiO2 map shows good consistency with several highly silicic regions on the Moon. This work holds considerable significance, the newly derived SiO2 distribution data is poised to be widely adopted in lunar research.

However, several points require clarification or revision to strengthen the manuscript:
1. While the manuscript's core content is comprehensible, structural revisions are necessary to enhance the clarity of result presentation. The most prominent issue is the overly lengthy Results and Discussion section, which should be reorganized into focused subsections for better logical flow. The content around line 63 ought to be relocated to the final paragraph of the Introduction. This rearrangement will first provide a comprehensive overview of existing research progress, followed by a clear articulation of the improvements and advancements achieved in this study. I argue that previous SiO_2 maps derived from inversion models have inaccurately estimated high-silica regions, failing to depict areas with SiO_2 contents exceeding 60 wt.%. Furthermore, the core outcome of this work lies in lunar SiO_2 mapping. The content related to Mercury can be fully separated into an independent section as a future outlook, which will better distinguish the primary research focus from extended applications.
2. It is necessary to add a standalone paragraph to explicitly describe the data used in this study, including three key categories: lunar samples utilized for inversion validation, additional extended samples, and other supporting datasets. This detailed data description will enhance the transparency and reproducibility of the research, allowing readers to better understand the foundation of the calibration model and inversion results. Figure 1, you can add a separate fitting curve for literature values alone (excluding the new synthetic glasses) alongside the existing combined fit, highlighting the significance of new synthetic glasses
3. I recommended to include a dedicated comparative analysis of the newly derived lunar SiO_2 distribution map with previous datasets, inversion results and Lunar Prospector Gamma-Ray Spectrometer (LPGRS) data. This comparison will not only highlight the advancements of the current study but also provide critical insights into the consistency and uniqueness of the new results. Significant discrepancies are expected between the new map and prior inversion outcomes, particularly in high-silica regions such as Lassell Massif, Aristarchus Crater, and Gruithuisen Domes. Previous modelsfailed to quantify SiO_2 contents exceeding 60 wt.% due to limited calibration across extreme compositional ranges, whereas the new map reliably captures values up to 76 wt.% (Lassell Massif) by leveraging the extended synthetic glass dataset. This stark difference merits in-depth discussion.

Reviewer 2:

Recommendation: Decline Submission

All pre-existing data used in the manuscript are publicly available and sufficient information is provided so that they can be found and accessed.

Yes

All significant data products generated as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI).

Yes

All significant numerical codes developed as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI or SWHID).

Yes

All pre-existing software used as part of the study are acknowledged, and sufficient information is provided to find, access, and understand the software. If the software is restricted, the conditions under which it can be accessed are publicly available.

Not applicable

If you answered no to any of the above questions, please provide supporting information.

I am uploading an annotated version of the manuscript.

No

Comments for the authors

The SiO_2 abundance on the surfaces of the Moon and Mercury

This manuscript attempts to quantify silica from CF wavelength position using a very small subset of laboratory acquired mid-IR reflectance data of glasses. Then they use this relationship to derive a function between CF and SiO2 and apply that to Diviner data. This is a very simplistic and misleading approach to solve this problem which does not account for the nuances related to the CF, bulk silica and Diviner dataset. The manuscript doesn't clarify how CF is estimated and does not explain how this method is comparable to method used by Diviner and where it fails. I cannot recommend it for publication in its current form.

Line 29-30: "The mid-infrared spectral Christiansen Feature is strongly dependent on a material's SiO2 content" Nope CF is indicator of silica polymerization not SiO2 content, CF can vary in materials with same silica content but different polymerization and crystallinity amongst other things.
Line 41-42: "Here, we present a new experimental calibration based on synthetic glasses with SiO2 concentrations from 0.5 wt.% to 97.6 wt.% SiO2 "Why only synthetic glasses and not Apollo /Luna samples or minerals, mixtures or rocks?
Line 65-67:" The Christiansen Feature (CF) is defined as the reflectance minimum or emission maximum and is also dependent on the chemical composition (Conel, 1969; Cooper et al., 2002)". This is an incomplete understanding of this feature. CF changes due to factors other than chemical composition such as crystallinity, particle size, albedo, temperature, porosity and environment (vaccuum versus ambient).
Line 67-69: "The CF was previously found to linearly correlate with the concentration of SiO2 in wt.% in rock powders with coefficients of determination from R2 =0.6 (Weber et al., 2023) to R2 = 0.772 (Cooper et al., 2002)" As the data variability and availability has increased, CF's correlation with SiO2 has consistently reduced as can be observed by several other works so this sentence is misleading.
Figure 1 only works with limited material. Show that this relationship holds with variation in particle size, porosity, minerals, mixtures, rocks and Apollo samples or it is a very misleading figure! Literature data on glasses?
A few other factors to consider here are following:

1. Was CF estimated the same it is estimated from Diviner channels 3,4 and 5 or via some other measure because if they were estimated via other measures, it needs to be redone. The authors should first convolve the data to Diviner channels and then estimate CF via parabolic fit and then display what kind of relationship it shows or it is not applicable to Diviner!
2. The Moon has a unique thermal environment and at the least mid-IR reflectance should not be used for studies planning to apply such relationships to orbital data. The authors need to carry out emissivity measurement and not use reflectance data at the least; the best-case scenario would be using simulated lunar environment emissivity spectra.

Line 106-107: "This guarantees similar analytical conditions and limits artifacts from grainy surfaces or crystallites" How?
Line 109-115: This paragraph is extremely misleading unless done for a variety of particle size, minerals, mixtures and rocks!
Line 116-117: Not to Sio2 concentration but silica polymerization.

A figure needs to be added for 3-band estimated CF versus SiO_2 estimated from this equation and a comparison between lab measured silica and quantified silica for the readers.
Also, what is the error bar on the silica predictions from this method?

CF maps of Diviner are known to be poor fits/incorrect values for silicic and ultramafic composition and that is why CF needs to be estimated the same way as done for Diviner wavelengths for this comparison or this is pointless.

AUTHOR REBUTTAL
round 1

Dear,

Thank you very much for your handling of this manuscript. We thank the reviewers for their comments.

Below, we address each comment individually in green. Modifications to the manuscript are shown in blue.

Kind regards

Chris

Thank you for submitting your manuscript entitled "The SiO2 abundance on the surfaces of the Moon and Mercury" [Submission Id: 226] to the journal Planetary Research. I have received 2 reviews of your manuscript, which are included below and/or attached. As you can see, the reviews indicate that major revisions are needed before we can consider proceeding with your paper. I am therefore returning the paper to you so that you can make the necessary changes. Please note that reviewer 2 points out that the relationship between spectral Christiansen Feature and SiO2 content is much more complicated that what shown in the paper. You need to address this issue carefully in the revisions.

Thank you for handling this manuscript. We would like to state that we strongly disagree with the main critique by the second reviewer! The CF is strongly dependent on the SiO2 concentration! All the other parameters have minor effects. Amorphous glasses are the ideal analogues, because they average out crystal size, crystallinity, or crystallographic orientation effects. For the response we include a figure where we plot CF against a proxy for polymerization in glasses, the ratio of non-bridging oxygen (NBO) over tetrahedrally coordinated cations, termed NBO/T, following the calculation by Mysen (2004, Chemical Geology 213, 1-16). The second reviewer appears to reject our approach categorically without even considering the evidence at hand. Here, we are able to constrain the SiO2 abundance on the Moon with an independent verification based on the comparison with the returned lunar sample suites. In addition, as the first reviewer points out, this is the first method which is able to reliably quantify the expected SiO2 concentrations in the high-silica regions discussed in this manuscript. Below we list all comments and reply to them individually.

Reviewer comments:

This work presents a calibration of the relationship between the mid-infrared Christiansen Feature and SiO2 abundance. The most prominent highlight of this study lies in supplementing measured sample data to enrich the model, that has not been achieved in previous SiO2 inversion studies. The accuracy of the inversion model has been significantly improved. Meanwhile, the derived SiO2 map shows good consistency with several highly silicic regions on the Moon. This work holds considerable significance, the newly derived SiO2 distribution data is poised to be widely adopted in lunar research.

However, several points require clarification or revision to strengthen the manuscript:

While the manuscript's core content is comprehensible, structural revisions are necessary to enhance the clarity of result presentation. The most prominent issue is the overly lengthy Results and Discussion section, which should be reorganized into focused subsections for better logical flow.

The reviewer makes a good point. We added sub-sections and titles to the discussion to make it easier to follow the structure

The content around line 63 ought to be relocated to the final paragraph of the Introduction. This rearrangement will first provide a comprehensive overview of existing research progress, followed by a clear articulation of the improvements and advancements achieved in this study.

We thank the reviewer for this suggestion and restructured the introduction.

I argue that previous SiO2 maps derived from inversion models have inaccurately estimated high-silica regions, failing to depict areas with SiO2 contents exceeding 60 wt.%. Furthermore, the core outcome of this work lies in lunar SiO2 mapping. The content related to Mercury can be fully separated into an independent section as a future outlook, which will better distinguish the primary research focus from extended applications.

We have restructured the results and discussion sections to make it easier to follow.

2. It is necessary to add a standalone paragraph to explicitly describe the data used in this study, including three key categories: lunar samples utilized for inversion validation, additional extended samples, and other supporting datasets. This detailed data description will enhance the transparency and reproducibility of the research, allowing readers to better understand the foundation of the calibration model and inversion results.

We have placed these descriptions of the data where they are discussed in the manuscript. We believe that it works better to describe them where they are discussed in the context of the manuscript. We have added additional details:

> For the calibration we include literature data of CF positions measured for planetary analogue glasses, that were measured by micro FTIR specular reflectance on polished surfaces (Haupt et al., 2026; Morlok et al., 2017, 2020, 2021). The data are chosen as pure glasses without crystallization features, with the same spectral resolution. This guarantees identical analytical conditions to avoid features that does not come from the compositional effect, which we calibrate for.

The CF dataset that we use from Lucey et al. (2021) is described in the beginning of the section 2.2. SiO2 on the lunar surface. We add their estimates of uncertainty for corrected CF and translate this to uncertainty in SiO2.

> The Diviner spectrometer mapped the surface of the Moon with three narrow-band channels near 8 µm, which allowed the calculation of the CF spectral positions (Donaldson Hanna et al., 2017; Greenhagen et al., 2010; Lucey et al., 2017). Here, we use a global CF dataset for the Moon, which was corrected for illumination, topography, geometry, and space weathering effects by Lucey et al. (2021). The map has a resolution of 32 pixels per degree, covering all longitudes and ±70° latitude. Lucey et al. (2021) noted that some artifacts remained at high latitudes (> 50°), which remain notable in the global map of SiO_2 wt.% at > ±50° latitude, calculated using the newly calibrated 2nd order polynomial from Table S2. Lucey et al. (2021) estimate an uncertainty of 0.02 µm for their corrected CF wavelengths. In the compositional range of mare basalts and anorthosites this translates to an uncertainty of 1 wt.% SiO_2.

For the comparison with the compositions of the returned samples we refer to literature specifically for every case. This includes Heiken et al., 1991, the Lunar Sample Compendium, Keil et al., 1972, Taylor et al., 1978, Li et al., 2022, Zong et al., 2022, Boschi et al., 2023, Che et al., 2021, Wang et al., 2024, Li et al., 2024, and Wang et al., 2025.

To improve the transparency, we added two supplementary figures (S4 and S5).

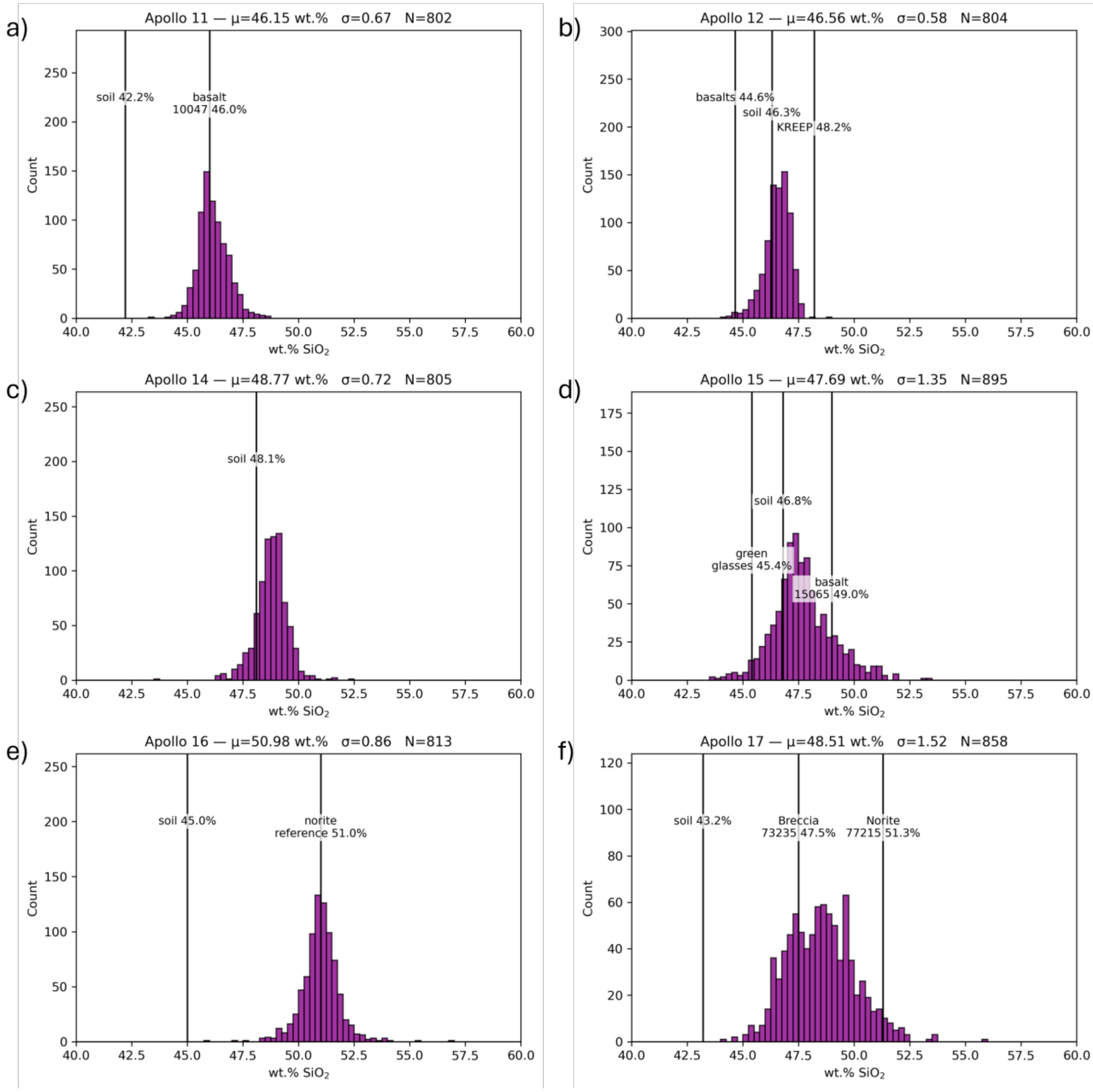


Figure S4. Comparison of calculated SiO_2 wt.% concentrations at the Apollo landing sites a) Apollo 11; b) Apollo 12; c) Apollo 14; d) Apollo 15; e) Apollo 16; f) Apollo 17. The histograms show the SiO_2 abundances at the landing sites over an area of 0.5° for reliable counting statistics (Table S3). For comparison we include the compositions of representative returned Apollo samples from literature compilations by Heiken et al. (1991), and the Lunar Sample Compendium (2012).

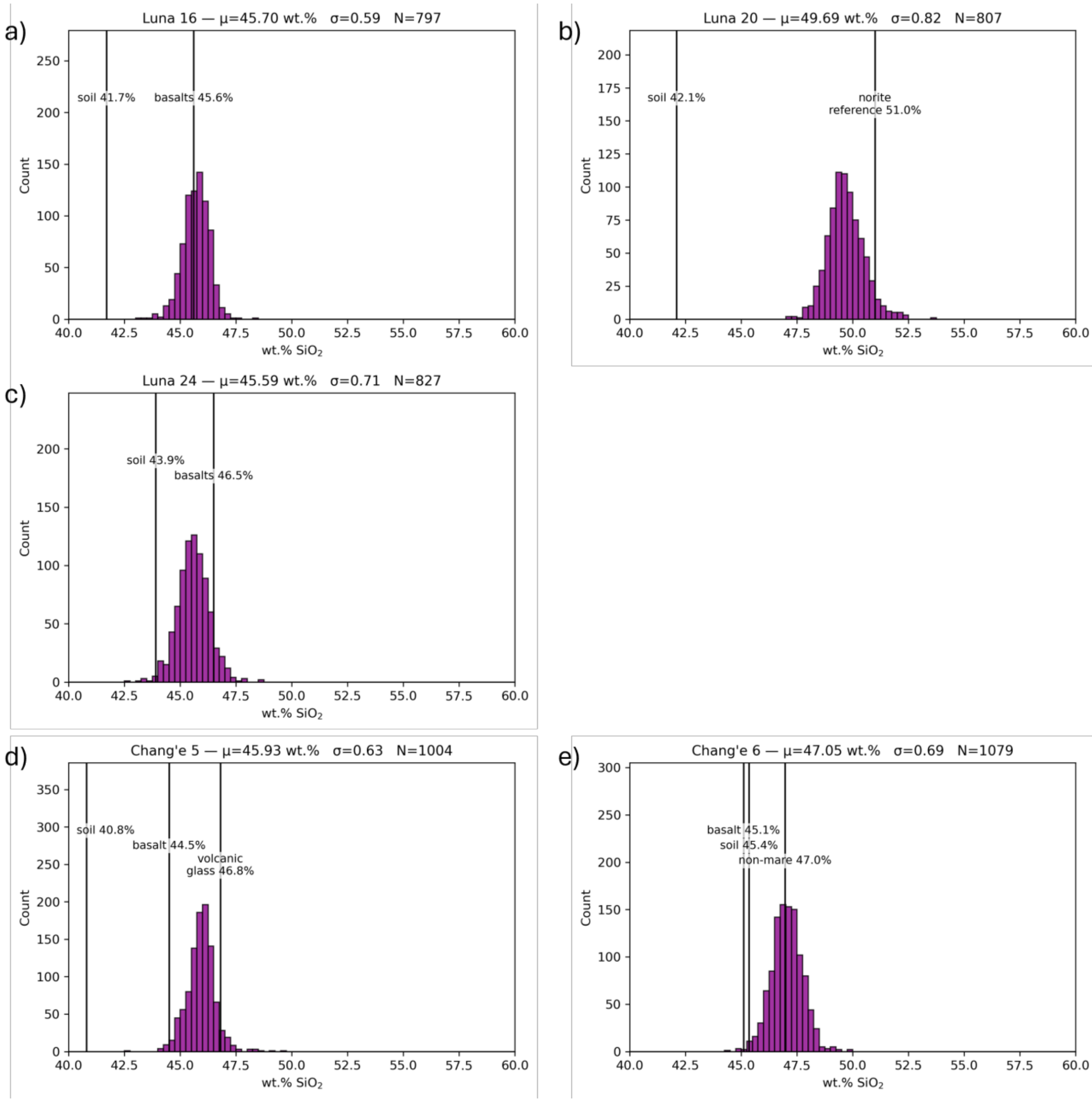


Figure S5. Comparison of calculated SiO_2 wt.% concentrations at the Luna landing sites a) Luna 16; b) Luna 20; c) Luna 24, and the Chang'e landing sites d) Chang'e 5; e) Chang'e 6. The histograms show the SiO_2 abundances at the landing sites over an area of 0.5° for reliable counting statistics (Table S3) For comparison we include the compositions of representative returned samples by the Luna missions (Keil et al., 1972; Taylor et al., 1978), and the Chang'e missions (Boschi et al., 2023, Che et al., 2021; Li et al., 2022; Li et al., 2024; B.-W. Wang et al., 204, Wang et al., 2025, Zong et al., 2022).

Figure 1, you can add a separate fitting curve for literature values alone (excluding the new synthetic glasses) alongside the existing combined fit, highlighting the significance of new synthetic glasses

The data we include from literature is measured in the same way as the new added data point. We decide to keep the figure clean, without adding additional fitting lines. We believe that they would distract from the main story.

3. I recommended to include a dedicated comparative analysis of the newly derived lunar SiO2 distribution map with previous datasets, inversion results and Lunar Prospector Gamma-Ray Spectrometer (LPGRS) data. This comparison will not only highlight the advancements of the current study but also provide critical insights into the consistency and uniqueness of the new results. Significant discrepancies are expected between the new map and prior inversion outcomes, particularly in high-silica regions such as Lassell Massif, Aristarchus Crater, and Gruithuisen Domes. Previous models failed to quantify SiO2 contents exceeding 60 wt.% due to limited calibration across extreme compositional ranges, whereas the new map reliably captures values up to 76 wt.% (Lassell Massif) by leveraging the extended synthetic glass dataset. This stark difference merits in-depth discussion.

Thank you for pointing this out. We added the following:

> The present study is the first that reliably quantifies the high-silica regions with compositions expected based on returned lunar granitic breccias, and which is independently validated via the returned samples suites (Figures S4, S5). For example, the inversion models by Chen et al. (2025) and Ma et al. (2022), both partially based on the CF map from the Diviner mission, fail to reproduce the high SiO_2 abundances at Aristarchus, Gruithuisen Domes, Lassell Massif, and Hansteen. On the other hand, observations by the gamma-ray spectrometer on the Lunar Prospector had insufficient spatial resolution to detect these regions, and also failed to resolve SiO_2 in the South Pole-Aitken basin (Prettyman et al., 2006).

Review 2

This manuscript attempts to quantify silica from CF wavelength position using a very small subset of laboratory acquired mid-IR reflectance data of glasses.

The manuscript does not rely on a “very small subset” of data, but instead uses an internally consistent dataset of synthetic glasses spanning the entire compositional range possible for silicates, and is substantially broader than any previous work in the literature. We intentionally do not include data on other types of materials than glasses, or measured by different methods and under different conditions, in order to be internally consistent for the compositional calibration.

Then they use this relationship to derive a function between CF and SiO2 and apply that to Diviner data. This is a very simplistic and misleading approach to solve this problem which does not account for the nuances related to the CF, bulk silica and Diviner dataset. The manuscript doesn't clarify how CF is estimated and does not explain how this method is comparable to method used by Diviner and where it fails. I cannot recommend it for publication in its current form.

The large number of possible degrees of freedom in previous studies is their main limitation. Here, we are focusing on the compositional effect alone, which yields excellent results as shown in Figure 1 and the good agreement with compositional data from returned lunar samples (see reply above with added supplementary figures). To our knowledge this is the first study that independently obtained this agreement with laboratory calibrations of the CF, and additionally resolves the high-silica regions on the Moon. This underlines the first order importance of the compositional effect, rather than the many additional effects the reviewer would like to focus on. By using homogeneous glasses, we avoid many of these issues to obtain averaged properties dependent on composition.

Importantly, a key contribution of the present study is the extension to extreme chemical compositions with very low SiO2 concentrations in the glasses. These are unique materials and the description of the synthesis demonstrates the challenges in making the glasses. A synthesis of larger quantities of homogeneous glasses with these extreme properties is not possible. It is therefore also not possible to make enough material for grain size dependent analysis or the large material requirements for emission measurements! This is why we use reflectance micro-FTIR. This measurement is physically linked by Kirchhoff's law of thermal radiation, which states that a material's spectral emissivity equals its spectral absorptivity.

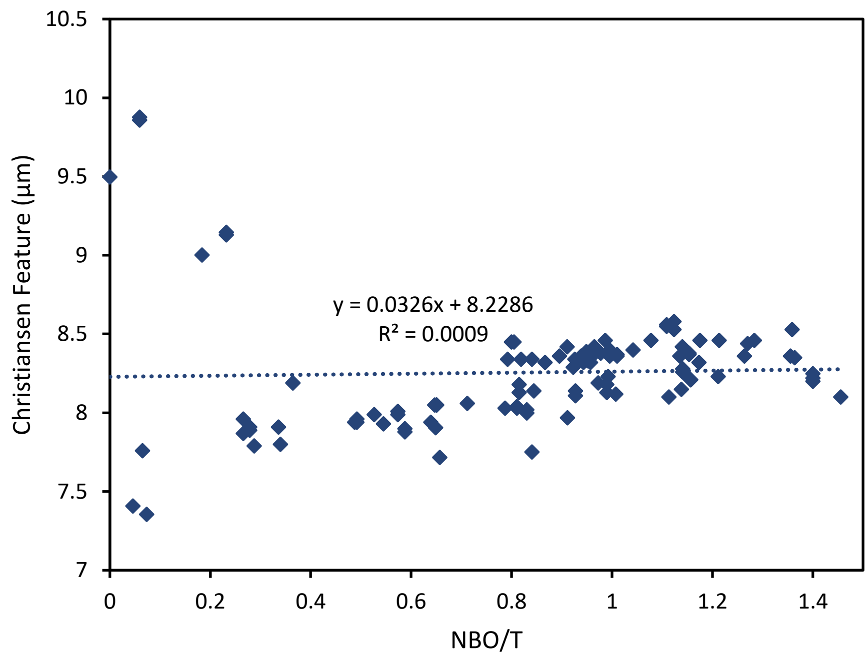
Line 29-30: "The mid-infrared spectral Christiansen Feature is strongly dependent on a material's SiO2 content" Nope CF is indicator of silica polymerization not SiO2 content, CF can vary in materials with same silica content but different polymerization and crystallinity amongst other things.

The reviewer is wrong here. The statement is incorrect and contradicted by both our dataset and prior experimental and analytical work.

While silica polymerization (here parameterized by NBO/T, the ratio of non-bridging oxygens over tetrahedrally coordinated cations in the amorphous network of the glass, Mysen, 2004, Chemical Geology 213, 1-16) influences vibrational modes, CF wavelength does not significantly correlate with NBO/T in our dataset. We explicitly tested this and find:

- CF vs. SiO_2 (wt.%): $R^2 = 0.957$ (Fig. 1 in Manuscript)
- CF vs. NBO/T: $R^2 = 0.0009$ (Figure below here in the response)

Thus, for glasses, SiO_2 concentration—not polymerization—is the dominant predictor of CF position, as we have stated in the manuscript. This is consistent with the physical interpretation that the CF corresponds to the wavelength at which the real part of the refractive index approaches unity, which is strongly governed by bulk Si–O bonding density, not polymerization state alone.



Line 41-42: "Here, we present a new experimental calibration based on synthetic glasses with SiO2 concentrations from 0.5 wt.% to 97.6 wt.% SiO2 "Why only synthetic glasses and not Apollo /Luna samples or minerals, mixtures or rocks?

Clearly the main, first order parameter controlling variation in the CF position is the SiO2 concentration (Figure 1 in the Manuscript). This is what we constrain here by covering the widest possible compositional range. As we state in the manuscript, we intentionally selected only pure glasses that were measured under the same conditions, with the same method.

The use of synthetic glasses is the only way that allows the isolation of compositional effects without confounding influences from crystallinity, grain boundary scattering, modal mineralogy, particle size distributions, or surface roughness.
Apollo and Luna samples, mineral mixtures, and rocks all introduce non-compositional spectral effects that obscure the fundamental relationship we aim to calibrate. This is precisely why earlier CF–SiO_2 relationships based on powders show reduced correlation coefficients.

In the manuscript we modified the relevant paragraph in the introduction to highlight the importance of glassy materials on the lunar surface:

> Here, we present a significantly improved calibration of an independent measure for the SiO_2 concentration in planetary silicate surface materials, based on the position of the CF in the mid-infrared spectral range. The CF is defined as the reflectance minimum or emission maximum, and occurs where the refractive index of a material reaches unity. The CF has previously been suggested to linearly depend on the chemical composition of silicates (Conel, 1969; Cooper et al., 2002, Pisello et al., 2022, Webert et al., 2023). However, this relationship has been determined over a limited compositional range, for

example from 48 wt.% to 73 wt.% SiO_2 by Pisello et al. (2022). Our new approach improves this relationship by extending the dataset to compositional extremes, with the synthesis of glasses ranging from 0.5 wt.% to 97.6 wt.% SiO_2. Glasses are ideal analogue materials to study compositional variations on atmosphere-less planetary bodies such as the Moon and Mercury. They are highly abundant on the lunar surface formed by pyroclastic and effusive volcanism, impact processes, and space weathering (Morlok et al., 2021, Wilbur et al., 2025, Zhao et al., 2023).

In section 2.1. we added:

For the calibration we include literature data of CF positions measured for planetary analogue glasses, that were measured by micro FTIR specular reflectance on polished surfaces (Haupt et al., 2026; Morlok et al., 2017, 2020, 2021). The data are chosen as pure glasses without crystallization features, with the same spectral resolution. This guarantees identical analytical conditions to avoid features that does not come from the compositional effect, which we calibrate for. The best fit to the data in wt.% of SiO_2 is a 2^{nd} order polynomial:

Line 65-67:" The Christiansen Feature (CF) is defined as the reflectance minimum or emission maximum and is also dependent on the chemical composition (Conel, 1969; Cooper et al., 2002)". This is an incomplete understanding of this feature. CF changes due to factors other than chemical composition such as crystallinity, particle size, albedo, temperature, porosity and environment (vacuum versus ambient).

It is true that various other parameters have been shown to affect the CF position. The manuscript does not claim otherwise. Nevertheless, the strong compositional dependence on SiO2 is clearly shown in Figure 1. The various effects are why we restrict the calibration to internally consistent polished glass samples. The method allows the isolation of the compositional effect. The comparison with the returned lunar samples (see added supplementary figures and reply to comment above), as well as the reliable capture and quantification of high-silica regions demonstrates that this approach is sound. See added text in replies to comments above.

Line 67-69: "The CF was previously found to linearly correlate with the concentration of SiO2 in wt.% in rock powders with coefficients of determination from R2 =0.6 (Weber et al., 2023) to R2 = 0.772 (Cooper et al., 2002)" As the data variability and availability has increased, CF's correlation with SiO2 has consistently reduced as can be observed by several other works so this sentence is misleading.

We revised this section and added references. See replies to comments above.

Figure 1 only works with limited material. Show that this relationship holds with variation in particle size, porosity, minerals, mixtures, rocks and Apollo samples or it is a very misleading figure! Literature data on glasses?

This point is addressed in the replies to the comments above. As stated, we aim to resolve the compositional dependence, and not determine regolith properties.

A few other factors to consider here are following:

1. Was CF estimated the same it is estimated from Diviner channels 3,4 and 5 or via some other measure because if they were estimated via other measures, it needs to be redone. The authors should first convolve the data to Diviner channels and then estimate CF via parabolic fit and then display what kind of relationship it shows or it is not applicable to Diviner!

The CF values applied to Diviner data are taken directly from Lucey et al. (2021), who estimate CF using the standard three-band parabolic fit (channels 3–5). We do not re-derive CF from Diviner data in this study, but apply our calibration to derive SiO2 concentrations. Changing the method of CF estimation for the analogue materials would not add any benefit, but only make the estimate less reliable. There is no added benefit.
Lucey et al. (2021) report an error of 0.02 µm on their corrected CF wavelengths. Using our calibration, we recalculate this to an uncertainty in SiO2 and added the following:

> Lucey et al. (2021) estimate an uncertainty of 0.02 µm for their corrected CF wavelengths. In the compositional range of mare basalts and anorthosites this translates to an uncertainty of 1 wt.% SiO_2.

We added the following description of our method of CF determination:

> The spectra were processed using Python open-source packages (Hunter, 2007; Virtanen, 2020). The CF was identified by determining the position of lowest reflectance by finding the low-point in a given spectrum using the Pandas data analysis library (McKinney, 2010). The measured positions of the CFs are listed in Table S1.

And yes, higher spectral resolution for lunar observations would be awesome. Here, we use the most up-to-date CF dataset by Lucey 2022 from the DIVINER team. We do not want to reproduce their data treatment. Instead, here the point is to make use of it and show how our calibration yields SiO2 wt.% estimates that are in good agreement with what we know from returned samples.

2. The Moon has a unique thermal environment and at the least mid-IR reflectance should not be used for studies planning to apply such relationships to orbital data. The authors need to carry out emissivity measurement and not use reflectance data at the least; the best-case scenario would be using simulated lunar environment emissivity spectra.

Yes, this is taken into account by Lucey et al. 2022. Here, we build on their work and make use of the CF dataset. Reflectance and emissivity CF positions are physically equivalent, as both are governed by the same refractive index condition (n = 1). Numerous studies (e.g., Salisbury & Walter, 1989; Lee et al., 2010) demonstrate that CF position is conserved between reflectance and emission measurements. Diviner CF products (e.g., the dataset we use by Lucey et al., 2022) already incorporate thermal corrections, making them directly comparable to laboratory-derived CF–composition relationships.

Line 106-107: “This guarantees similar analytical conditions and limits artifacts from grainy surfaces or crystallites” How?

See added text to the introduction and responses to the comments above.

Line 109-115: This paragraph is extremely misleading unless done for a variety of particle size, minerals, mixtures and rocks!

We strongly disagree with this comment. The good fit that we obtain with our new calibration speaks for itself. The comparison with returned lunar samples demonstrates that our approach can reproduce the compositional signatures in regards to SiO2. We also show that this is the first time, where a quantification of SiO2 in high-silica regions reliably reproduces the expected high SiO2 concentrations.

Line 116-117: Not to Sio2 concentration but silica polymerization.

As stated above, this is demonstrably false for our dataset. See response to comments above. Figure 1 clearly demonstrates the excellent dependence on SiO2 wt.% in the glasses!

A figure needs to be added for 3-band estimated CF versus SiO2 estimated from this equation and a comparison between lab measured silica and quantified silica for the readers.

As stated above, we use the corrected CF dataset by Lucey et al. 2022. We do now want to reproduce their figure here. We added a description of our CF measurement from the laboratory spectra, see response above.

Also, what is the error bar on the silica predictions from this method?

We have added the estimate of the uncertainty in our predictions. We base this on the scatter n the dataset and obtain a standard deviation of ±3.4 wt.%

> From the scatter in our data, we estimate an uncertainty for the calibration of ± 3.4 wt.% SiO_2.

We also added a description of the uncertainty for the CF data from Lucey et al. (2021):

Lucey et al. (2021) estimate an uncertainty of 0.02 µm for their corrected CF wavelengths. In the compositional range of mare basalts and anorthosites this translates to an uncertainty of 1 wt.% SiO_2.

CF maps of Diviner are known to be poor fits/incorrect values for silicic and ultramafic composition and that is why CF needs to be estimated the same way as done for Diviner wavelengths for this comparison or this is pointless.

Again, we would be very happy to see global lunar mid-IR data with high spectral resolution. This would be a substantial step forward. Nevertheless, we have to work with the data available and we strongly disagree with the notion that this endeavor is pointless. As stated above, the comparison with returned lunar samples and the analysis of high-silica terranes underlines the reliability of our new approach. These comparisons show that our calibration of the CF-SiO2 relationship can be applied to the surface of the Moon, and similar other planetary surfaces (e.g., Mercury), independent of pre-existing convictions or opinions.

EDITOR DECISION
round 2

Dear Christian Renggli,

I would like to thank you for submitting your manuscript "The SiO_2 abundance on the surfaces of the Moon and Mercury" (#226) to Planetary Research. I have now received the reviews and associate editor assessment of your submission, which are included at the bottom of this email. Based on my evaluation of your submission, your manuscript should in principle be suitable for publication after revision.

Please provide us with a point-by-point response to all comments and identify what changes you have made to the revised manuscript. In addition to the rebuttal, we ask that you also provide a document that tracks all changes that have been made to your manuscript since its initial submission.

When you have completed your revisions, you can upload the revised manuscript, your response and a tracked changes document from your submission dashboard.

If you have any questions about the recommendations in your review, or if you are unsure how to respond or proceed, please do not hesitate to contact me from your submission dashboard.

Sincerely,

Frédéric Schmidt
Editor, Planetary Research

Editor recommendation

The main added value of the article is the clear relationship between CF vs composition and rejection of relationship between CF vs polymerisation on pure glasses based on experimental data. This point is well described and should definitively considered for publication.

As the auhors stated << Apollo and Luna samples, mineral mixtures, and rocks all introduce non-compositional spectral effects that obscure the fundamental relationship we aim to calibrate. This is precisely why earlier CF–SiO_2 relationships based on powders show reduced correlation coefficients. >>. Thus there are many other effects that affect the CF for real data that are NOT pure glasses, Diviner data included. A large discussion of these effects that must limit the interpretation on real data has to be included in the article. Ideally a quantification of the error due to those effects should also be included.

Associate editor recommendation

Based on my reading of the revised manuscript and rebuttals, I think the authors have addressed the comments/suggestions appropriately, especially those from Reviewer #1.
In particular, Reviewer #2 has two good comments/suggestions:
(1) adding a brief literature review on thermal infrared spectroscopy and the related methodological issues
(2) need some explanation on the different observation conditions of laboratory spectroscopy and orbital DIVINER and how the algorithm derived from laboratory spectroscopy can be used to orbital DIVINER data.

Besides, I have two additional minor comments:
(3) explain why glasses are good analogues for lunar surface compositions, not crystalline minerals?
(4) Why not use the Diviner CF data sets with a much higher resolution (128 ppd; https://pds-geosciences.wustl.edu/lro/urn-nasa-pds-lro_diviner_derived1/data_derived_gdr_l3/cylindrical/img/)? But 32 ppd in the present paper.
I recommend accepting the paper after the author address the above four comments and those from reviewer #1

The following comments were received from the reviewers.

Reviewer 1:
Recommendation: Revisions Required Without Review

All pre-existing data used in the manuscript are publicly available and sufficient information is provided so that they can be found and accessed.

Yes

All significant data products generated as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI).

Yes

All significant numerical codes developed as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI or SWHID).

Not applicable

All pre-existing software used as part of the study are acknowledged, and sufficient information is provided to find, access, and understand the software. If the software is restricted, the conditions under which it can be accessed are publicly available.

Not applicable

If you answered no to any of the above questions, please provide supporting information.

I am uploading an annotated version of the manuscript.

No

Comments for the authors

For previous comment 3,
To properly demonstrate the advancement and reliability of the newly derived SiO2 distribution map, you should add detailed quantitative comparisons, rather than only descriptive discussion.
1. Direct pixel-by-pixel or region-averaged numerical comparisons of SiO2 abundances between the new map and previous inversion results (e.g., Chen et al., 2025; Ma et al., 2022) or LPGRS data.

2. Statistical metrics such as bias, root-mean-square error (RMSE), correlation coefficients, and histogram of SiO_2 contents.
you should demonstrate that the new results exhibit strong consistency with LPGRS data specifically in low SiO_2 regions. LPGRS data provides reliable results for studying SiO_2 content.

Reviewer 2:
Recommendation: Decline Submission

All pre-existing data used in the manuscript are publicly available and sufficient information is provided so that they can be found and accessed.

Yes

All significant data products generated as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI).

Yes

All significant numerical codes developed as part of the study have been uploaded to a public repository (or will be at the time of acceptance) and are cited using a persistent identifier (such as a DOI or SWHID).

Not applicable

All pre-existing software used as part of the study are acknowledged, and sufficient information is provided to find, access, and understand the software. If the software is restricted, the conditions under which it can be accessed are publicly available.

Not applicable

If you answered no to any of the above questions, please provide supporting information.

I am uploading an annotated version of the manuscript.

No

Comments for the authors

The authors have not incorporated or satisfactorily addressed any of my concerns. Since the authors refuse to do literature review on the subject, I have done the painstaking work to add a few papers and book chapter that the authors must read about spectroscopy, moon and instrument measurements. However, again I cannot recommend this article for acceptance in its current form.
“T_h_e_ _m_a_n_u_s_c_r_i_p_t_ _d_o_e_s_ _n_o_t_ _r_e_l_y_ _o_n_ _a_ _“v_e_r_y_ _s_m_a_l_l_ _s_u_b_s_e_t_” _o_f_ _d_a_t_a_,_ _b_u_t_ _i_n_s_t_e_a_d_ _u_s_e_s_ _a_n_ _i_n_t_e_r_n_a_l_l_y_ _consistent dataset of synthetic glasses spanning the entire compositional range possible for silicates, and is substantially broader than any previous work in the literature. We intentionally do not include data on other types of materials than glasses, or measured by different

methods and under different conditions, in order to be internally consistent for the compositional calibration."

The measurements from Diviner are

1) Not done in reflectance space but in emissivity space
2) Not under perfect laboratory conditions but have noise and changes due to instrument, roughness, thermal conditions, and so many other factors
3) Capture minerals and mineral mixtures and not only glasses so this needs to be incorporated for

I would heavily recommend that the authors read these papers. Here are a few manuscripts for authors to understand thermal infrared spectroscopy, Moon and workings of Diviner.

Mustard, J. F., & Glotch, T. D. (2019). Theory of reflectance and emittance spectroscopy of geologic materials in the visible and infrared regions. Remote compositional analysis: Techniques for understanding spectroscopy, mineralogy, and geochemistry of planetary surfaces, 21-41.

Hanna, K. D., Greenhagen, B. T., Patterson Iii, W. R., Pieters, C. M., Mustard, J. F., Bowles, N. E., ... & Thompson, C. (2017). Effects of varying environmental conditions on emissivity spectra of bulk lunar soils: Application to Diviner thermal infrared observations of the Moon. Icarus, 283, 326-342.

Shirley, K. A. (2018). The effects of particle size and albedo on mid-infrared spectroscopy for the Moon. State University of New York at Stony Brook.

Kumari, N., Breitenfeld, L. B., Shirley, K., & Glotch, T. D. (2025). Characterizing extreme compositions on the moon using thermal infrared spectroscopy. Journal of Geophysical Research: Planets, 130(5), e2024JE008814.

Kumari, N., Glotch, T. D., Shirley, K. A., Greenhagen, B. T., & Byron, B. D. (2024). Effects of space weathering on the Christiansen feature position of lunar surface materials. Icarus, 412, 115976.

"The large number of possible degrees of freedom in previous studies is their main limitation"

It is not the limitation of those studies but instead indicative of the fact that those authors are aware of various things impacting lunar surface and have used their knowledge to not simplify a complex problem and solve it in a misleading manner.

"Importantly, a key contribution of the present study is the extension to extreme chemical compositions with very low SiO2 concentrations in the glasses"

It is not, Kumari et al., (2025) have done this and showed that in SLE CF estimated from a wide compositional range cannot be used to estimate silica content.

Kumari, N., Breitenfeld, L. B., Shirley, K., & Glotch, T. D. (2025). Characterizing extreme compositions on the moon using thermal infrared spectroscopy. Journal of Geophysical Research: Planets, 130(5), e2024JE008814.

The reviewer is wrong here. The statement is incorrect and contradicted by both our dataset and prior experimental and analytical work.

Again, please go back to the definition for physics of CF. The authors have not discovered CF.

"The use of synthetic glasses is the only way that allows the isolation of compositional effects without

confounding influences from crystallinity, grain boundary scattering, modal mineralogy, particle size distributions, or surface roughness.”
But lunar surface has those properties so essentially this doesnot translate well there. The goal should not be to ignore those properties but address them but the authors are instead choosing to ignore those properties and treat this like a simple problem which it is not.

“We do not re-derive CF from Diviner data in this study, but apply our calibration to derive SiO2 concentrations. Changing the method of CF estimation for the analogue materials would not add any benefit, but only make the estimate less reliable. There is no added benefit.”
Even if everything else is ignored, if the authors want to establish a relationship between CF and SiO2, CF derived from hyperspectral data cannot be used and they need to derive the CF value byy the same technique used to derive the CF from Diviner data and then redo this. I will recommend them to read and understand how big of a bluder this is!

Hanna, K. D., Greenhagen, B. T., Patterson Iii, W. R., Pieters, C. M., Mustard, J. F., Bowles, N. E., ... & Thompson, C. (2017). Effects of varying environmental conditions on emissivity spectra of bulk lunar soils: Application to Diviner thermal infrared observations of the Moon. Icarus, 283, 326-342.
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“Yes, this is taken into account by Lucey et al. 2022”
No, it is not! Lucey et al., (2021) have only carried out empirical space weathering corrections and not TIR to MIR reflectance changes. I’d recommend authors to read that manuscript again , hopefully more carefully this time!

AUTHOR REBUTTAL
round 2

Dear Editors,

Below, we address each comment individually in green. Modifications to the manuscript are shown in blue.

Kind regards

Chris Renggli

Editor recommendation
The main added value of the article is the clear relationship between CF vs composition and rejection of relationship between CF vs polymerisation on pure glasses based on experimental data. This point is well described and should definitively considered for publication.
As the auhors stated "Apollo and Luna samples, mineral mixtures, and rocks all introduce non-compositional spectral effects that obscure the fundamental relationship we aim to calibrate. This is precisely why earlier CF–SiO_2 relationships based on powders show reduced correlation coefficients. ". Thus there are many other effects that affect the CF for real data that are NOT pure glasses, Diviner data included. A large discussion of these effects that must limit the interpretation on real data has to be included in the article. Ideally a quantification of the error due to those effects should also be included.

The main contribution of the letter is the new compositional calibration. Importantly, it is the compositional effect that we calibrate. Here, we do not determine other potential effects affecting emission from the lunar surface including porosity, grain size, material mixtures etc. As we outline in the added literature, this has been done at length and this paper is not intended as a literature review. No analogue material or laboratory setting is capable of reproducing the nature and conditions of the lunar surface. Here, we focus on composition and validate this approach by comparing to the compositional diversity of returned lunar samples. As we show with the comparison to the returned lunar sample suite, already added in the first round of revisions, this works empirically.
We strongly disagree with the notion that a "large discussion" and literature review should be added to this paper. It is a letter and we want to keep this concise. In response to the strong opinions by the second reviewer we tried to include some additional literature. We do not want to present a literature review on regolith effects on the CF, nor do we present different CF corrections of Diviner data. Here, the novelty is the calibration! We simply apply it to an existing, already treated and published, corrected CF dataset from Lucey et al., 2021. The result of this application is the SiO2 map. We then show how well this agrees with compositional ranges of returned lunar samples. This is a simple empirical observation. Future work may attempt to resolve sample site heterogeneities in the context of SiO2 variations, but this is not in the intended scope of this letter.

As requested, we looked the data from the GRS, Ma et al. 2022, and Chen et al., 2025 in detail again. As we show below, these datasets all have issues to a degree that a quantitative comparison is not fruitful. In fact, our comparison with the returned lunar samples shows that our new SiO2 global map does a much better job at reproducing them, compared to any one of these three previous approaches.

Associate editor recommendation

Based on my reading of the revised manuscript and rebuttals, I think the authors have addressed the comments/suggestions appropriately, especially those from Reviewer #1. In particular, Reviewer #2 has two good comments/suggestions:

(1) adding a brief literature review on thermal infrared spectroscopy and the related methodological issues

We added the following text for context on what affects the CF.

Multiple factors influence the CF position, including pressure environment, temperature, irradiation, and grain size, with decreasing pressure and temperature shifting the CF to lower wavelengths, while increased solar irradiation and smaller grain sizes (particularly 0-32 µm fractions) shift it to higher wavelengths (Donaldson Hanna et al., 2017; Logan and Hunt, 1970; Logan et al., 1973; Henderson and Jakosky, 1997; Shirley and Glotch, 2019; Donaldson Hanna et al., 2012). The effect of space weathering on the CF position remains debated (Kumari et al., 2024a), with Salisbury et al. (1997) and Lucey et al. (2017) reporting no significant correlation between the CF position and I_s/FeO, the standard measure for lunar soil maturity defined as the abundance of nanophase iron relative to the bulk FeO content. Furthermore, simulated micrometeorite bombardment in experiments does not lead to a shift in the CF (Weber et al., 2020). Since laboratory analysis of heterogeneous analogue material mixtures involves many parameters often counteracting each other, silicate glasses with broad compositional variations serve as ideal analogues to isolate and calibrate the compositional dependence of the CF position specifically, as no significant CF shifts are observed with varying grain size fractions or between different measurement methods (Morlok et al., 2017; Morlok et al., 2021; Morlok et al., 2022).

(2) need some explanation on the different observation conditions of laboratory spectroscopy and orbital DIVINER and how the algorithm derived from laboratory spectroscopy can be used to orbital DIVINER data.

With our new calibration we investigate the compositional effect of SiO2 on the CF position. This paper is not a review or study of laboratory methodologies, nor one on the processing or analysis of DIVINER data. We just use a published dataset (Lucey et al., 2021) to apply our new calibration and empirically validate it by comparison with returned lunar data. This request by the second reviewer is beside the point of this paper.

Besides, I have two additional minor comments:

(3) explain why glasses are good analogues for lunar surface compositions, not crystalline minerals?

See added text above. The benefit of studying glasses is that one can study an extensive range of SiO2 contents with a singly material type (e.g. glass).

(4) Why not use the Diviner CF data sets with a much higher resolution (128 ppd; https://pds-geosciences.wustl.edu/lro/urn-nasa-pds-lro_diviner_derived1/data_derived_gdr_l3/cylindrical/img/)? But 32 ppd in the present paper.

We used the dataset from Lucey because it is already corrected for some artefacts. The new contribution of this study is the calibration of the compositional CF-SiO2 relationship. We then apply it to the existing corrected dataset by Lucey. Regional or detailed local high-resolution investigations of the obtained SiO2 variations in comparison with other remote sensing data will be valuable future work, but is beyond the scope of the present study.

I recommend accepting the paper after the author address the above four comments and those from reviewer #1

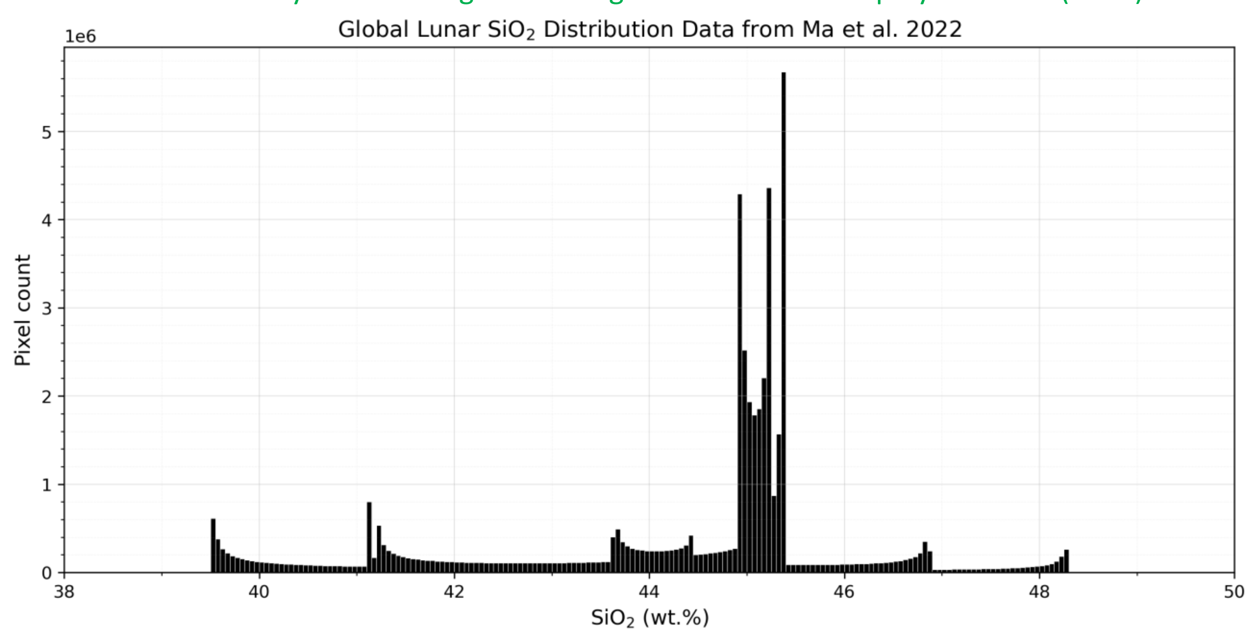
Reviewer 1

To properly demonstrate the advancement and reliability of the newly derived SiO2 distribution map, you should add detailed quantitative comparisons, rather than only descriptive discussion.

1. Direct pixel-by-pixel or region-averaged numerical comparisons of SiO2 abundances between the new map and previous inversion results (e.g., Chen et al., 2025; Ma et al., 2022) or LPGRS data.

We have revisited the previous SiO2 abundance studies. Regarding LPGRS see response to the next comment.

The SiO2 map by Ma et al. (2022) appears to reproduce the expected bimodality of mare and highland terranes when looking at the figure in the paper. Notably, their model is based at least in part on the same CF dataset by Lucey et al. (2021) to which we apply our CF-SiO2 calibration. However, a quantitative inspection of their calculated SiO2 distribution reveals unnatural artefacts. This is clearly shown in a global histogram of the SiO2 map by Ma et al. (2022).



A pixel-by-pixel comparison with this dataset does not produce any useful insight.

The data by Chen et al. 2025 is unfortunately not openly available. But it is also not useful to make a detailed comparison, given the inconsistencies in their dataset. For example, their observations of the Mare terranes produce compositional contrasts with both the highest and the lowest SiO2 abundances in these regions.
In summary, the comparison with the three studies reporting SiO2 values in the literature was not fruitful. We argue that the comparison with samples which we included in the first revision is clearly demonstrating the strength of our approach, reproducing returned sample compositions, and reproducing the observed bimodality of the Moon's surface composition reflected in the compositions of the highland and the mare terranes.

2. Statistical metrics such as bias, root-mean-square error (RMSE), correlation coefficients, and histogram of SiO2 contents.
you should demonstrate that the new results exhibit strong consistency with LPGRS data specifically in low SiO2 regions. LPGRS data provides reliable results for studying SiO2 content.

The LPGRS data does not provide a reliable estimate of the SiO2 abundance on the Moon. In contrast to other elements Si and Ca are very poorly constrained by Gamma-ray spectroscopy. Notably, this is also the case for X-ray spectroscopy of the Moon and Mercury. For example, in the case of Mercury MESSENGER observations SiO2 was estimated based on hypothetical normative mineralogy calculations. As we point out in the introduction, this is an important motivation for the present manuscript. Considering the LPGRS data, Prettyman et al., 2006 state "*Correlations involving Si and Ca are shown in Figure 42 for the 20° data set. Maps of SiO2 and CaO are shown in Figure 43. While the scatterplots of LP data follow similar trends, the LP data do not overlap the sample data. In addition, the precision of the abundance data is relatively poor. The lack of quantitative correspondence with the sample data may be due to uncertainties in basic nuclear data used in the generation of component library spectra or the method used to determine the background.*". A statistical comparison with data that is problematic as described is of not much use in our opinion. Further detailed investigations of this topic are certainly of interest, but beyond the scope of this letter.

Reviewer 2

The authors have not incorporated or satisfactorily addressed any of my concerns. Since the authors refuse to do literature review on the subject, I have done the painstaking work to add a few papers and book chapter that the authors must read about spectroscopy, moon and instrument measurements. However, again I cannot recommend this article for acceptance in its current form.
"T_h_e_ _m_a_n_u_s_c_r_i_p_t_ _d_o_e_s_ _n_o_t_ _r_e_l_y_ _o_n_ _a_ _"v_e_r_y_ _s_m_a_l_l_ _s_u_b_s_e_t_" _o_f_ _d_a_t_a_,_ _b_u_t_ _i_n_s_t_e_a_d_ _u_s_e_s_ _a_n_ _i_n_t_e_r_n_a_l_l_y_ _consistent dataset of synthetic glasses spanning the entire compositional range possible for silicates, and is substantially broader than any previous work in the literature. We intentionally do not include data on other types of materials than glasses, or measured by different methods and under different conditions, in order to be internally consistent for the compositional calibration."

The measurements from Diviner are

1) Not done in reflectance space but in emissivity space
2) Not under perfect laboratory conditions but have noise and changes due to instrument, roughness, thermal conditions, and so many other factors

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I would heavily recommend that the authors read these papers. Here are a few manuscripts for authors to understand thermal infrared spectroscopy, Moon and workings of Diviner.
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See replies to editors' comments above.

"The large number of possible degrees of freedom in previous studies is their main limitation"
It is not the limitation of those studies but instead indicative of the fact that those authors are aware of various things impacting lunar surface and have used their knowledge to not simplify a complex problem and solve it in a misleading manner.

We protest the notion that we are misleading or trying to oversimplify things. The reviewer appears ideologically opposed and it appears that they did not attempt to consider our results and discussion in detail, where we show and discuss how our new SiO2 surface model empirically works better than any previous approach, when compared to returned lunar samples. The degree of agreement speaks for itself and provides a new angle and a different perspective on this complex problem.

"Importantly, a key contribution of the present study is the extension to extreme chemical compositions with very low SiO2 concentrations in the glasses"
It is not, Kumari et al., (2025) have done this and showed that in SLE CF estimated from a wide compositional range cannot be used to estimate silica content.

Kumari, N., Breitenfeld, L. B., Shirley, K., & Glotch, T. D. (2025). Characterizing extreme compositions on the moon using thermal infrared spectroscopy. Journal of Geophysical Research: Planets, 130(5), e2024JE008814.
The reviewer is wrong here. The statement is incorrect and contradicted by both our dataset and prior experimental and analytical work.
Again, please go back to the definition for physics of CF. The authors have not discovered CF.

We never argued that we discovered the CF. By using an internally consistent dataset we obtain an excellent calibration of the CF-SiO2 relationship. Here, the data speaks for itself. I don't understand why the reviewer is so adamantly opposed to this.

"The use of synthetic glasses is the only way that allows the isolation of compositional effects without confounding influences from crystallinity, grain boundary scattering, modal mineralogy, particle size distributions, or surface roughness."
But lunar surface has those properties so essentially this doesnot translate well there. The goal should not be to ignore those properties but address them but the authors are instead choosing to ignore those properties and treat this like a simple problem which it is not.

"We do not re-derive CF from Diviner data in this study, but apply our calibration to derive SiO2 concentrations. Changing the method of CF estimation for the analogue materials would not add any benefit, but only make the estimate less reliable. There is no added benefit."
Even if everything else is ignored, if the authors want to establish a relationship between CF and SiO2, CF derived from hyperspectral data cannot be used and they need to derive the CF value byy the same technique used to derive the CF from Diviner data and then redo this. I will recommend them to read and understand how big of a bluder this is!

Hanna, K. D., Greenhagen, B. T., Patterson Iii, W. R., Pieters, C. M., Mustard, J. F., Bowles, N. E., ... & Thompson, C. (2017). Effects of varying environmental conditions on emissivity spectra of bulk lunar soils: Application to Diviner thermal infrared observations of the Moon. Icarus, 283, 326-342.
Kumari, N., Breitenfeld, L. B., Shirley, K., & Glotch, T. D. (2025). Characterizing extreme compositions on the moon using thermal infrared spectroscopy. Journal of Geophysical Research: Planets, 130(5), e2024JE008814.
"Yes, this is taken into account by Lucey et al. 2022"
No, it is not! Lucey et al., (2021) have only carried out empirical space weathering corrections and not TIR to MIR reflectance changes. I'd recommend authors to read that manuscript again, hopefully more carefully this time!

To evaluate the reliability of our approach we added the comparison with returned lunar samples in the past round of reviews. The reviewer has not taken these observations into account. We present a calibration based on analogue materials over an unprecedented SiO2 range and a single material type to avoid matrix effects, rather than regolith properties such as grain size and porosity. The comparison supports our approach, even if this may come as a surprise. It is simply an observation.

EDITOR DECISION
round 3

20th May 2026

Analysis rebuttal Renggli et al., 2026 for consideration in Planetary Research

Renggli et al. 2026 use a controlled lab dataset including extreme SiO2 content (0.5 to 97%) to extend the relationship between SiO2 and CF position.

Kumari et al. 2025 use a compiled lab dataset with diverse conditions (grain size, mineralization, …) on a reduced SiO2 content range. They found poor correlation with SiO2 and propose a linear relationship. Many other authors proposed that (such as Cooper et al).

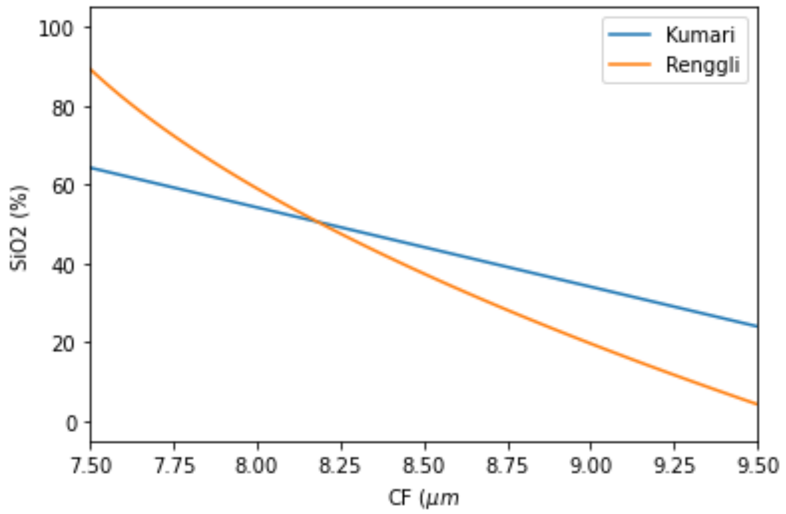


Figure 1: Plot of the relationship between CF position and SiO2 content from Kumari et al. 2025 and the new one from Renggli et al. 2026. The non-linearity is not extremely important but the relationship and the slope is slightly different.

The final map of lunar SiO2 provided in Renggli et al. 2026 is based on the Lucey et al. 2021 CF feature map that already made a lot of correction (instrumental, space weathering…).

=> Please verify and indicate explicitly in the manuscript the product you used. For instance product from the Equation 3 from Lucey et al. 2021.

The new version of the manuscript is now mentioning all potential spurious effect but you did not answer the main question addressed by the reviewers that could be formulated as: "How is your new relationship improving the knowledge of lunar SiO2 content?". This claim in the rebuttal << our new SiO2 surface model empirically works better than any previous approach, when compared to returned lunar samples. >> is not demonstrated at all. Please use the previous relationship from Kumari et al. 2025 (and/or Cooper et al. 2002, or Lucey et al. 2021, …) to prove that your new relationship is in better agreement with the actual data from landing site.

In your rebuttal, you reject the comparison with Ma et al, 2022. Fig 5 a. on the basis of the histogram. Even this argument is valid to limit the usefulness of this product, this is not answering the question “How is your new relationship improving the knowledge of lunar SiO2 content?”

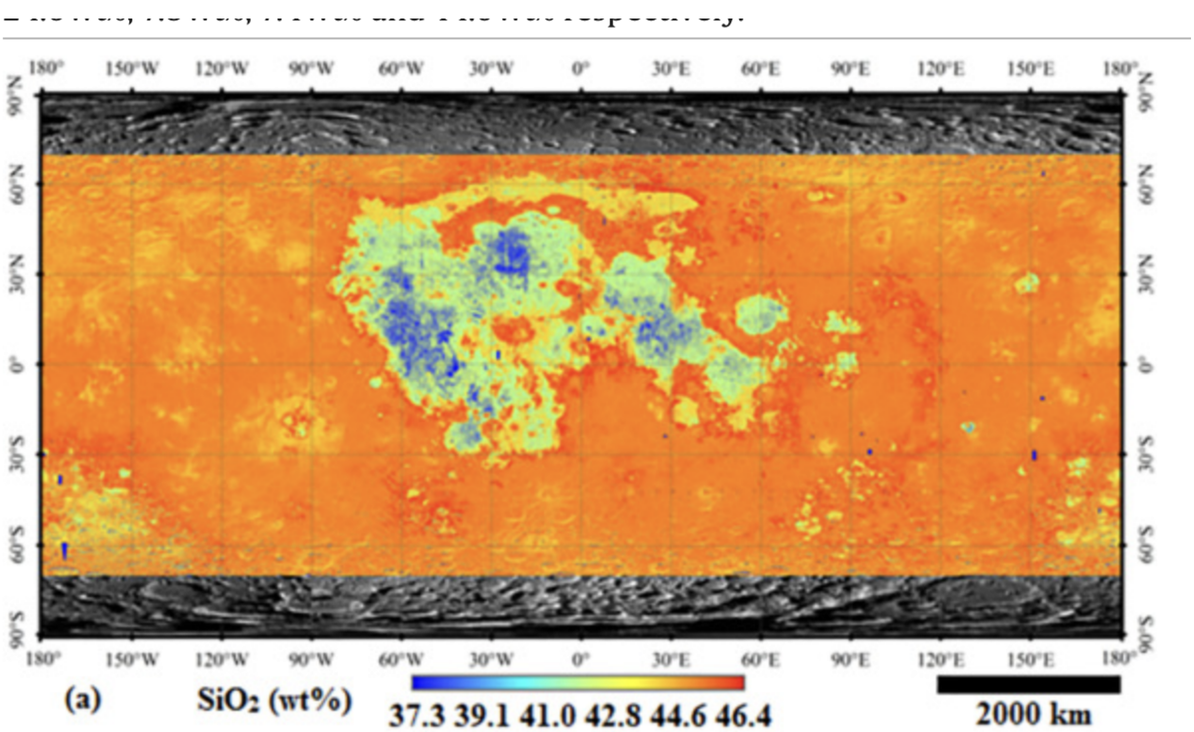


Figure 2: Ma al, 2022 Fig 5 a. The dichotomy can be clearly seen so a fair comparison with Renggl method, using the same lat/long range around the landing site is possible.

=> The quantification of agreement between the new relationship and the actual data from landing site is only by eye. It would definitively be required that you provide a quantitative assessment of this agreement. At least, plot the distribution of:
- Ma et al., 2022
- a linear relationship CF=> SiO2 (Kumari et al. 2025, Cooper et al. 2002, or Lucey et al. 2021, …)
- your data
to demonstrate the improvement and produce a quantitative proxy to estimate that.

=> Since you estimate that LPGRS data does not provide a reliable estimate of the SiO2 abundance on the Moon. Please add a line somewhere to justify this lack of comparison.

=> Please use the dedicated term “calculated SiO2” every time you use your new function. For instance in the caption of Figure 2 and 3. Landing site can be referred as “ground truth” to avoid any confusion.

AUTHOR REBUTTAL
round 3

Analysis rebuttal Renggli et al., 2026 for consideration in Planetary Research

Renggli et al. 2026 use a controlled lab dataset including extreme SiO2 content (0.5 to 97%) to extend the relationship between SiO2 and CF position.

Kumari et al. 2025 use a compiled lab dataset with diverse conditions (grain size, mineralization, …) on a reduced SiO2 content range. They found poor correlation with SiO2 and propose a linear relationship. Many other authors proposed that (such as Cooper et al).

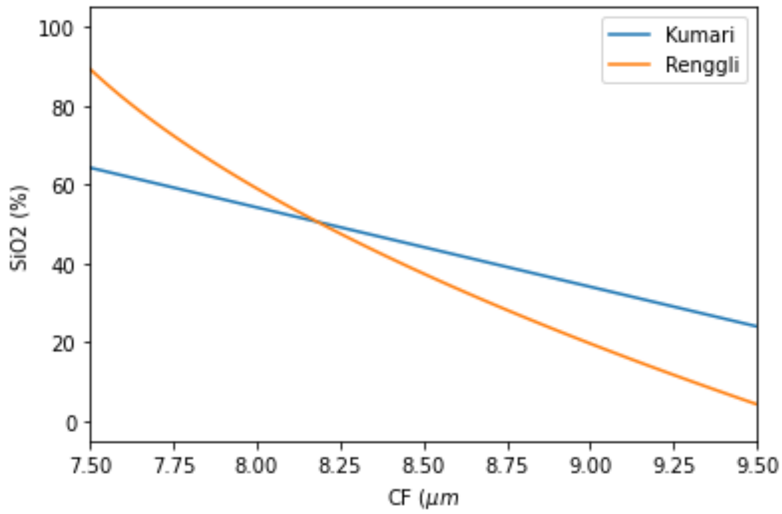


Figure 1: Plot of the relationship between CF position and SiO2 content from Kumari et al. 2025 and the new one from Renggli et al. 2026. The non-linearity is not extremely important but the relationship and the slope is slightly different.

Where the two calibration curves cross-over, in the range around 50 wt.% SiO_2 there is of course little difference in the two models. The difference in slope however, has substantial implications for the high- and low-SiO_2 range. As we show below in the histograms the model by Kumari systematically overestimates SiO_2 in the lower-SiO_2 range (see histograms for Apollo 11, for example), whereas estimates for the high-Si regions are systematically underestimated.

The final map of lunar SiO2 provided in Renggli et al. 2026 is based on the Lucey et al. 2021 CF feature map that already made a lot of correction (instrumental, space weathering…).

=> Please verify and indicate explicitly in the manuscript the product you used. For instance product from the Equation 3 from Lucey et al. 2021.
We use the final data product by Lucey et al. (2021) which is openly available on Zenodo and shown in their Fig.8. To clarify, we added the following text:

> Here, we use a global CF dataset for the Moon, which was corrected for illumination, topography, geometry, and space weathering effects by Lucey et al. (2021) as shown in their Figure 8 and openly available at https://doi.org/10.5281/zenodo.4558194.

=> The new version of the manuscript is now mentioning all potential spurious effect but you did not answer the main question addressed by the reviewers that could be formulated as: “How is your new relationship improving the knowledge of lunar SiO2 content?”. This claim in the rebuttal << our new SiO2 surface model empirically works better than any previous approach, when compared to returned lunar samples. >> is not demonstrated at all. Please use the previous relationship from Kumari et al. 2025 (and/or Cooper et al. 2002, or Lucey et al. 2021, …) to prove that your new relationship is in better agreement with the actual data from landing site.

See in longer response with additional comparison figure and paragraph below. Note that Lucey et al. 2021 did not calculate SiO2 from the CF. It is our new calibration that makes this possible in a reliable way. In the response below we added a new paragraph and supplementary figure including comparison to Kumari et al. and to Ma et al.

=> In your rebuttal, you reject the comparison with Ma et al, 2022. Fig 5 a. on the basis of the histogram. Even this argument is valid to limit the usefulness of this product, this is not answering the question “How is your new relationship improving the knowledge of lunar SiO2 content?”

We argue, that our new model is the first that can reproduce SiO2 from CF remote sensing data at landing sites that are in agreement with returned sample compositions. In reply to the comment below we added a new paragraph comparing to Ma et al. and Kumari et al. Here we revised the following sentence to clarify this:

> The significantly improved reproducibility of compositional ranges at landing sites for which returned samples are available, based on our new calibration, allows us to discuss the SiO_2 abundances in other lunar regions and surface features more reliably.

Importantly, the comparison to the returned samples allows us to take the new calibration and investigate regions without returned samples and determine SiO2 with confidence, such as in the SPA and the high-Si regions, as discussed in the manuscript. In addition, the tested calibration will be key to apply this approach to Mercury for which we do not have any returned samples.

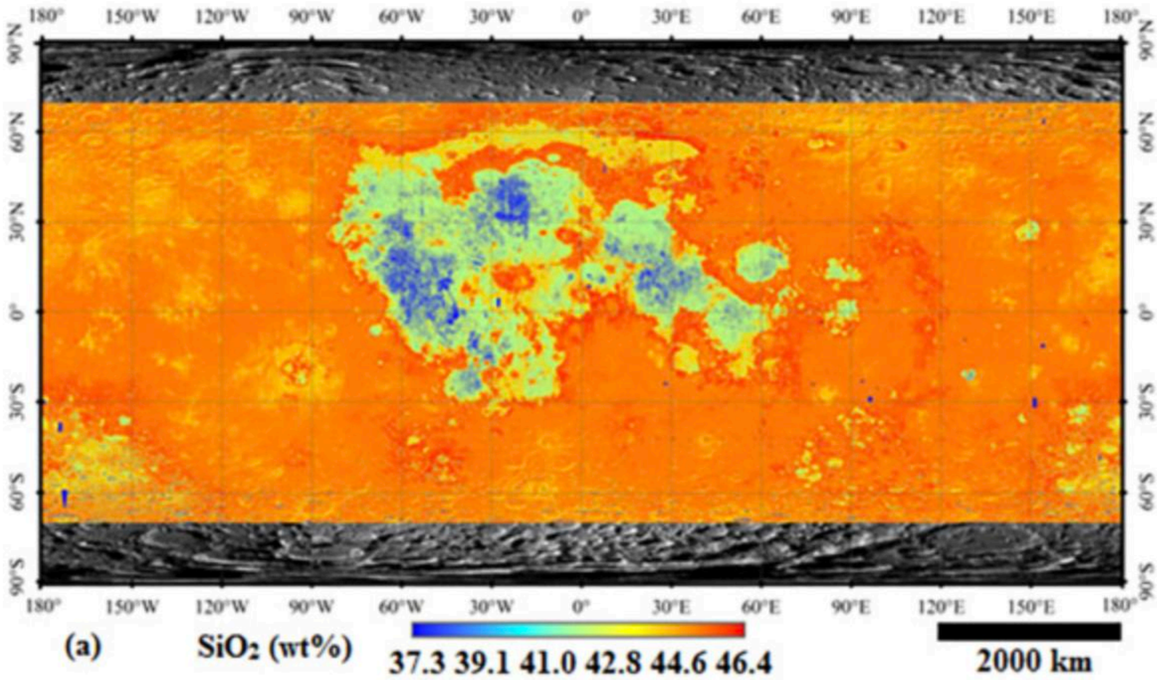


Figure 2: Ma al, 2022 Fig 5 a. The dichotomy can be clearly seen so a fair comparison with Renggl method, using the same lat/long range around the landing site is possible.

=> The quantification of agreement between the new relationship and the actual data from landing site is only by eye. It would definitively be required that you provide a quantitative assessment of this agreement. At least, plot the distribution of:
- Ma et al., 2022
- a linear relationship CF=> SiO2 (Kumari et al. 2025, Cooper et al. 2002, or Lucey et al. 2021, …)
- your data
to demonstrate the improvement and produce a quantitative proxy to estimate that.

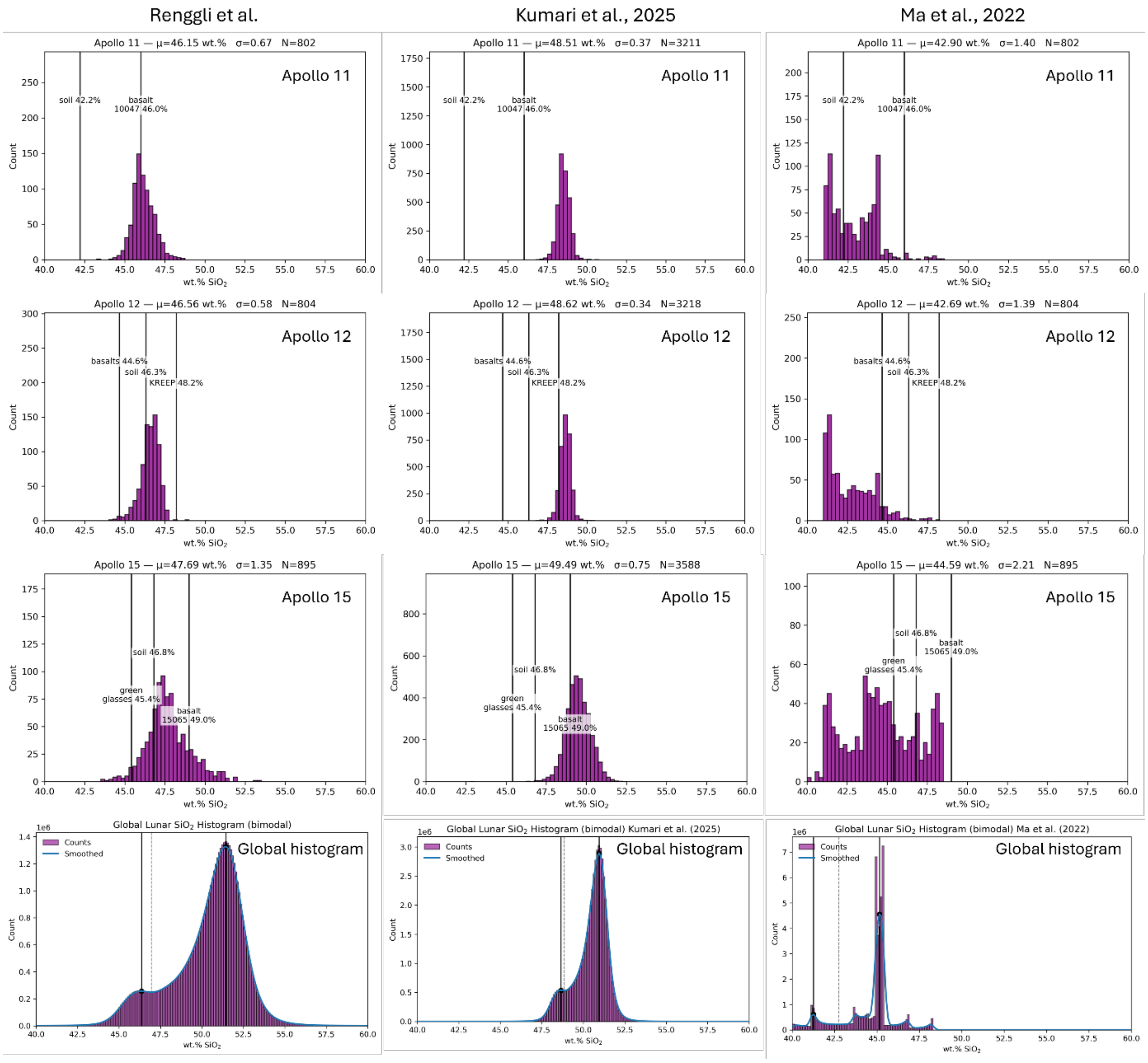
Even for the late Apollo missions, the number and geographic distribution of returned samples is limited. An objective quantitative comparison between remote sensing and returned sample analysis is a fundamental problem in the field and given by the limitations in both the returned samples, as well as the spectral and spatial resolutions of the remote sensing data. The comparison “by eye” at least shows where samples fall in the ranges of calibrated remote sensing data.

Here we add the following paragraph to the discussion addressing the differences of our new approach to Ma et al. and Kumari et al.

> Here, we compare our new calibration and calculated SiO_2 abundances on the Moon with other literature approaches (Figure S6). First, we applied the linear CF-SiO_2 relationship from Kumari et al. (2025) to the same CF dataset by Lucey et al. (2021) to which we applied our new calibration. This approach yields a narrower bimodal distribution of SiO_2 compared to our calibration, with mare terrain SiO_2 concentrations of 48.3 ± 0.5 wt.% SiO_2 and the highland regions with 50.7 ± 0.7 wt.% SiO_2. The

comparison with returned lunar samples shows that the linear CF-SiO_2 relationship from Kumari et al. (2025) results in systematically overestimated SiO_2 abundances for mare terrains in particular (Figure S6). Second, we compare our calculated SiO_2 abundances to the model by Ma et al. (2025). The histograms show that their calculated SiO_2 concentrations are affected by model artefacts and do not show natural distributions, which fail to reproduce lunar sample compositions and underestimate SiO_2 concentrations (Figure S6).

We also added the new Figure S6 showing this comparison:



=> Since you estimate that LPGRS data does not provide a reliable estimate of the SiO2 abundance on the Moon. Please add a line somewhere to justify this lack of comparison.

We added a sentence with reference in the introduction that refers to the lack of quantitative correspondence between the LP data and returned sample compositions:

However, the Lunar Prospector SiO_2 data did not overlap with sample data, showing systematic shifts to lower values (Prettyman et al., 2006).

=> Please use the dedicated term “calculated SiO_2” everytime you use your new function. For instance in the caption of Figure 2 and 3. Landing site can be referred as “ground truth” to avoid any confusion.
We added this clarification where it was missing, including in the captions.