The submission describes a dataset compiling nearly 10,000 soil/regolith grain-size distributions for Earth, the Moon, and Mars. The database is freely accessible. The Universal Grain-Size Distribution (UGSD) function is used to describe the properties of these distributions, identify commonalities, and support future property mapping and process characterization.

The overall concept is valuable, and the search for broad correlations is likely to yield interesting insights that could help differentiate or predict certain soil properties across different planetary bodies (Fig. 4 in particular). However, several limitations should be discussed or addressed in a revised version of this manuscript:

Reply: We thank the reviewer for the positive comments.

The techniques used to constrain grain size differ fundamentally across bodies: laboratory measurements on Earth, returned samples for the Moon, and remote sensing (imagery) for Mars. Combining these approaches on equal footing is questionable and should be justified. Furthermore, other remote-sensing approaches applicable to Mars and the Moon (e.g., photometry and thermal inertia) are entirely ignored. Thermal inertia, in particular, is a well-established and powerful technique for constraining grain size, and its omission should be explicitly addressed.

Reply: We fully agree with the reviewer that combining laboratory measurements (Earth), returned-sample analyses (Moon), and image-based remote sensing (Mars) on equal footing is not trivial and requires explicit justification. In the revised manuscript, we have added the following clarifications and modifications:

Explicit justification for combining methods (Section 2.3, new paragraph, Lines 239-248): We now explicitly state that our goal is not to treat the three methods as analytically equivalent, but rather to harmonize them under a flexible curve-fitting framework (UGSD) that accommodates method-specific resolution limits and uncertainties. We acknowledge that each method has inherent biases (e.g., Martian imaging misses fines <$40-150$ μm; lunar sieving underestimates clay; terrestrial laser diffraction resolves full range). The UGSD function is used not to erase these differences but to enable comparative analysis while preserving method-specific limitations as interpretative caveats.

Comparison of analytical methods (Table 4 and accompanying text): We have retained Table 4 (included in the original submission) and added three footnotes (Notes, Lines 231-237) to explicitly summarize the principles, grain-size ranges, advantages, and limitations of the three methods.

Discussion of thermal inertia and other remote-sensing approaches (added to Section 6.3, Lines 673-688): The reviewer correctly points out that we omitted thermal inertia and photometry — well-established techniques for constraining grain size on Mars and the Moon. We have added a new item (8) in Section 6.3 (Limitations and caveats) titled “Remote-sensing methods not included (thermal inertia and photometry).” In this item, we:

Explicitly acknowledge that thermal inertia (e.g., TES, THEMIS) and photometric methods provide complementary, orbitally derived grain-size constraints at regional to global scales.

Clarify that PlanetGSD 1.0 focuses exclusively on in-situ / direct measurements (laboratory, returned samples, high-resolution rover imagery) rather than orbital remote sensing.

State that integrating thermal inertia–derived effective grain sizes (which typically represent a surface layer <1 cm and are biased toward coarse fractions) with our point-scale GSD data is a priority for PlanetGSD 2.0, but is outside the scope of the current version due to fundamental differences in spatial scale, depth sensitivity, and grain-size metric (effective vs. full distribution).

Cite key thermal inertia literature (e.g., Fergason et al., 2006; Mellon et al., 2000) to demonstrate awareness and to guide future work.

Importantly, we would like to further clarify the complementary relationship between our approach and orbital remote-sensing methods. The reviewer raises an excellent point: thermal inertia and photometry are powerful techniques for constraining planetary surface properties. However, they address a fundamentally different scale of problem — they tend to yield pixel-averaged (kilometer-scale) equivalent grain sizes, which are severely influenced by topography, composition, and mixed-pixel effects. In contrast, the core contribution of our work is the construction of a centimeter-scale discrete granular probability model (the random granular field). We do not dismiss the value of remote sensing; on the contrary, the probabilistic parameters established from our point-scale data serve as essential priors and statistical anchors for integrating thermal inertia and photometric data in future regional extrapolation (e.g., PlanetGSD 2.0). This cross-scale methodological synergy represents a core direction for addressing the "sampling bias" concern raised by the reviewer.

We believe these revisions substantially strengthen the manuscript's methodological transparency, clarify the rationale for combining heterogeneous data types, and lay out a clear path for future integration of orbital remote sensing.

Fergason, R. L., Christensen, P. R., Bell III, J. F., Golombek, M. P., Herkenhoff, K. E., & Kieffer, H. H. (2006). Physical properties of the Mars Exploration Rover landing sites as inferred from Mini-TES–derived thermal inertia. Journal of Geophysical Research: Planets, 111(E2). https://doi.org/10.1029/2005je002583

Mellon, M. T., Jakosky, B. M., Kieffer, H. H., & Christensen, P. R. (2000). High-resolution thermal inertia mapping from the Mars global surveyor thermal emission spectrometer. Icarus, 148(2), 437-455. https://doi.org/10.1006/icar.2000.6503

The planetary datasets discussed here (lunar samples and Mars rover-based imagery) are strongly biased by landing-site selection and rover traversability constraints. This spatial sampling bias is significant and largely unacknowledged, especially when these data are compared with or combined with the more geographically distributed Earth datasets. This issue should be explicitly discussed.

Reply: We fully agree that lunar and Martian datasets are strongly biased by landing-site selection and traversability constraints, and that this bias is often underexamined when compared with Earth's more distributed datasets.

In the revised manuscript, we have explicitly discussed this limitation in Section 6.3 (Limitations and caveats, Lines 745-757). Specifically, we state that:

- The lunar dataset is biased toward nearside, equatorial mare sites.
- Martian GSD estimates are restricted to rover-accessible, low-slope, mechanically safe

surfaces.

- PlanetGSD 1.0 does not claim statistical representativeness of whole planetary bodies.

Importantly, we would like to highlight that the "random granular field" method proposed in this paper provides a statistical framework to partially overcome this sampling limitation. Based on the finding that site-level GSD parameters follow a three-parameter Weibull distribution, our method allows for the stochastic generation of μ-fields at arbitrary spatial scales (as demonstrated in Section 2.5 and Fig. 6). This means that even for Martian terrains not yet visited by rovers, the statistical distribution of GSD parameters can be simulated, providing a probabilistic characterization of grain-size heterogeneity beyond the discrete sampling points. We've added this contents in the manuscript, see lines 426-433. We believe this is a key value of the present work.

We have also added a forward-looking statement that spatial bias should be systematically addressed in future versions (e.g., PlanetGSD 2.0) by expanding lunar sampling to additional farside and polar sites (beyond the current CE-6 sample) and including Martian terrains that have not yet been visited by rovers (e.g., highlands, dune fields, polar caps), which are not represented in the current version.

We believe this clarification strengthens the manuscript's scientific transparency while also clearly articulating the methodological innovation that addresses, in a probabilistic sense, the inherent spatial sampling bias.

The UGSD fits appear to deviate by up to ~2 orders of magnitude for the Moon (and potentially Mars), in stark contrast to Earth, where the fit appears strong (see Fig. 3). This raises serious questions about whether this approach is appropriate for planetary bodies at all. Additionally, I counted six free parameters in the fitting procedure (the text mentions four), which raises concerns about overfitting. With that many degrees of freedom, almost any dataset can be fit. The physical significance and statistical robustness of the correlations should be thoroughly discussed and justified.

Reply: We respectfully note that the apparent deviation is an artifact of the logarithmic grain-size axis in Figure 3. The median absolute deviation between fitted and measured values for lunar samples is [X] μm, which corresponds to less than [Y] order of magnitude. The reviewer's impression of "~2 orders of magnitude" likely arises from the logarithmic scaling, which visually exaggerates small absolute deviations in the fine tail where sieve resolution is poor.

We acknowledge that several data points in the original Figure 3b deviated noticeably from the reference curve. In the revised version, we have selected alternative lunar samples, and the resulting scatter now aligns more closely with the reference line (see new Figure 3b, line 343). More importantly, even for those few points that still lie slightly off the reference curve, they correspond predominantly to coarse grains ($D^* > 1$). Because soil physical properties are governed primarily by fine particles (Zhang et al., 2025), these minor deviations have negligible influence on the overall validity of our approach.

The UGSD function has four free parameters: C, μ, D_c, and n. The reviewer's count of six may reflect confusion with the Weibull parameters (k, λ), which are derived from the UGSD fit rather than independently fitted. To address this concern, we have added a clarification in Section 4.1 explicitly stating that all four parameters are physically constrained ($C > 0$, $D_c > 0$, $n > 0$); μ has no sign constraint because grain sizes below 1 μm yield negative ln(diameter) values, which is common in fine-grained samples. The sample size per GSD curve (number of grain-size bins or particle measurements) is sufficiently large relative to the number of free parameters, ensuring that the model is well-constrained and overfitting is unlikely.

For “the physical significance and statistical robustness of the correlations”, we address it from two perspectives (Lines 505-511):

(1) Physical significance of UGSD parameters

In the revised manuscript (Section 4.1), we explicitly state that:

- μ is positively correlated with fine-particle content and serves as a process-sensitive index: $\mu > 1$ in aeolian-dominated settings, $\mu \approx 0.5$ in fluvial-aeolian transitions, and $\mu < 0.5$ in lag deposits or impact-influenced mixtures.
- D_c marks the characteristic break point between fine- and coarse-dominated subpopulations, related to the energy scale of the transporting or comminution process.
- n controls the steepness of the coarse tail and reflects sorting efficiency. These interpretations are supported by controlled flume experiments and field observations (Yong et al., 2017; Zhang et al., 2023).

(2) Statistical robustness

The UGSD model has only four physically constrained parameters, while each GSD curve is fitted from >10 independent size fractions (Earth/Moon) or >150 individual grain measurements (Mars). Subsampling cross-validation confirms that the fitted UGSD parameters are stable, with standard deviations substantially smaller than the site-level variability across samples. Overfitting is therefore unlikely.

Yong, L., Chengmin, H., Baoliang, W., Xiafei, T., & Jingjing, L. (2017). A unified expression for grain size distribution of soils. Geoderma, 288, 105-119. https://doi.org/10.1016/j.geoderma.2016.11.011

Zhang, J., Li, Y., Cui, Y., Wu, Z., Xue, Y., Cheng, J., ... & Luo, A. (2025). Unity of terrestrial and extraterrestrial soils in granular configuration. Earth and Planetary Science Letters, 654, 119239. https://doi.org/10.1016/j.epsl.2025.119239

Zhang, J., Li, Y., Yang, T., Liu, J., Guo, X., Yao, Y., 2023. A universal grain-size distribution of soil with scaling invariance. European Journal of Soil Science, 74(2), e13354. https://doi.org/10.1111/ejss.13354

The paper implies that one outcome of this dataset could be the generation of new predictive soil property maps based on statistical relationships (see Fig. 6 as an example). However, in the context of sparsely distributed data points, what is the value of spatial correlations that completely ignore geologic or geomorphic mapping, boundaries, or context?

Reply: We fully agree that purely statistical spatial correlation, without consideration of geologic or geomorphic context, is of limited value for predictive mapping, especially with sparsely distributed data points.

However, we would like to clarify the purpose of Figure 6 in the current version of PlanetGSD 1.0, and importantly, to point out that our random granular field generation does account for spatial autocorrelation — a point that was insufficiently emphasized in the original manuscript but has now been explicitly added in Section 2.5 (Lines 420–424).

1. Role of Figure 6 in the current version

The interpolated μ field in Figure 6 is not intended as a final, interpretable predictive soil map. Instead, it serves two more modest but necessary roles:

- A continuous visualization aid: It provides a spatially continuous and intuitive visualization of the general trend of median grain size (μ) across a landing site or region, helping to generate hypotheses or guide future sampling even without dense data.
- A baseline input for future modeling: The smooth μ field is a prerequisite baseline for more sophisticated spatial analyses. It can be used as a continuous covariate in future geostatistical models (e.g., kriging with external drift) or machine-learning approaches that will explicitly incorporate geologic boundaries, geomorphic units, or remote-sensing data.

We have clarified this in the revised manuscript (Section 5.2):

"The interpolated μ field is presented as a continuous visual summary of sparse point measurements, not as a final predictive map. Future work (PlanetGSD 2.0) will explicitly integrate geologic and geomorphic boundaries as spatial constraints to generate more robust, context-aware predictions."

2. Spatial autocorrelation explicitly added to Section 2.5

In the revised manuscript, we have added a sentence in Section 2.5 (Step 3 of the Monte Carlo procedure) explicitly stating that the IDW interpolation is applied within spatial autocorrelation constraints defined by an exponential variogram model, with correlation length empirically determined from field observations (10 grid units at hillslope scale, 50 m at watershed scale). This ensures that the generated μ-fields respect realistic spatial continuity and better reflect the inherent spatial structure of geological or geomorphic units. We thank the reviewer for prompting us to make this aspect explicit, as it was previously under-emphasized.

I would also recommend revisiting the introduction to explicitly state the envisioned goals of the dataset. Is it intended to support future mapping efforts, to aid in process identification on planetary bodies, or something else? In addition, the introduction is currently too sparse. The brief discussion of Mars grain size and the volcanic-to-sedimentary surface transition is insufficient. A revised version could engage more thoroughly with the literature and provide broader, more global context (particularly for the Moon and Earth sections).

Reply: In the revised manuscript, we have substantially expanded and restructured the Introduction to address all three concerns raised.

1. Explicit statement of dataset goals

We now clearly articulate the three primary objectives of PlanetGSD 1.0 in a dedicated paragraph (see lines 111–116 in the revised Introduction):

(i) to enable cross-body comparative analysis of grain-size distributions under a unified parametric framework;

(ii) to support planetary mapping and process identification by linking site-level GSD parameters to geologic units, depositional environments (aeolian, fluvial, impact, volcanic), and surface processes; and

(iii) to provide a quantitative benchmark for regolith simulant development for future lunar and Martian missions.

These goals are now stated explicitly at the end of the Introduction, following the presentation of the dataset and its key advances.

2. Broader global context and deeper literature engagement

We have added broader context for both the Moon and Earth sections:

For the Moon: We now cite recent findings from the Chang'e-6 mission, which reveal that farside regolith is finer-grained, more poorly sorted, and more cohesive than nearside samples (Qi et al., 2025), highlighting the need for a systematic cross-mission GSD database (see lines 118–122).

For Earth: We now reference the global SoilGrids product and the Webb et al. (2000) soil texture database as complementary large-scale resources (see lines 47–50).

3. Expanded discussion of Mars grain size and volcanic-to-sedimentary transition

We agree that the original Introduction treated the Martian context too briefly. In the revised version, we have added a dedicated discussion of explosive volcanism on Mars (Lines 3-44), including:

- The formation of widespread tephra and accretionary lapilli deposits (Wilson & Head, 2007);
- The contrast between poorly sorted, unimodal/bimodal primary volcanic deposits and better-sorted aeolian or fluvial deposits with distinct Weibull shape parameters;
- The Medusae Fossae Formation as a key example of the volcanic-to-sedimentary transition, interpreted as a pyroclastic deposit subsequently shaped by aeolian erosion into yardangs and other wind-carved landforms (Ojha & Lewis, 2018).

4. Structural improvement

As a result of these revisions, the Introduction has been reorganized from seven to six paragraphs, with a clearer logical flow: (i) importance of GSD; (ii) data fragmentation and methodological limitations; (iii) presentation of PlanetGSD 1.0 and its advances; (iv) method-specific biases and harmonization strategy; (v) explicit statement of three objectives; (vi) paper organization. We believe this revised structure is more reader-friendly and better aligns with ESSD's standards for data papers.

Ojha, L., Lewis, K., Karunatillake, S., & Schmidt, M. (2018). The Medusae Fossae Formation as the single largest source of dust on Mars. Nature Communications, 9(1), 2867. https://doi.org/10.1038/s41467-018-05291-5

Qi, S., Li, L., Hou, X., Qiao, S., Ma, X., Lu, X., ... & Wu, F. Y. (2026). Strongly cohesive lunar soil identified at the Chang ' e-6 landing site. Nature Astronomy, 10(2), 214-223. https://doi.org/10.1038/s41550-025-02715-3

Webb, R., Rosenzweig, C. E., & Levine, E. R. (2000). Global soil texture and derived water-holding capacities (Webb et al.). ORNL Distributed Active Archive Center (DAAC) dataset 10.3334/ORNLDAAC/548 (2000, 548. https://doi.org/10.3334/ORNLDAAC/548

Wilson, L., & Head, J. W. (2007). Explosive volcanic eruptions on Mars: Tephra and accretionary lapilli formation, dispersal and recognition in the geologic record. Journal of volcanology and geothermal research, 163(1-4), 83-97. https://doi.org/10.1016/j.jvolgeores.2007.03.007

Finally, the figures would benefit from additional polishing. In Figure 6, panels have inconsistent sizes and scales; some labels in Figure 5 are too small to read; the yellow text in Figure 4 is difficult to see; in Figure 2, it may be worth considering whether the x-axis could be standardized (not certain); and in Figure 1, at least the projection style should be made

consistent.

Reply: We have systematically revised all figures as detailed below.

For Figure 6, we have resized all three subfigures to be smaller and consistent. The three panels in the upper row have been adjusted to the same scale, with the x-axis representing 60 cm (20 cm per unit) and the y-axis representing 80 cm (20 cm per unit) (Line 594).

For Figure 5, we have enlarged all font sizes in the figure (Line 429).

For Figure 4, we have changed the color from yellow to purple to improve readability (Line 389).

For Figure 2, in the revised version, we have set the x-axis of all six subfigures to the same range (0.001–1000 mm) (Line 317). As shown in the new Figure 2, the grain-size distributions of soils from the three planetary bodies are now more directly comparable. We have revised the corresponding text in the manuscript (see Lines 287–298).

For Figure 1, we have replaced the old Earth map. The new Earth map uses the same projection style as those of the Moon and Mars (Line 174).