

This manuscript “**Asymptotic Behavior of Lidar Scattering Properties of Absorbing Dust Aerosols Across Rayleigh and Geometrical-Optics Regimes: Theory and Implications**” by Luna et al. presents a systematic theoretical investigation of how particle size and iron-oxide mineralogy control the asymptotic behavior of lidar observables- specifically the lidar ratio, linear depolarization ratio, and single-scattering albedo for nonspherical mineral dust. Using the TAMUdust2020 irregular hexahedral database and triaxial ellipsoid calculations, the authors derive limiting behaviors in the Rayleigh regime and the geometrical-optics regime. A central claim is that these asymptotic limits are fundamentally driven by absorption and size parameter rather than particle shape. The authors then integrate single-particle properties over idealized and in-situ measured size distributions (FENNEC, AER-D, AERONET) to explain multiwavelength spectral features, including the frequently observed "inverse-v" depolarization pattern. The paper concludes by identifying an "optical ambiguity" whereby super-coarse, iron-rich dust can mimic fine-mode aerosol signatures in standard lidar retrievals, with important implications for spaceborne missions.

The topic is timely and highly relevant to the aerosol physics and remote sensing communities. The theoretical framework connecting single-particle physics to bulk, multiwavelength lidar observables is interesting, and the mineralogical focus aligns well with new constraints from imaging spectroscopy (e.g., EMIT). Overall, the science is sound, and the conclusions are well-written. However certain claims, particularly regarding the exact GO limit of SSA, the practical degeneracy of super-coarse dust, and the shape-insensitivity assertion would benefit from clarification. I recommend the authors address the points below:

1. In section 3.2, the authors derive results that for large, strongly absorbing particles $w \sim 1/2$ (Eq. 16), based on the assumption that $C_{sca}^D \approx C_{geo}$ and $C_{sca}^R \ll C_{geo}$. However, in section 4.1 around line 284, the text states that “..that asymptote remains above 0.5 and reflects both refractive-index and shape effects.” Furthermore, Figure 2 (right column) and Figure 4 (right column) show bulk SSA values at large sizes/radii approaching $\sim 0.55-0.65$ rather than 0.5, even for high iron-oxide fractions. This raises the question is $w \sim 1/2$ a strict theoretical limit only for perfectly absorbing particles or idealized geometries, whereas finite absorption and realistic shapes may yield a higher asymptote? Or does the 0.5 limit apply only to the single particle level while PSD averaging shifts the bulk value? Please clarify under which conditions the 1/2 limit is exact versus approximate, and please discuss why the numerical results converge to value > 0.5 . Also please clarify the mathematical condition (e.g., is it $k \cdot x \gg 1$, or a threshold on k itself)?. For a given iron-oxide fraction, does the limit strictly require x tends to infinity, or is there a finite x where the asymptote is effectively reached? Clarifying this would help readers know when the 1/2 limit is physically relevant versus merely mathematical.

2. The manuscript correctly emphasizes that the asymptotic GO and Rayleigh limits are insensitive to particle shape, and the comparison between hexahedra (Figure 2) and spheroids (Figure 3) indicate this. However the intermediate size regime ($x \sim 10-100$), which are highly relevant for lidar observations at 355-1064 nm of coarse dust), the depolarization ratios differ substantially in magnitude between the two models (for e.g. $\delta \sim 0.5$ for hexahedra vs. 0.3-0.4 for spheroids at 355 nm). This absolute difference will translate to around 20-40% relative difference, which is large enough to shift aerosol-typing thresholds in algorithms like CALIPSO or EarthCare. Since the operational lidar retrievals often sample this transition region rather than the true asymptotic limit, the practical retrieval uncertainty due to shape choice maybe larger than the “weakly sensitive” framing suggested. Could the authors provide a discussion that while functional form (peak-and-decline for absorbing particles) is robust, the absolute magnitude of δ and the exact location of the peak in x -space remain shape dependent. Could the authors show a relative difference between the two models as a function of x ? This would further help the community assess where shape uncertainty matters most.

3. Can the authors either overlay their modeled spectral depolarization curves on Haarig et al. observations or provide a quantitative discussion comparing modeled ranges (e.g., δ_{355} , δ_{532} , δ_{1064}) against reported observational values from SALTRACE or Barbados?

4. The manuscript reports $S > 300$ sr at 355 nm (Figure 8a-c). However, elastic-backscatter lidars like CALIOP and CATS assume $S \approx 40-44$ sr for dust. Are these modeled extreme values within the physically realizable range for atmospheric dust, or would they be filtered as non-physical outliers in operational retrievals? Is it possible that the extinction is associated with other particle types mixed together, such as absorbing carbon particles, which have been labeled together with dust by the existing lidar algorithms?

5. On page 18, the authors state that an automated classification algorithm observing high S with low δ (≈ 0.18) may misclassify iron-rich, super-coarse dust as a mixture of dust and smoke or pure pollution. However, Figure 8e shows that the FENNEC depolarization ratio spans a broad range ($\sim 0.1-0.45$ at 355 nm depending on iron-oxide fraction). Could the authors specify the exact combination of particle size distribution parameters (e.g., median radius, geometric standard deviation) and iron-oxide volume fraction that produces $\delta \sim 0.18$? Tying the optical ambiguity claim to a concrete point in the parameter space would strengthen the argument and allow readers to assess whether this scenario is representative of typical Saharan dust conditions or an extreme edge case. Given that there are also extensive wildfire sources which may mix with Saharan dust, it is possible that the non-iron component has substantial amounts of carbon? If so, based on specific size distributions of this mixed fraction, how would this lead to different ranges specifically at 355 nm? Would including data at 532 nm and 1064 nm help clarify these mixtures?