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# Mid-infrared spectra inform on the complexity of extrasolar dust clouds

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Crucial knowledge about dust clouds in substellar atmospheres comes from Spitzer observations. We summarize here what we have learned about the formation, composition, evolution, and distribution of dust clouds from the analysis of the silicate absorption in Spitzer mid-infrared spectra.

The emergent spectra of the warmest brown dwarfs and exoplanets are shaped by dust clouds in their atmospheres. Therefore, understanding these objects depends on our knowledge of dust clouds. Despite many indirect studies on these clouds, the only *direct* evidence of the existence of dust clouds is a $\sim$9 $\mu$m silicate absorption. Prior to JWST, Spitzer was the only telescope able to observe this silicate absorption. We list here the lessons learned about dust clouds from analyses of the silicate absorption.

Dust clouds in substellar atmospheres:

- Comprise a combination of $\lesssim 1$ $\mu$m-sized amorphous silicate (enstatite, forsterite, quartz, and/or pyroxene) and iron grains (Cushing et al., 2006; Burningham et al., 2021; Luna & Morley, 2021; Vos et al., 2023; Suárez & Metchev, 2023).
- Are near ubiquitous in L-type atmospheres and form, then thicken, and sediment out of the photosphere in the $T_{\rm eff}$ range ≈2000–1300 K (Suárez & Metchev, 2022).
- Sediment less efficiently in young objects (Suárez & Metchev, 2023; Suárez et al., 2023).
- Are preferentially concentrated at the equator compared to the poles (Suárez et al., 2023).
- Are responsible for their color diversity (Cushing et al., 2006, 2008; Burgasser et al., 2008; Looper et al., 2008; Suárez & Metchev, 2022; Suárez et al., 2023, see Figure 1) and, potentially, their variability (Suárez & Metchev, 2022).

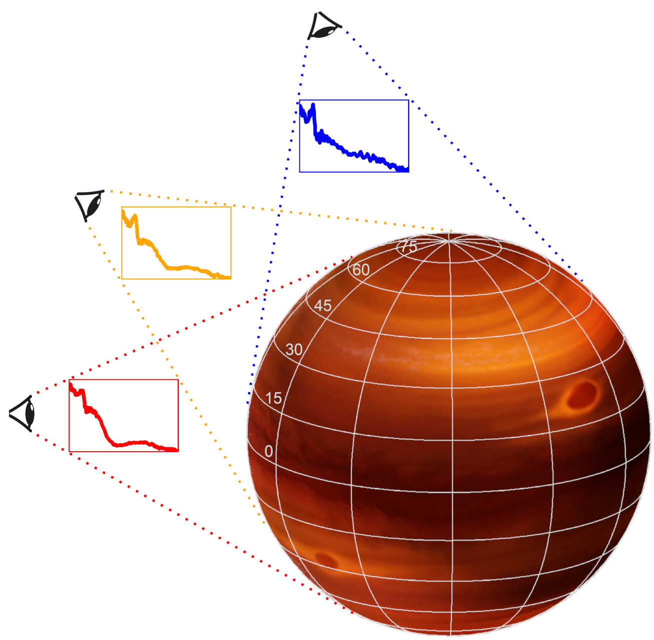


**Figure 1.** The appearance of substellar objects is highly influenced by their viewing inclination. Figure adapted from Suárez et al. (2023) to show that lower latitudes exhibit stronger silicate absorption and are redder.

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