FIVE MARS YEARS OF GALE CRATER CLOUD OPACITY MEASUREMENTS.

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Introduction: For the past five Mars Years (MYs), the Mars Science Laboratory (MSL) Curiosity rover has been observing the southern edge of the Aphelion Cloud Belt (ACB), an equatorial water-ice cloud feature that forms each year near aphelion, from the ground. Since sol 24, two cloud movies have been executed on a regular cadence with the goal of examining diurnal, annual, and interannual variations in cloud opacities, morphologies, and altitudes, as well as their scattering phase function.

Previous work examined the first two MYs of data and found a slight increase in opacities in the early morning compared to the late afternoon, as well as increased opacities overall during the ACB season [2, 3, 4]. Very little interannual variability in the opacity of ACB clouds between MY 32 and MY 33 was observed [4], which is consistent with orbital observations of the interannual consistency of the ACB [5, 6, 7, 8]. Although an apparent increase in opacity in MY 33 is observed, it is attributed to a larger number of high-opacity early morning observations.

Because consistent early morning observations were not conducted until MY 33, it was not possible to determine if the diurnal difference in opacity was a persistent or transient feature of the ACB. With five MYs of data processed, three and a half of which include full diurnal coverage, we can now fully assess the year-to-year variability of ACB clouds over Gale.

Methods:

Atmospheric movies. Using the Navigation Cameras (Navcams) onboard MSL, two types of atmospheric movies are acquired on a regular cadence: Zenith Movies (ZMs) and Suprahorizon Movies (SHMs). ZMs are pointed almost directly straight up (~85°), allowing for the determination of the clouds' angular velocities and direction of motion; SHMs are pointed more obliquely (~26°), permitting a more robust examination of cloud morphologies. Both movies consist of eight frames taken across ~6 minutes.

Opacity measurement. Opacities are calculated using two equations that make different assumptions about the nature of the clouds being observed, assumptions that are valid at different points during the year. Full derivations of these equations and explanations of the assumptions they make can be found in Kloos et al. [3] and Moores et al. [9].

The equation used during the ACB season requires the scattering phase function of the clouds as an input. Because the phase function of ACB clouds is not well-constrained, Kloos et al. [3, 4] assumed that it was fixed at a constant value of 1/15. Although this assumption appears to be valid at large scattering angles, it breaks down close to the Sun, resulting in anomalously high opacity measurements.

If we take the calculated opacities at large scattering angles (>70°) to be representative of the opacities at low scattering angles, we can invert the opacity equation and use the mean of the large scattering angle opacity measurements as an input to determine a more appropriate shape for the phase function. This phase function can then be compared to others that have been previously derived to gain insight into the microphysical nature of ACB ice crystals, as has been previously done using MSL data [10, 11, 12].

Results:

Variability of the ACB. After applying the phase function correction, we observe minimal variability in the ACB. In particular, we are unable to replicate the diurnal difference found by Kloos et al. [4] (see Figure 1). This is surprising, as the lower overnight temperatures should promote the formation of higher-opacity clouds that would be observed in the early morning before dissipating. Kloos et al. [4] measured SHM opacities in MY 33 higher than those seen at any

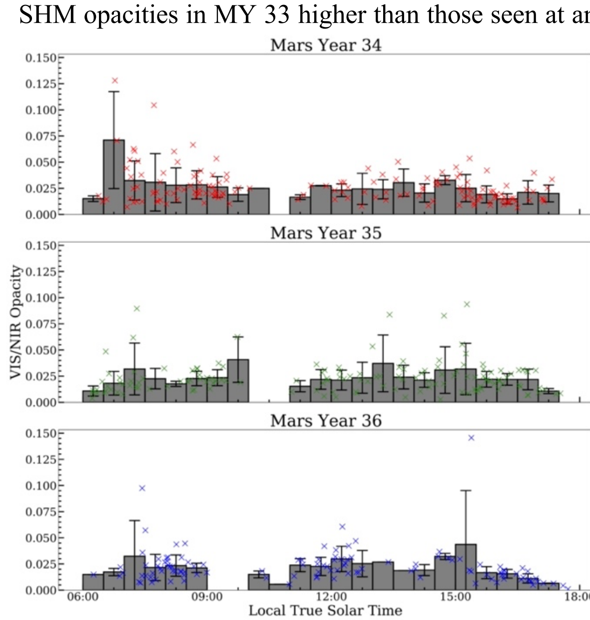

Figure 1. *Optical depths for the MYs 34–36 ACB seasons averaged across half-hour bins of Local True Solar Time. There is no obvious difference in opacity between the AM and PM observations.*

other time during the mission, which could account for the diurnal difference of that MY.

We also see very little interannual variability in opacity. Although this is expected, previous work has shown that Global Dust Storm (GDS) events, such as the one that occurred in MY 34, can suppress the opacity of the ACB in the following MY [13]. This does not appear to be the case for the MY 35 ACB season, consistent with other MSL observations suggesting that the MY 34 GDS had little to no effect on the MY 35 ACB [11].

Phase function comparisons. In Figure 2, we compare our derived phase functions with those of six ice crystal geometries at 660 nm and a particle size of 3 µm [14]. Although we see better agreement than previous work that used substantially larger particle sizes (50 µm), no single geometry can convincingly explain our measurements, suggesting that ACB clouds are dominated by multiple geometries or that they have exotic geometries not seen in terrestrial clouds.

Conclusions: We have updated the record of water-ice cloud opacities observed over Gale Crater by the MSL mission to cover five full Mars Years. The diurnal difference in opacities seen in MY 33 does not appear in MYs 34–36. The MY 34 GDS does not seem to have affected the mean opacity of the MY 35 ACB.

As part of our opacity measurements, we derive scattering phase functions for MYs 34–36. By comparing our phase functions with those of six ice crystal geometries frequently observed in terrestrial clouds but with Mars-like particle sizes, we conclude that ACB clouds are unlikely to be dominated by any one of these geometries individually.

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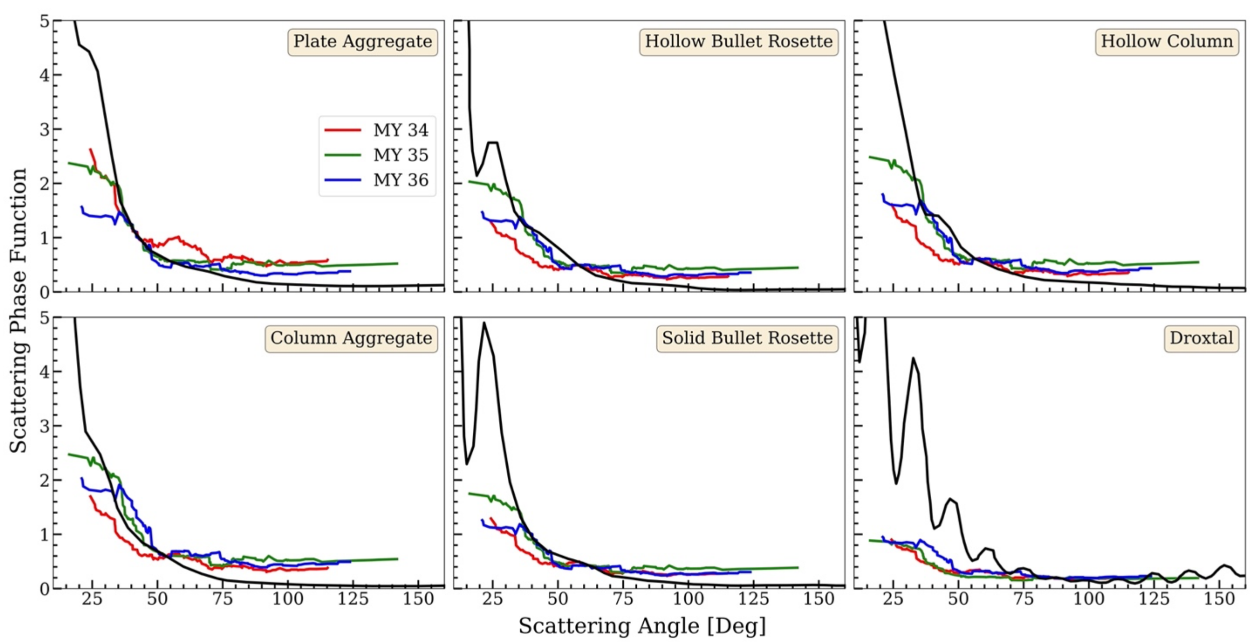

Figure 2. *Comparisons between our three derived phase functions and those of six ice crystal geometries with 3 µm particle sizes. The MSL phase functions have been normalized to the value of the comparison phase function at the median scattering angle.*