# Inferences of Martian atmospheric dust and water ice content derived from radiative transfer models of passive MSL observations by MastCam.

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## Introduction

The participating science project "Observations of Water Ice and Winds from the MSL Rover" [1], included proposed atmospheric measurements using several MSL imagers. To date, several such data products have been acquired by Curiosity. A focus on combined MastCam and modelling analysis is presented here.

Despite MSL being designed for other scientific priorities, Curiosity has an excellent suite of instruments for near surface measurement of the atmosphere [1]. The creative use of MSL cameras extends the atmospheric science return to include observations of water ice.

## The Idea

**We examine MastCam images of the sky** in two colour filters. We compare the intensity of blue light to the intensity of red light to make a measured blue-to-red ratio (B/R).

**We model the Martian atmosphere**, including number and sizes of dust and ice particles. We put solar-intensity red and blue light through this atmosphere, using the same sun angle and viewing angle as those used for the MastCam images.

**We compare model output with images**, varying the number and sizes of atmospheric particles until the modelled B/R matches the measured B/R.

## MastCam Images

The MastCam's left and right cameras (large and smaller square apertures visible in this figure) can be used simultaneously to image the sky, with a 445 nm blue filter on one camera and a 750 nm red filter on the other. Alternately, the left camera can acquire successive images in the red and blue filters.

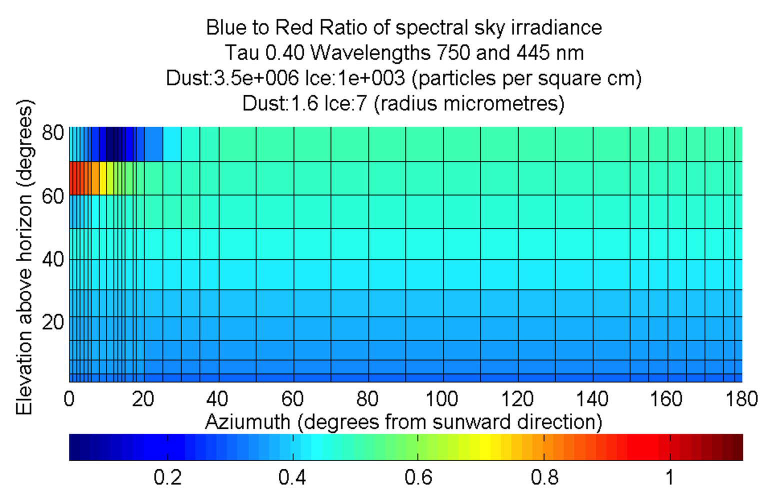
Scaling by total atmospheric optical depth measurements, we can produce a blue-to-red ratio which can be compared with modelled ratios.

## Radiative Transfer Model

We have adapted a doubling-and-adding 2-layer hemispherical radiative transfer model [7] for sunlight through Mars's atmosphere for use with MSL's viewing geometry.

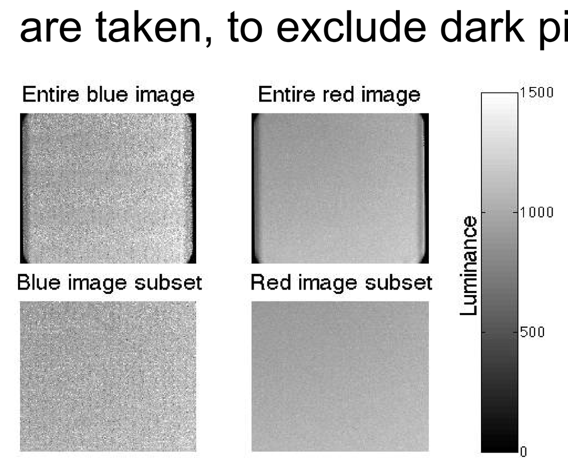
*Code Output:* The code outputs spectral radiance at several wavelengths at 11 points in elevation and 38 in azimuth. These are converted to an expected B/R ratio at all points (shown below).

*Segment Selection:* The appropriate B/R ratio value is chosen to match the coordinates of the MastCam comparison images. For the Sol 24 images shown here, this is 30 degrees elevation, 0 degrees azimuth (about halfway up the left side of the plot at right).




## Image Processing

These 100 μs MastCam Left exposures of the sky on Sol 24 have been radiometrically calibrated. Subframes (800 x 1000 pixels) are taken, to exclude dark pixel areas.



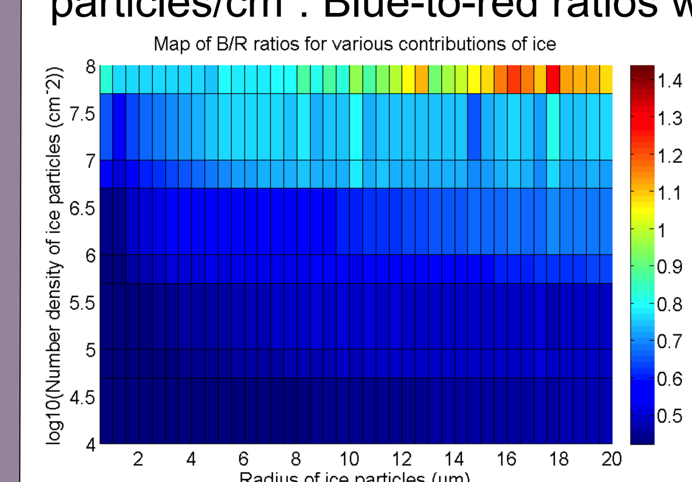

Mean luminance:
Blue: 1034 +/ 61
Red: 1008 +/ 130

B/R = 1.0252 +/ 0.1434.

The ratio of these mean values provide the blue to red ratio which will be compared to model output. To match the results above, we will look for combinations of ice size and number density which produce blue-to-red ratios slightly greater than 1.

## Results

*Dust and Ice Parameters:* The dust was kept fixed at r = 1.6 um and 3.5E6 particles/cm$^2$. The ice was varied from r = 0.1 to r = 20 um and 1 to 1E20 and particles/cm$^2$. Blue-to-red ratios were calculated.




B/R = 1.025 is yellow on this plot, and matches with the Sol 24 sky spot analysis.

Initial model results indicate that there is a minimum number of 1e7.5 cm^-2 ice particles aloft if the particles are large, and a higher minimum number if they are small. Further checks are required for confidence in this result.

## The Reason This Method Works

**Ice and dust have different scattering efficiencies for blue and red light.**

Rayleigh scattering from tiny particles varies as $\lambda^{-4}$; blue light is scattered more efficiently than red light.

Mie scattering from larger particles is less wavelength-dependant, but more size-dependant.

*Figure 3 (below) [6]: Sky colour depends on sun angle, observing angle, and particle size.*

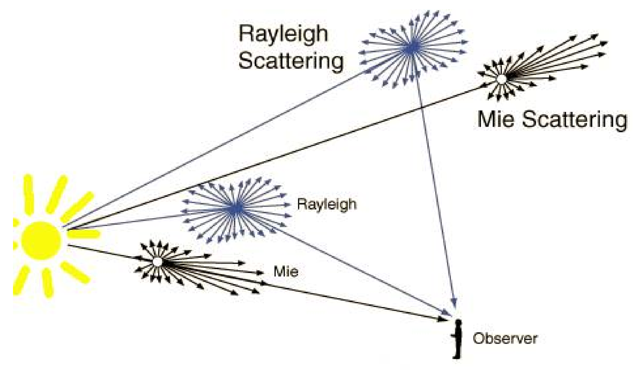
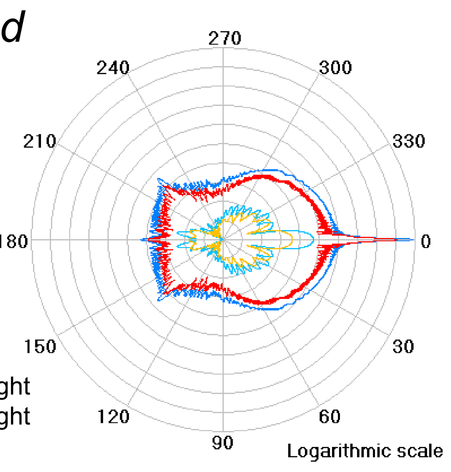



*Figure 4 (below): Mie scattering efficiency plot [5]. Sunlight enters from left (180°). Profiles show intensity of blue (440 nm) and red (750 nm) light scattered in each viewing direction by dust and ice particles.*




Water Ice, 20 um radius, 440 nm light
Water Ice, 20 um radius, 750 nm light

Montmorillonite dust, 1.5 um radius, 440 nm light
Montmorillonite dust, 1.5 um radius, 750 nm light

*The larger ice particles scatter both wavelengths more efficiently than do the smaller dust particles. Note also that some viewing angles are more conclusive for B/R ratio comparisons than others.*

## Further Refinements

*Parameter Space:* It is clear from the result above that examination of a larger parameter space in both ice and dust size and number density is required. This work can begin immediately.

*Ambiguity:* In cases where the modeled result is ambiguous, with several combinations of particle number densities and sizes leading to the same blue-to-red ratio, further analysis may be undertaken using alternate filter pairs.

*Dust composition:* Further exploration of the dust composition is required. With new results arriving from mineralogical studies on MSL, it will be possible to refine the modeled dust properties.

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