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# Final Results of Doppler Velocimetry Winds on Mars' Atmosphere

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In 2018 a regional dust storm on Mars has evolved to a global scope, becoming one of the largest dust storms ever observed. These rare and unpredictable events are poorly known. A key factor for its evolution is the role played by the Martian winds. Measuring winds on Mars is a real challenge for remote observations but a global dust storm offers to us a unique opportunity thanks to an innovative technique to measure the Doppler effect of solar Fraunhofer lines back-scattered on the Mars dust cloud. A high spectral resolution is required to resolve the solar lines and to allow us to measure with precision the line shifts due to aerosol motion and in this manner retrieve the related wind map.

We used dedicated ground-based observations made with the Ultraviolet and Visual Echelle Spectrograph (UVES) at the European Southern Observatory's Very Large Telescope (VLT) facility in Chile. This instrument's high resolution (R ~100000) allows for the dust cloud velocity to be measured, by computing the Doppler shift induced in the Fraunhofer lines (λ of 420-1100 nm) in the solar radiation that is back-scattered in the dust suspended in the Martian atmosphere, by the motion of that same dust particles, with an average error of approximately 5 $ms^{-1}$.

The processes that allow for the development of global dust storms are poorly understood. Furthermore, the cut-off mechanisms that spur the end of these storms are also without consensus and may even vary from storm to storm. During such events dust can be lifted to heights above 50 km across all latitudes and longitudes, increasing the optical depth along the dust layer in atmospheric suspension and increasing the heat absorbed at each altitude covered by dust [1,2]. Global dust storms are complex stochastic events that can drastically alter the atmospheric dynamics [3,4]. These storms usually develop in the southern hemisphere during southern Summer and Spring ( Ls ≈ 180º - 360º), however, the 2018 storm started developing in the northern hemisphere on Ls ≈ 185º.

Our understanding of both the initiation and decline of global dust storms is only marginal, nevertheless we do know that such events probably originate from the superimposition of three circulation components: the Hadley cell, thermal tides and topographically controlled circulations. This mechanism was suggested by Leovy (1973) [5] and relies on the seasonally increased insolation and dust loading coupled with the above-mentioned components to allow certain storms to become global at the planetary scale. The decay of dust storms is even more obscure as the cause for the halting of the dust lifting hasn't been unambiguously identified. Either the depletion of surface dust available for lifting shuts off the lifting events (which requires replenishment of the surface dust sources) or the decrease in intensity of the various components allows for the surface wind stress to drop below the required threshold for dust lifting [6,7].

Mars' atmosphere is highly transparent in the visible and ultraviolet ranges and the back-scattered radiation in those wavelength ranges in the atmosphere is negligible which precludes the application of the Doppler velocimetry method that we developed and fine-tuned for the case of Venus [8,9,10,11,12]. However, during global dust storms, the opacity of the atmosphere increases and allows for the scattering of enough light in the suspended dust in the middle atmosphere for the application of our Doppler method in an effective way.

The adaptation of our Doppler velocimetry method took in account the geometry of our observations. Spherical geometry was used to locate the observations within the planet, as seen from Earth at the time of each observation, and to compute the de-projection of the radial Doppler velocities from the observer's line-of-sight, for each point of the slit and for each exposure. The rotation velocity's contribution to the overall Doppler shift was removed by computing and subtracting the rotation velocity at each point on Mars sensed by the spectroscopic slit. Furthermore, the contributions made to the total shift by the Young effect were evaluated and deemed negligible under the specific geometry of our observations.

The scope of this work is to study the dynamical behaviour of Mars' middle atmosphere during a global dust storm using ground-based observations made with the high-resolution spectrograph UVES at ESO's Very Large Telescope and Doppler velocimetry methods, for the first time, to complement observations of orbiter instruments.

The success and validation of the application of this method to the atmosphere of Mars may provide a new tool to investigate the Martian atmosphere during dust storms. We intent is to contribute for a better understanding of the atmosphere's dynamics during planet encircling dust events. We measured the wind velocity and its spatial variability, through high resolution spectroscopy and Doppler velocimetry.

The main goal of this research line is therefore, to provide wind measurements using visible Fraunhofer lines scattered at Mars' dust hazes, which allows spatial wind variability studies and will make possible to obtain a latitudinal profile of the wind along the cited global dust storm and a wind map of the dust storm as a function of the latitude and local time over the planet as seen from Earth.

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