Vol.3, No.4, 285-290 (2011)
http://dx.doi.org/10.4236/ns.2011.34036

Natural Science

Detecting the light of the night sky in Mars

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Received 10 February 2011; revised 3 March 2011; accepted 27 March 2011.

ABSTRACT

In this paper a new methodology is outlined to detect the dust content in the Martian atmosphere during nighttime. In the previous Lander missions to Mars, scientists were able to determine the dust load in the Martian atmosphere during daylight using spectral lines of the Sun. Since the dynamics of Martian dust storms had been determined to be very rapid changing over times of hours and not days, it is imperative to determine the dust load during nighttime, so future astronauts to Mars can take protective measures for their equipment. They can also factor this effect for their planned activities during daytime. The new methodology greatly improves the classical method for determining the extinction in the Earth's atmosphere. The classical method uses observations of bright stars from which the optical depth, τ_{total}, can then be deduced from the classical brightness equation. The classical method succeeds reasonably well at high elevation angles from the horizon but fails dramatically at low elevation angles. It also determines τ_{total} from the slope of a plot of observed brightness of a bright star vs. air mass at all elevations. The plot shows a straight line at high elevations angles, which then curves and becomes uncertain at low elevation angles. The new methodology bypasses this severe difficulty by simply eliminating this plot, and by acquiring the brightness of a bright star above the atmosphere (no extinction) and compares it to the observed bright- ness of the same star below the atmosphere at all elevations.

Keywords: Mars Nightsky; Bright Stars Atmospheric Extinction in Mars' Nightsky; Detecting Atmospheric Dust in Mars; Detecting Martian Dust storms During Night

1. INTRODUCTION

This paper is the first step to build on for a technique to be incorporated in future NASA Mars missions. The main objective is to acquire information on the Martian dust load and other atmospheric constituents in the atmosphere during nighttime. This, we believe, is an important information, since by knowing the dust load during the night using instrumentation (described below) by the astronauts, may give them the capability to predict the dust environment characteristics would be during the following day. Another important point is that if the astronauts know the dust load during nighttime, then they would be able to shut some instruments down, and take other protective measures. Obviously, if the dust storm is intense enough to completely hide the stars then it would render our method completely useless during these times.

This technique can be accomplished by comparing two sets of observations: one is to observe pre-selected bright stars such as Vega from the landing site on Mars, and the other is to observe the same stars from above the atmosphere or space in general. It can be accomplished using one instrument or two identical ones. Once the bright stars intensity profile are taken—only once—from space, then the magnitude of the star's brightness as seen by one or both of these particular instruments is established, without any atmospheric extinction and once, and for all.

To acquire information on the dust load in the Martian atmosphere during nighttime would require the following: the star tracking instrument must be pointed to a preselected bright star (such as Vega), and record its apparent brightness. The bright star must be preselected according to the Martian night sky at the time of the landing and thereafter so it has a high elevation (close to the zenith). This high elevation will guarantee several observations at different air masses so that the variation in the star's extinction as a function of air mass be recorded. It is also required that the instrument would follow the star's trajectory in the sky until it sets below the horizon. This condition requires also that the instrument either follow the star and make continuous observations, or take observations at fewer points along the star's meridian (if for any reason the continuous observations are not possible).

As mentioned earlier, the new method requires that the same instrument must make one observation of the preselected bright stars above the Martian atmosphere *i.e.* from space. These required observations from space can be made during the flight to Mars, and if that is not possible (since instruments are not usually exposed to space during the flight to Mars), then the space observation could be made sometimes before the start of the mission. For example, it can be made by the same instrument from the Bay of the space shuttle or preferably onboard the Space Station.

Once this methodology is established, its value will be effective as a set of information necessary for future astronauts to consider as part of their environmental monitoring during their stay. It has the important value as a complementary data to the daytime monitoring of the dust load (using the Sun), and other interrelationships that can be inferred. It would also be a continuing activity on all future missions to Mars and a mainstay of the monitoring routine. The need for such observations is essential in order to have a complete picture of the motions of dust storms in the Martian atmosphere. If the Martian dust storms resemble those on Earth in nature but larger in magnitude, then it is possible to deduce the following, based on the experience gathered from observing bright stars from Earth. A dust storm during daytime, if intense enough, would hide the sky's blue color and the Sun, and completely hide the stars during nighttime. This also means that the dust environment near the ground is very heavy. The point to be made here is that the way the sky appears gives an indication of how heavy the dust load near the ground is.

2. TECHNICAL APPROACH

Determining the dust extinction coefficient τ_{eff} on the Earth atmosphere has been an ongoing effort for a very long time. The use of bright star observations in determining this coefficient has a long history with an impressive amount of data collected by Earth observatories from various locals, and modeling analyses of this data are abundant. The improvements of the new method over the classical method of observations, analysis, and results, are outlined below. The new method along with its simplicity offers a great leap of improvement over the classical method.

We envision that a Star Imager and Tracker (hereafter SIT) instrument designed for the purposes outlined here may be added to the lander's package so that it makes observations of the same bright stars from the landing site. The SIT (with multi-filtering system) should have a maneuverable mount so it can follow the star until it sets below the horizon thus capturing the extinction suffered by the star's brightness as a function of air mass. The bright stars must be pre-selected according to the Martian night sky at the time of the landing and thereafter so it has a high elevation (close to the zenith). This high elevation will guarantee several observations at different air masses so that the variation in the star's extinction as a function of air mass be recorded.

The simple mathematical analysis outlined in the section below would give direct information on the dust extinction coefficient $\tau_{effective}$. This information would compliment the information acquired on the dust load during daylight, which were made by observing the Sun from past Mars landers at eight low-transmission solar filters, 443 671 880, and 990 nm [1], when such observations will be conducted again in future Mars missions. Comparisons between daytime and nighttime would obviously reveal any dramatic changes, or relatively small changes.

3. BRIGHT STARS IN THE MARTIAN SKY

Observing bright stars in the Martian night sky should be better than from Earth due to the fact that there is no light pollution as there is on Earth. From the International Mars Pathfinder (hereafter IMP) archives we quote D. Dubov the following: "The camera can expose for up to 32 seconds, which gives it a respectable low-light capability". Peter Smith reports: "that the University of Arizona have recently imaged Orion (the constellation, not the nebula) and gotten good results." We expect to image bright stars and planets during the mission and can probably image Earth as well. Please note however, Earth is less than a pixel wide in the IMP."

A more recent information regarding imaging Earth, we quote D. Mittman from the Pathfinder archives: "We have not yet received a good picture of Earth from our landing site on Mars and probably won't. The reason has to do with one of the discoveries we've made since landing on Mars: the atmospheric dust extends further up into the atmosphere than first thought. This dust catches the sun's light before sunrise and lightens the sky early in the morning. By the time Earth rises over our landing site (about 2:30 AM mars-local solar time), the skies are already beginning to brighten. Even if the sky were to remain dark enough to take a picture of Earth, the morning clouds would almost always block our view." These two quotes should stress the fact that bright stars and perhaps the Earth (if conditions are favorable) can indeed give us the needed information on the dust load during Martian nighttime.

4. INVESTIGATION APPROACH

Smith [1] used basically similar methodology to the one outlined below. However it still followed the classical method in the sense that the Sun was not observed above the Martian atmosphere with the same instrument. This condition is absolutely necessary in our new method in order to generate accurate values of the extinction coefficient by dust. Smith [1] found daytime opacities of 0.42 to 0.52 and found changes during the daytime *i.e.* morning vs. afternoon, and evening. The IMP has also been used to determine the optical depth at night by imaging the zero-magnitude stars Arcturus, Vega, and Altair. However, they found higher optical depth at night (0.75 +/− 0.04) than day, which they attribute to "The high optical depth has meant that images through the geology filters typically only provide around 250 counts on these objects in the maximum exposure time of 32.76 s. However, the diopter filter, used to investigate the magnets in the near field, has a much wider bandpass and provides several times the signal at the cost of a smeared image of the star." They reduced 21 images of the star Arcturus taken over several nights and an air mass range of 1.0 to 1.7 which gave the above optical depth figure. They also attribute the higher optical depth at nighttime vs. daytime to the formation of water ice.

Historically, information on the aerosols in the lower part of the Earth's atmosphere (~ 45 km) is of prime interest to both astronomers, and atmospheric chemists and scientists, for different reasons. The classical method used by astronomers to obtain information on the extinction coefficient caused by aerosols can be summarized by the following: using a small telescopic photopolarimeter with a narrow-band filter, one bright star can be observed until it drifts near the horizon, continuously. The star's path over the sky covers a range of elevation angles having different air masses. The star's brightness from this data is then plotted vs. its elevation angle or the respective air masses. A least squares fit to the data would then result in a solid line where the data is linear (higher elevations). The slope of this line is proportional to the extinction coefficient of the atmosphere at the time and local of the observations.

Using this classical method to remove the atmospheric effects from astronomical observations, we use the zodiacal light (**ZL**) as a good example since it is a well-observed phenomenon from space, and more extensively from the ground. Ground-based observations of the ZL from Hawaii, Tenerife the Canary Islands, and other sites has been going on for decades using photopolarimeters (see [2,3,4,5,6,7,8]). The difficulties encountered in the ground-based observations of the ZL are one of separation from atmospheric and non-atmospheric contaminants. The atmospheric contaminants are airglow line and continuum emissions, extinction (scattering and absorption) of the ZL by atmospheric particulates and off-axis light scattered into the instrument. The non-atmospheric contaminants are: bright stars in the field of view (**FOV**), integrated starlight (**ISL**, light from stars that cannot be resolved by the instrument), and diffuse galactic light (light scattered by interstellar dust).

In the case of Rayleigh scattering the differences between the Earth atmosphere and the Martian atmosphere must be taken into account (however it may prove to be minimal) in the modeling techniques which serves to separate this component from the residual aerosol component. To give an example of data obtained on the atmospheric extinction coefficient using the classical method, **Figure 1** shows a broad-band (blue, green) measurements of Vega, on 9/10, November, 1966, from Mt. Haleakala, Hawaii [9]. If the data were linear with air mass, the slope would be proportional to the extinction coefficient.

5. THE CLASSICAL VS. THE NEW METHOD

The atmospheric extinction can be calculated from the classical relation:

$$B_{obs} = B_o e^{-\tau\, m(Z)} \tag{1}$$

where B_o is the brightness of the star outside the atmosphere. In the old method described above, the graph of log B_{obs} vs. the air mass $m(Z)$ should be a straight line from which both the extinction coefficient and B_o can be determined. In reality, the best-fit line to the data is a straight line only at small air masses (linear part of the data). As air mass increases the data becomes non-linear and the atmospheric extinction coefficient cannot be calculated but rather estimated. The non-linear part at high air masses is the part that gives information on the dust/aerosol part in the atmosphere.

Our proposed method will measure B_o directly by observing the preselected star from space and B_{obs} by the same imager at the Martian landing site. This measurement is at the core of this new technique. So for each $m(Z)$, computed for the respective Z angle from the zenith by using the Van Rhijn function for the landing site, we will have the respective values of both B_o and B_{obs} measured. This will give us directly without the need to any plotting or measuring the slope of a best-fit line to the data, which suffers from being non-linear at high air masses. Thus, we can rewrite **Eq.1** as:

$$\ln B_{obs} = \ln B_o + \left[-\tau_{eff}\ m(Z)\right] \ln e \tag{2}$$

$$\tau_{eff} = \frac{\ln B_o - \ln B_{obs}}{m(Z)}$$

and the only unknown term is τ_{eff}.

τ_{eff} Includes Rayleigh scattering by the Martian atmospheric gases and mostly extinction by dust, which we call $\tau_{residual}$.

The new methodology outlined here constitutes a major advancement in determining τ_{eff} very accurately. This is so, since τ_{eff} will be determined directly from the observations using **Eq.2**, and without recoursing to plots of log intensity vs. air mass which then deduces τ_{eff} from the slope of the best-fit-line of the data that is not linear at high air masses (see **Figure 1** for atmospheric Earth observations). New plots can be generated, such as τ_{eff} vs. $m(Z)$, to obtain the variations of τ_{eff} at low and high air masses. The data generated from these observations will serve as a library of data of the dust load during nighttime. The atmospheric extinction has two components: one is Rayleigh scattering which for Mars would mostly be CO_2 molecular scattering, and the second which is more dominant is extinction by dust particles which we call τ_{res}.

In Earth atmospheric observations for example, Weinberg [9] made extensive observations of star extinction from Mt. Haleakala, Hawaii during the years 1964 to 1968. From these observations, Weinberg [10] concluded that there are no significant yearly changes of τ_{res}, however, there are seasonal variations that peak in April and October, and low in January and July. **Figure 2** shows the aerosol extinction τ_{res} at 4760Å, as a function of time between the years 1964 to 1968 [10].

As was obvious from the extinction observations made at Mt. Haleakala, Hawaii, extinction due to the aerosol content of the atmosphere shows no correlation with local air temperature or humidity. It also showed that the extinction coefficient for aerosols varies with wavelength as $\tau_{res}\,\alpha\lambda^{-\delta}$. The best-fit curve to the Hawaii data gives δ = 1.98.

This method of deriving the atmospheric extinction suffers from the fact that the incoming irradiance above the atmosphere of the star is computed using observations made by major observatories. Assumptions must be made of the magnitude of the star at each specific wave

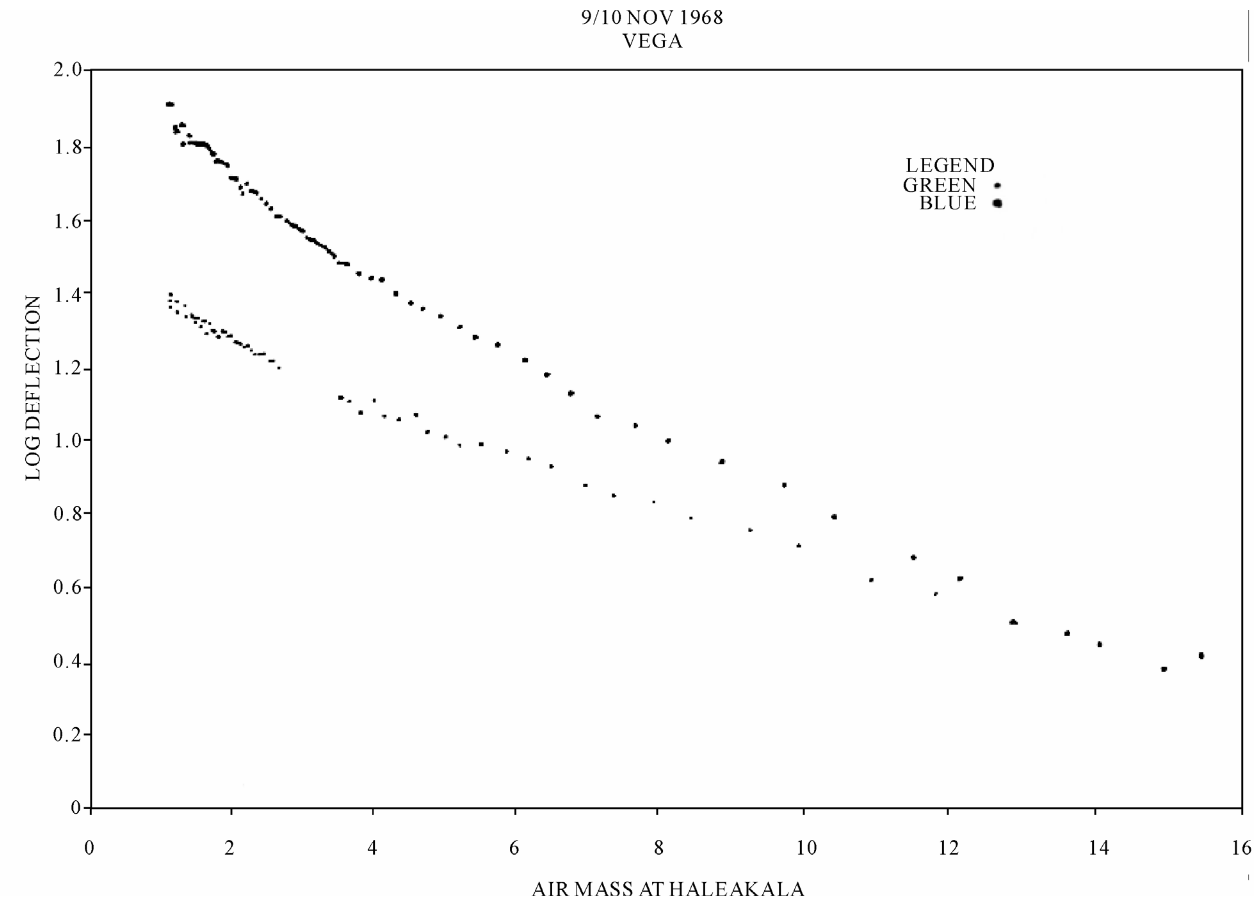

Figure 1. Shows broadband (blue, green) measurements of Vega on 9/10 November, 1966 [15].

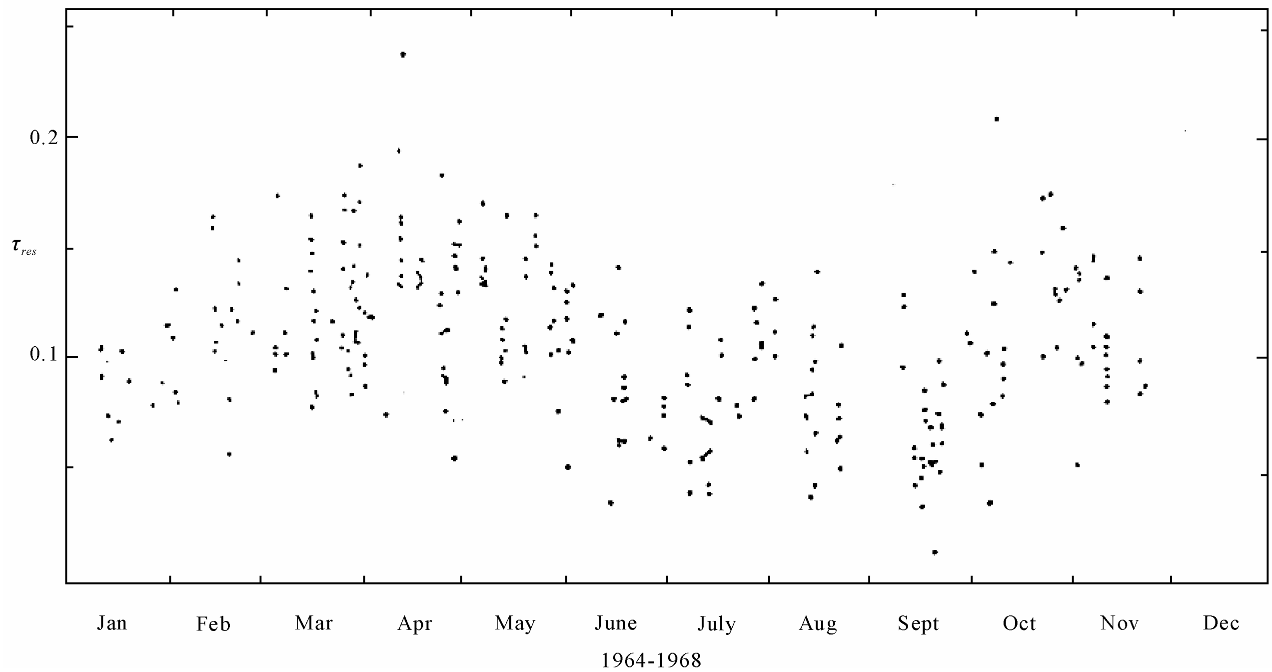

Figure 2. Shows the aerosol extinction coefficient τ_{res} at 4760 Å, as a function of time between the years 1964 to 1968 [15].

length of the narrow-band filters used in these observations by convolution of each star's spectra. This will introduce some serious errors in the analysis of the data. The new method however, eliminates all assumptions, interpretations, statistical analysis, and some modeling, which profoundly affects the results sought.

The SIT instrument suggested here will be simple rather than complex. The basic elements of the SIT are a small (~5 cm in diameter) objective that is suitable for observing bright stars only and with spectral capability (*i.e.* filter wheel). A star tracking motor will be added so the instrument can track the star in its apparent motion in the nightsky.

There has been numerous activities along with reported results using spacecrafts that went to Mars concerning the dust profile in the Martian atmosphere. For example, we site two references among others: one is Hoekzema [11] and the other is: Smith D. Michael [12].

6. CONCLUSIONS

This paper outlines a new methodology to measure the extinction of bright stars in the Martian atmosphere from future NASA manned and unmanned missions. Thus information on the dust column density in the Martian atmosphere can be determined during nighttime. This will compliment data already obtained on the dust column density during daytime from observations of the Sun in the Martian atmosphere using special filters. The new methodology outlined here can be accomplished with the technology that exists today.

7. ACKNOWLEDGEMENTS

This research was supported by NSF Grant No. ATM -9220736.

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