

Preliminary Observations of the Dynamics of Martian Ionosphere using Mars Initial Reference Ionosphere (MIRI) Model

Dibyendu Sur ¹, Jasmine Firdaus ²

Assistant Professor, Department of Electronics and Instrumentation Engineering, Narula Institute of Technology, Kolkata, India ¹

Student, Department of Electronics and Instrumentation Engineering, Narula Institute of Technology, Kolkata, India ²

ABSTRACT: The paper provides the morphology of the planet Mars ionosphere and observation of the ion densities from Aphelion to Perihelion positions of Mars. The composition of charged particles and different layers are discussed. The research on the Mars ionosphere is relatively new and has plenty of opportunities for further findings. A prediction model on Mars ionosphere is designed by Boston University, Charles University, Smithsonian Institution and University of Iowa. The model is referred to as Mars Initial Reference Ionosphere (MIRI). The background concepts behind the formation of the model have been discussed. Preliminary results of the variations of ion densities after every two earth months during 2016 have been studied in order to analyse the basic anatomy of the Mars ionosphere. The model MIRI has been used to analyse the variations of the maximum ion density in terms of Nmax and Total Electron Content (TEC) at different Solar Zenith Angle and the probable reasons for the variations are also discussed.

KEYWORDS: M1 layer, M2 layer, Nmax, Solar Zenith Angle (SZA), TEC.

I. INTRODUCTION

Mars is the fourth planet of the solar system by the distance from the Sun and probably the closest to Earth by its physical characteristics. The researches on Mars are being conducted for many years by scientists all over the world. It is needed mainly for the existence of mankind mainly due to the increasing population, temperature and pollution on earth. Mars has a solid upper surface and the most important feature is its likeliness with the earth's atmosphere. It consists of a gaseous layer surrounding the planet. Though there are several dissimilarities in the Mars atmosphere with earth's atmosphere in terms of thickness, height expansion, composition, temperature, humidity etc.

The Mars ionosphere is not similar to the Earth's ionosphere. It predominantly has two layers M1 and M2. The detailed findings of the layers are discussed in the subsequent sections.

II. RELATED WORK

Kuiper is the first Mars mission in 1995 from which the presence of CO₂ at Mars was known [1]. Viking 1 & 2 were two similar spacecraft which were sent to Mars. These spacecrafts consists of one orbiter and one lander. The direct measurement of Mars was first done by planetary mission Viking 1 & 2 [1]. From Viking 1 & 2 orbiter, the information related to the peak electron, altitudes of peak electron density etc were obtained using the radio occultation technique. The Viking 1 & 2 Lander provided the ion density profiles of different ions such as CO₂, O⁺ etc [2]. An empirical model has been designed using MARSIS data [3]. Another model MIRI is designed by Center for Space Physics, Boston University, USA, Department of Physics and Astronomy, The University of Iowa, USA, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic, Center for Earth and Planetary Studies, Smithsonian Institution, USA. The model is designed using data from different Mars-bound satellites such as Mars Express (MEX), Mars Atmosphere and Volatile Evolution (MAVEN), Mars Reconnaissance Orbiter (MRO) and Mars Global Surveyor (MGS). The model uses maximum electron density (Nmax) for the time span of 2005-2012 [4]. The Nmax is obtained using Solar Zenith Angle (SZA). The Total Electron Content (TEC) is also obtained from the height integral of the electron densities in different elevations [5, 6]. The study of ion losses from the upper side of Mars ionosphere is also important to know the exact structure of the Mars ionosphere [7].

III. OBJECTIVES

The main objectives of this paper are given below:

- To give the reader a basic concept of the Mars ionosphere.
- To describe how using the Mars Initial Reference Ionosphere (MIRI) model the TEC profile of Mars ionosphere on a particular day can be studied.
- To explain the results of our observations of studying the Nmax and TEC profile of Mars ionosphere at the interval of two months during moderate to low solar activity periods of 2016.

IV. DESCRIPTION OF MARS IONOSPHERE

The Mars ionosphere is totally different from the Earth's ionosphere regarding ion compositions and variations of ion densities with altitude. Ions and free electrons are produced mainly for the solar radiation reaching at the dayside of the planet by the photo ionization method. The layers and composition of the Mars ionosphere are discussed below.

- **Layers:**

From the information of different Mars missions, it is observed from the analysis of the ion density profile that there are two distinct layers at the Martian ionosphere such as (i) M1 and (M2). The first peak is observed at a height close to 110 km which is known as M1 layer. The second peak is found at a height of near about 135 km. This layer is known as M2 layer. M2 layer is the primary ionospheric layer as the ion density at this layer is higher than that at M1.

- **Compositions:**

Like terrestrial ionosphere, the Mars ionosphere is also comprised of free electrons and positive charged particles. The positive ions are predominantly H^+ , He^{++} , He^+ , O^+ , O_2^+ and CO_2^+ . Some energetic neutral atoms and molecules are also present in the ionosphere. In the Mars ionosphere there is a flow of ions to the direction of nightside from the dayside ionosphere. Apart from production processes of ions, ions loss processes are also dominant in the form of photochemical reaction or by ion-electron recombination process.

V. MARS INITIAL REFERENCE IONOSPHERE MODEL (MIRI)

Using the Mars Initial Reference Ionosphere (MIRI) model the morphology of Mars Ionosphere on a particular day and particular direction can be predicted. The day information provides the solar activity levels from the solar flux database. From this model the peak electron densities can be estimated using the Solar Zenith Angle (SZA) and the solar flux at the Martian orbit. The model database is obtained using data from Mars Express (MEX), Mars Atmosphere and Volatile Evolution (MAVEN), Mars Reconnaissance Orbiter (MRO) and Mars Global Surveyor (MGS). The MIRI 2018 version is a semi-empirical model that comprises ten years of database (2005-2015) of Nmax along different zenith angles. The height integrated ion densities in different altitudes constitute the TEC. The model also provides TEC information with respect to SZA. Another parameter required for calculating the Nmax is the solar flux. The current day solar flux and 81-day average solar flux index are used for this model. The solar flux is calculated at 1.524 AU distance from the Sun which is the average distance between the Sun and the Mars. The model MIRI is available online in the website sirius.bu.edu/miri.

VI. OBSERVATIONS AND RESULTS ANALYSIS

The results of variations of maximum electron density (Nmax) and TEC with respect to solar zenith angle (SZA) of our observations are discussed and tabulated for the minimum and maximum value of SZA. The observations are conducted during 2016. Six observations are conducted during January 1, March 1, May 1, July 1, September 1 and November 1, 2016. The corresponding Martian solar days (sols) are converted using The Mars Climate Database Projects website mars.lmd.jussieu.fr. Mars takes 668.6 sols to revolve around the Sun. A year starts when the northern hemisphere is under spring equinox. The first year was calculated from May 24, 1953. The corresponding solar longitude is zero. The entire 668.6 sols are divided into twelve months. Each month covers an angular distance of 30° . Thus the total year consumes 360° . Having an elliptic path around the Sun, the different months take different number of sols. The maximum number of days required when the Mars is in aphelion position whereas the months with a lesser number of sols are observed when Mars is positioned in perihelion position. The dates which are used for observation and the corresponding sols and Martian years are shown in Table 1 (assuming the time correspondent to 0 UT).

Table 1: Observation dates and corresponding Sols and Martian years

Observation No.	Earth Dates	Martian Year	Martian Month Number	Martian Sols	Solar Longitude of Mars
1	January 1, 2016	33	3, Aphelion (Largest Sun-Mars distance)	191	89
2	March 1, 2016	33	4, (Northern Hemisphere Summer Solstice)	250	116
3	May 1, 2016	33	5	309	145.4
4	July 1, 2016	33	6	369	177.8
5	September 1, 2016	33	8, Dust Storm Season	429	214.3
6	November 1, 2016	33	9, (Perihelion (Smallest Sun-Mars distance))	488	252.6

Thus in our observation, we have witnessed the Martian ionospheric Nmax both from Aphelion and Perihelion position.

Variation maximum electron density (Nmax) with respect to Solar Zenith Angle (SZA)

The variations of maximum electron density (Nmax) with respect to solar zenith angle (SZA) on every first day of alternative months starting from January are shown in Fig. 1. The deviations or errors are shown in the form of error bar in each curve.

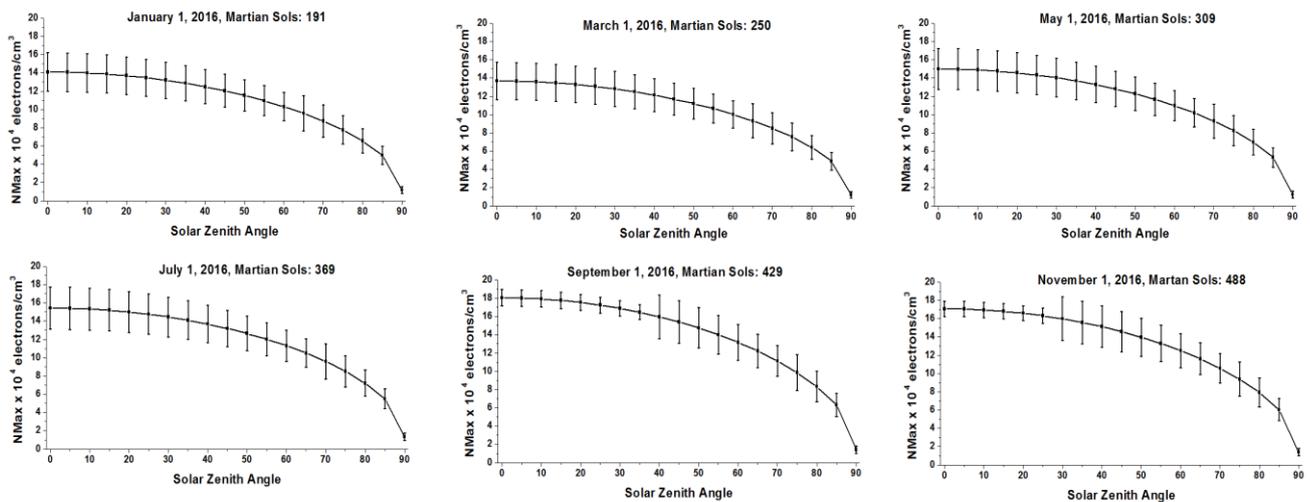


Fig.1.Variation of maximum electron density (Nmax) with respect to solar zenith angle (SZA) on January 1, 2016, March 1, 2016, May 1, 2016, July 1, 2016, September, 2016 and November 1, 2016

The listed data of Nmax for varying solar zenith angles on every first day of alternative months starting from January are collected from the Mars Initial Reference (MIRI) model and plotted as shown in Fig. 1. To compare the Nmax on those days, their values are merged in a single figure as shown in Fig. 2.

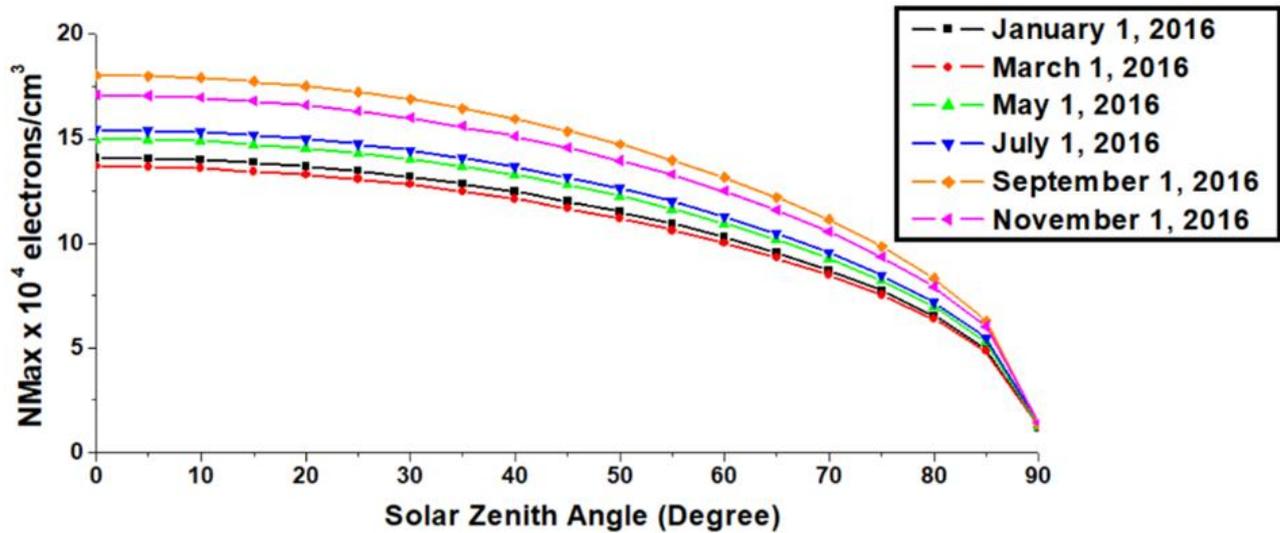


Fig. 2. Combined variations of maximum electron density (Nmax) with respect to solar zenith angle (SZA) on January 1, 2016, March 1, 2016, May 1, 2016, July 1, 2016, September, 2016, November 1, 2016

From Fig. 1 and Fig. 2 it can be seen that the maximum Nmax is observed near zero zenith angle. This is obvious as during Sun in the overhead position, the maximum ionization process is possible and maximum Nmax is possible. The variation of daytime and night-time Nmax is around $13-17 \times 10^4$ electrons/cm³. The seasonal variation of maximum Nmax is also observed during 2016. It can be seen that the Nmax is maximized during September 1, 2016 (Martian Sols: 429). The second maximum Nmax was observed during November 1, 2016 (Martian Sols: 488). The Perihelion between Sun and Mars is observed during Solar Longitude: 247. The same on November 1, 2016 was 252.6. The minimum Nmax is observed on March 1, 2016. This day is closer to the Aphelion position of Mars from the Sun. The corresponding solar longitude was 116 on March 1, 2016. The Aphelion position longitude is 67. This is closer to January 1, 2016 when the solar longitude was 89. The corresponding maximum Nmax was the second smallest among the other days. The variations of Nmax in Aphelion and Perihelion positions are consistent with [8] and [9].

The values of Nmax during these days are tabulated in Table 2 for all SZA. The increments and decrements of Nmax for SZA 0° (overhead conditions) and 90° (ground) from the previous observations are also tabulated in Table 2.

Table 2: Increment of Nmax at SZA = 0 degree and 90 degree

Date	Nmax × 10 ⁴ (e ⁻ cm ⁻³) at solar zenith angle = 0 degree	Increment in Nmax × 10 ⁴ (e ⁻ cm ⁻³) at solar zenith angle = 0 degree	Nmax × 10 ⁴ (e ⁻ cm ⁻³) at solar zenith angle = 90 degree	Increment in Nmax × 10 ⁴ (e ⁻ cm ⁻³) at solar zenith angle = 90 degree
January 1, 2016	14.1		1.18	
March 1, 2016	13.68	- 0.42	0.36	- 0.82
May 1, 2016	14.99	1.31	1.26	0.90
July 1, 2016	15.43	0.44	1.33	0.07
September 1, 2016	18.04	2.61	1.39	0.06
November 1, 2016	17.08	- 0.96	1.41	0.02

Variation maximum Total Electron Content (TEC) with respect to Solar Zenith Angle (SZA)

Similar variations of TEC with respect to SZA during the same dates are shown in Fig. 3. The combined TEC plots for all those dates are shown in Fig. 4. The TEC are computed from Shallow Radar (SHARAD) instrument. This instrument is installed onboard Mars Reconnaissance Orbiter (MRO). This TEC is preferred over the model derived TEC by the MIRI Scientific group. This data is validated using Radio Occultation Science Experiment (ROSE) [6].

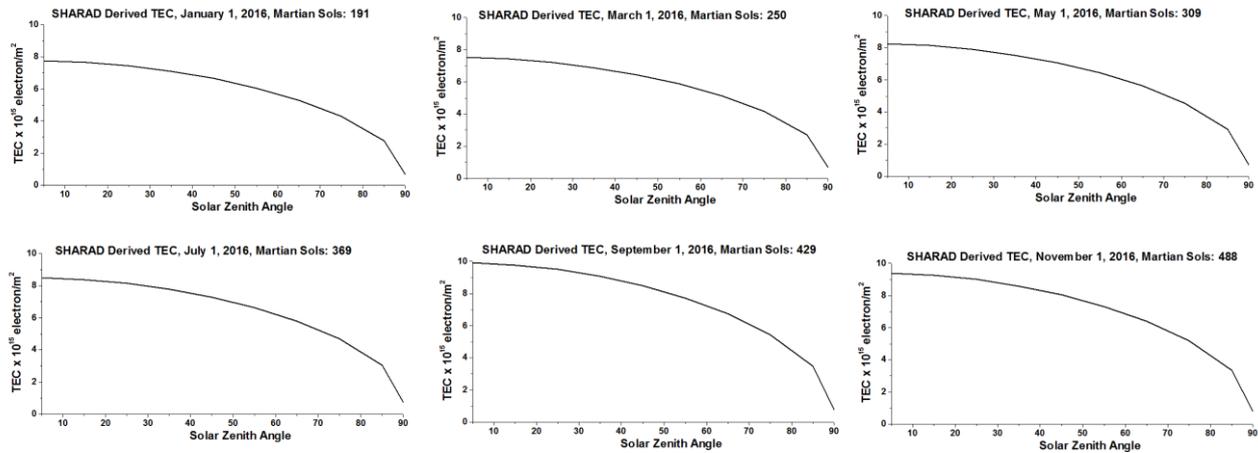


Fig.3. Variation of Total Electron Content (TEC) with respect to solar zenith angle (SZA) on January 1, 2016, March 1, 2016, May 1, 2016, July 1, 2016, September, 2016 and November 1, 2016

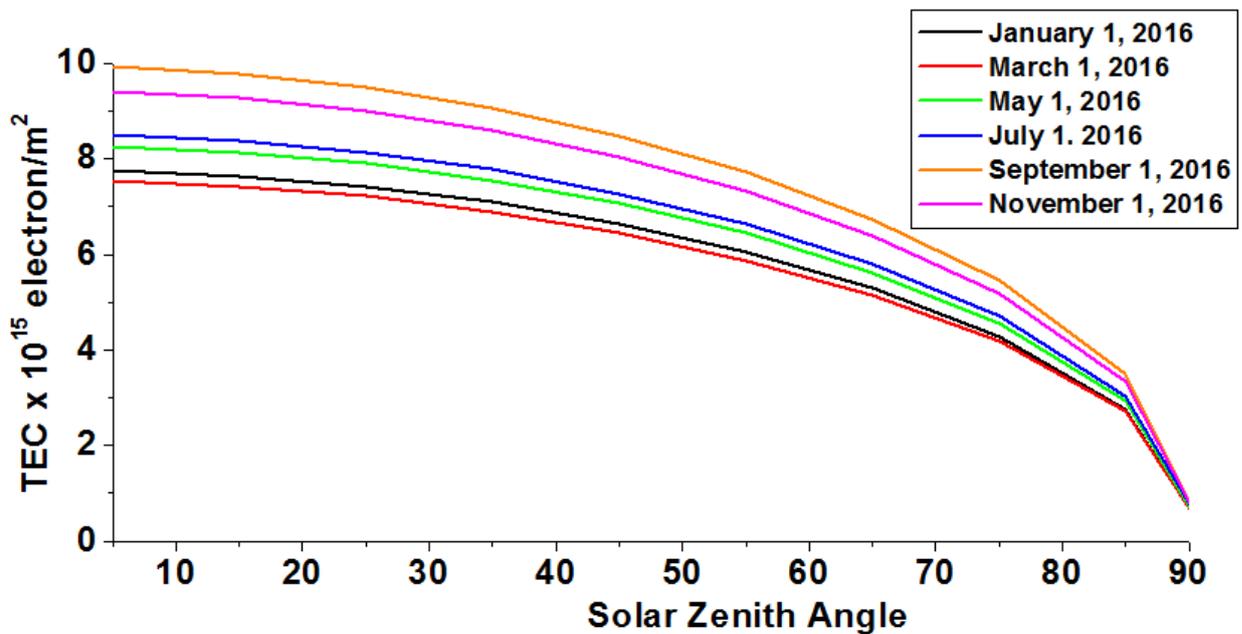


Fig. 4. Combined variations of SHARAD derived Total Electron Content (TEC) with respect to solar zenith angle (SZA) on January 1, 2016, March 1, 2016, May 1, 2016, July 1, 2016, September 2016, November 1, 2016

From Fig. 3 and Fig. 4, it can be seen that the TEC also maximizes in low solar zenith angles which is consistent with Nmax variations. Minimum TEC at solar zenith angle 5° were seen on March 1, 2016 and January 2016 when Mars is near Aphelion position. The maximum TEC were observed on September 1, 2016 and November 1, 2016 when Mars is near Perihelion position. Like Nmax, a comparative table is given for increment and decrement in TEC for SZA 5° AND 90° during the dates observed in Table 3.

Table 3: Increment of TEC at SZA = 5 degree and 90 degree

Date	TEC $\times 10^{15}$ ($e^{-}m^{-2}$) at solar zenith angle = 5 degree	Increment in TEC $\times 10^{15}$ ($e^{-}m^{-2}$) at solar zenith angle = 5 degree	TEC $\times 10^{15}$ ($e^{-}m^{-2}$) at solar zenith angle = 90 degree	Increment in TEC $\times 10^{15}$ ($e^{-}m^{-2}$) at solar zenith angle = 90 degree
January 1, 2016	7.76		0.67	
March 1, 2016	7.53	-0.23	0.68	0.01
May 1, 2016	8.26	0.73	0.71	0.03
July 1, 2016	8.5	0.24	0.75	0.04
September 1, 2016	9.93	1.43	0.79	0.04
November 1, 2016	9.4	-0.53	0.8	0.01

VII. CONCLUSIONS

The observation conducted on the Mars ionosphere during the moderate to low Solar activity period of Solar cycle 24. The observations through a reliable model such as MIRI showed the seasonal variations of ionization in the Mars ionosphere. The study includes Mars to be positioned in both Aphelion and Perihelion position from the Sun. The ionosphere characteristics are observed in terms of Nmax and TEC with respect to SZA. The overall effects during 2016 are just a precursor of long term study of Mars ionosphere. In the future, the observations shall be conducted for a longer period of time for better understandings of the geophysics of the Mars ionosphere.

VIII. ACKNOWLEDGEMENTS

The authors would like to thank Professor Michael Mendillo, Center for Space Physics, Boston University and all the MIRI working group members from Boston University, Charles University, Smithsonian Institution and University of Iowa for providing the model online.

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