Results from Radio Occultation studies using Indian Mars Orbiter Mission

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Abstract

Using data collected by the Indian Mars Orbiter Mission in October 2021, we investigated coronal regions of the Sun by analyzing the Doppler spectral width of radio signals to estimate solar wind velocity. A simplified equation is introduced to directly relate these two parameters. The study focuses on observations conducted from October 2 to October 14, 2021; a relatively quiet phase of solar cycle 25. The analysis targeted the coronal region within heliocentric distances of 5–8 $R_\odot$, near the ecliptic plane. In this region, solar wind velocities ranged from 100 to 150 km/s, while electron densities were on the order of 10^{10} m^{-3}. We also compared our results with electron density observations and models derived from previous studies. Though the decrease in the electron densities with respect to increasing helio-centric distance matches quite well with the theoretical models, MOM estimates fall at the lower edge of the distribution. This difference may be attributed to the prolonged weak solar activity during the MOM observations, in contrast to prior studies conducted during periods of comparatively higher solar activity in earlier solar cycles.

Introduction

The Solar wind is a stream of charged particles which escape into the interplanetary medium. Extensive studies so far have revealed the vital role of coronal heating in solar wind acceleration in the region of 2-10 Solar radii [2, 3, 4]. This region is challenging to observe in-situ due to the extreme conditions of the Solar plasma such as extremely high temperatures. Using radio occultation experiments to study the Sun using the signal fluctuations is an excellent tool as it is both accessible and allows studies of the Solar Corona from 1.8 to 40 $R_\odot$. These experiments are conducted using probes in orbit around other planets like Mars during their conjunction events, enabling studies of the Sun with no risks to the probe. The variations in the signal when it crosses the Solar coronal medium helps us to study various parameters like the plasma density, solar winds, and magnetic field fluctuations.

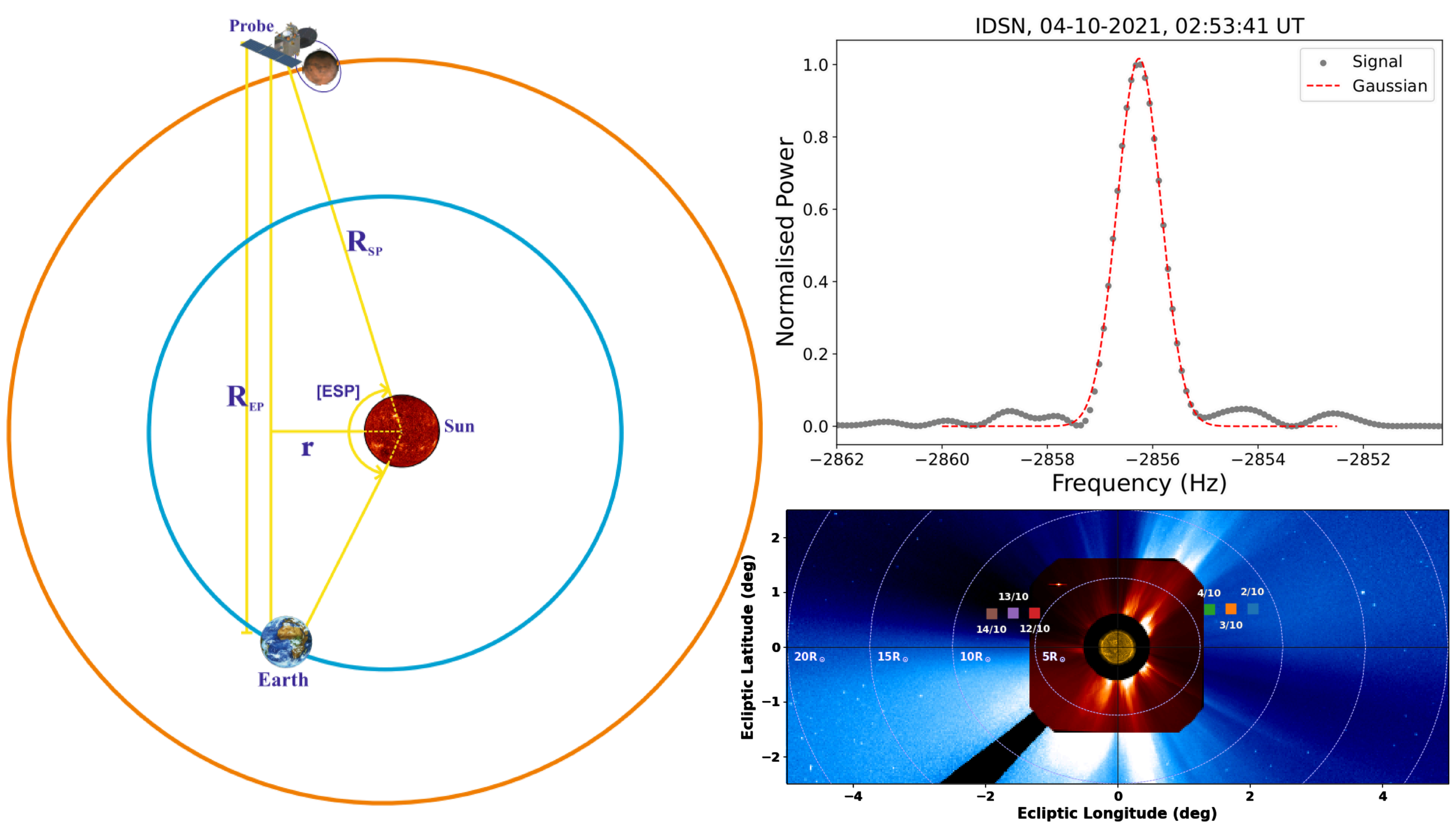
MOM Mission parameters

Mission Parameters	
Launch Date	5th November 2013
Martian Orbit Insertion	24th September 2014
Planned Mission Duration	6 months
Duration of Operations	8 years, 9 days
Apoapsis	$\sim$ 72000 km
Periapsis	260 to ~ 550 km
Orbital Period	$\sim$ 66h
Inclination	$\sim 150^\circ$
Velocity near Periapsis	~ 4.5 km/s

Antenna Parameters	
Diameter	2.2m (HGA)
Operating Frequency	2292.96 MHz
Power Requirement	440 W DC power
Beamwidth	$\pm 2^\circ$ (Right Circularly Polarized)
Peak Gain	31 dB

Radio occultation experiment

In this study we present the results from the radio occultation experiment conducted using the Indian Mars Orbiter Mission during the Mars-Sun conjunction in 2021, when we probed the solar corona in the region of 5 to 8 $R_\odot$ and derived solar wind velocities between 100 to 150 km/s. The following figure shows the geometry of a radio occultation experiment. Here, [ESP] is the Earth-Sun-Probe angle in radians, R_{offset} is the distance of closest approach in Solar radii ($R_\odot$), R_{SP} is the distance between the Sun and the MOM satellite, R_{EP} is the distance between Earth and MOM.



1. (a) The geometry of the radio occultation experiment is shown. (b) Shows the received signal from the satellite after it passed through the solar corona (c) Transit of the MOM behind the Sun. Image is a composite made by stacking the SDO AIA 171 A, SOHO LASCO C2 and C3 images from the NASA website for 2 Oct 2021.

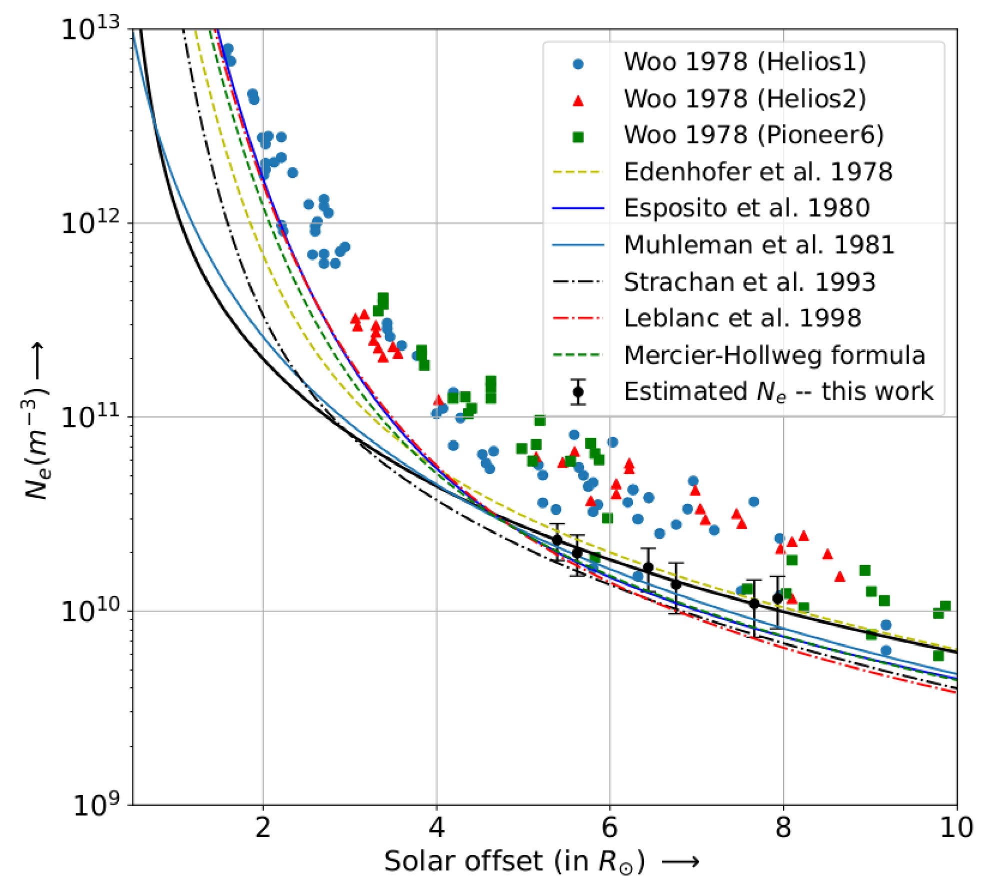
Using the second moment of the received signal from the spacecraft, we have derived the electron density values at the proximal points, further using them to calculate the solar wind velocities. Further, reducing all the equations involved to a simpler form, we have derived a formula for the calculation of wind velocities using three parameters: A constant k_0, the geometry component which is easily calculated using the SPICE toolkit by NASA and the spacecraft kernels, and the second moment of the received signal. The final equation for finding solar wind velocity, using the second moment of the observed spectra comes out to be -

$$v_\perp = k_0 \left[\frac{r \times R_{EP} \times (1+R_{SP})^2}{R_{SP}}\right] B_S^{\frac{1}{6}} \quad (1)$$

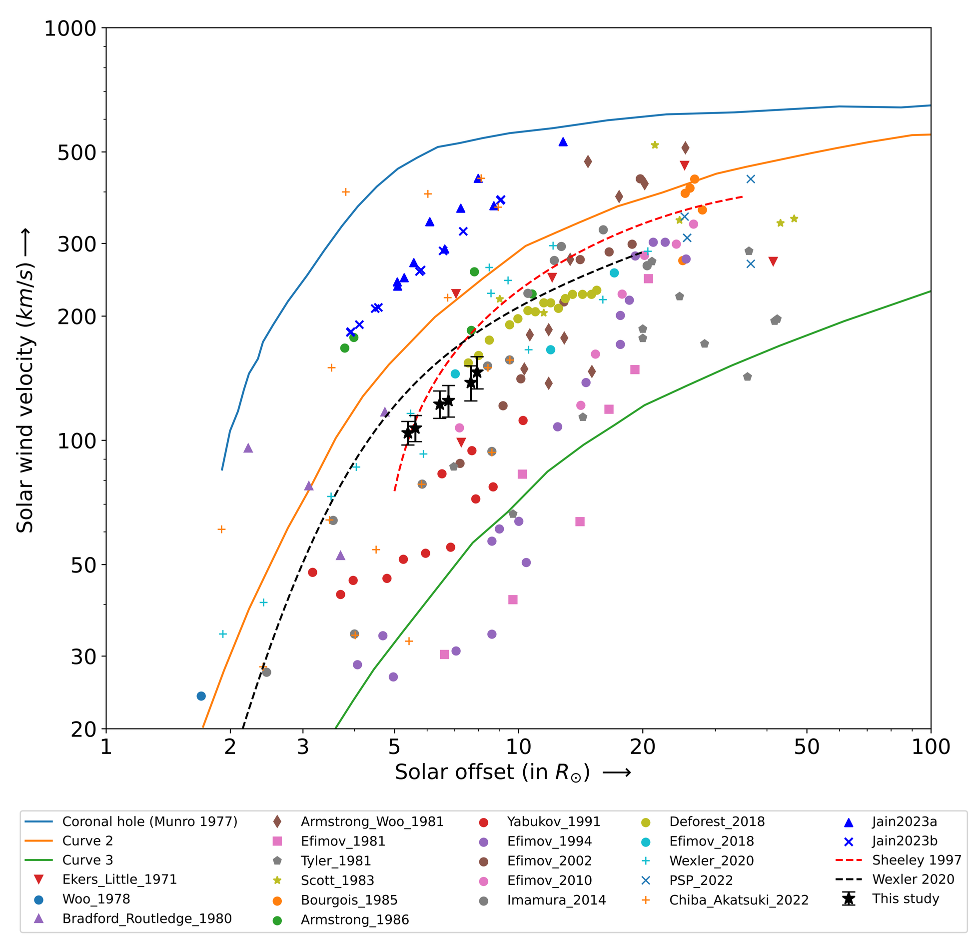
where

$$k_0 = \frac{5.77 \times c_0^{5/6} \times R_\odot \times 10^8}{} = 1.687 \quad (2)$$

Results



3. Electron number density compared with other models present in literature (2 to 10 $R_\odot$). The black points represent the derived values from our study.



4. Our results compared against the solar wind measurements done across a period of more than 50 years, using a variety of methods from in-situ to remote sensing observations

Table 1: Combined Solar Wind Velocities and Errors measured by MOM (In km/s)

Date	Solar Offset ($R_\odot$)	MOM (km/s)	Error (km/s)	Error (%)
2nd Oct 2021	7.93	146.35	$\pm$ 13.11	$\pm$ 8.95
3rd Oct 2021	6.76	124.83	$\pm$ 10.96	$\pm$ 8.78
4th Oct 2021	5.62	107.07	$\pm$ 7.78	$\pm$ 7.27
12th Oct 2021	5.39	104.27	$\pm$ 6.85	$\pm$ 6.57
13th Oct 2021	6.49	122.37	$\pm$ 9.35	$\pm$ 7.64
14th Oct 2021	7.66	138.07	$\pm$ 13.46	$\pm$ 9.75

Conclusions

- Using Doppler broadening of the received signals, we obtained velocities of solar wind between $100 - 150$ Km/s for the heliocentric distances 5 - 8 $R_\odot$ from October 2 to October 14, 2021 [1].
- The velocities of solar wind derived in the presented radio occultation study agree with previously reported values (ref to fig 4), and show the acceleration of the solar wind in the Middle Solar Coronal region as well.

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