Driven of the properties of the quasi- perpendicular fast forward shock: on the 7 June 2014

Mohammad Javad Kalaee[1]

[1] *Space Physics Group, Institute of Geophysics, University of Tehran, Tehran, Iran*
mjkalaee@ut.ac.ir

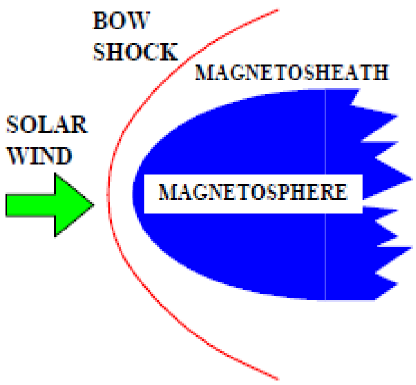
Abstract

Shock processes occur naturally in various astrophysical and space situations, the most common such as supernova explosions and solar winds in the interplanetary medium. MHD Shock Waves and discontinuities are often observed in the solar wind. We studied a strong shock wave event on 7 June 2014, during a solar maximum. The properties of forward shock are investigated and all physical parameters of interplanetary shock analyzed. To determine the propagation speed of the shock a full numerical solution of shock adiabatic equation is carried out. The upstream parameters, such as Alfven velocity and sound speed are calculated, and also the angle between the upstream magnetic field direction and the shock normal is estimated.

Keywords: Shock Waves, entropy, solar wind

Introduction

Shock processes occur naturally in various astrophysical and space situations, the most common such as supernova explosions and solar winds in the interplanetary medium. From a theoretical point of view, the magnetohydrodynamics model applies to plasma magnetic flows and the propagation of shock waves in such medium (De Hoffmann and Teller, 1950; Sen.1956) is of great interest to many researchers in various fields such as astrophysics, space plasma physics, and geophysics. Shock waves in the solar wind are often referred to as interplanetary shocks. Most of the interplanetary shocks have seen in the solar wind near Earth, especially in during the solar activity (Watari et al., 2001; Echer et al., 2003, Mullan and Smith, 2006, Kilpua et al., 2015). Usually, interplanetary shocks are observed as abrupt changes in all physical parameters of solar wind, such as flow speed, density, pressure, magnetic field, and temperature (Burlaga, 1995; Kivelson and Russell, 1995), but entropy change from the upstream to downstream side of the shock ramp is most important. Also, interplanetary structures can be effective, on the Earth's magnetic field so that causing magnetic storms (Gonzalez, 1999).
We studied a strong shock wave event on 7 June 2014, during a solar maximum. Plasma and magnetic field parameter variations through the shocks are calculated, and derived quantities for shock - shock speed. To determine the propagation speed of the shock a full numerical solution of shock adiabatic equation is carried out (Kalaee, 2020).



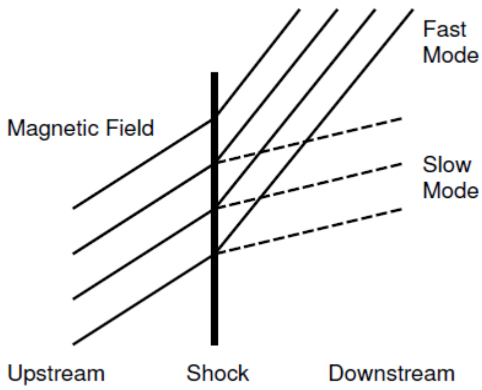


Figure 1. A schematic view of the interaction of the solar wind with the magnetosphere (left); Sketch of magnetic fields across a fast and a slow shock wave mode (right).

Observations

We used the OMNI database that coverage of the solar wind observation, such as: magnetic field, flow speed, proton number density and temperature of proton.
Figure 2 shows an example of a fast forward interplanetary shock on June 7th 2014, during solar maximum. Panel a and b show the total magnetic field B(nT), and flow speed, V_p (km/s), respectively. For a fast forward shock, the values of four parameters mentioned above are increasing. In Figure 2 the upstream and downstream sides of shock and are indicated by the letters ”U” and ”D” respectively, and average parameters were calculated for the these interval limited time. As shown that in Figure 2 about two hours after shock, AE-index abruptly increased that indicates the influence of shock on the magnetosphere and the current in the magnetopause.

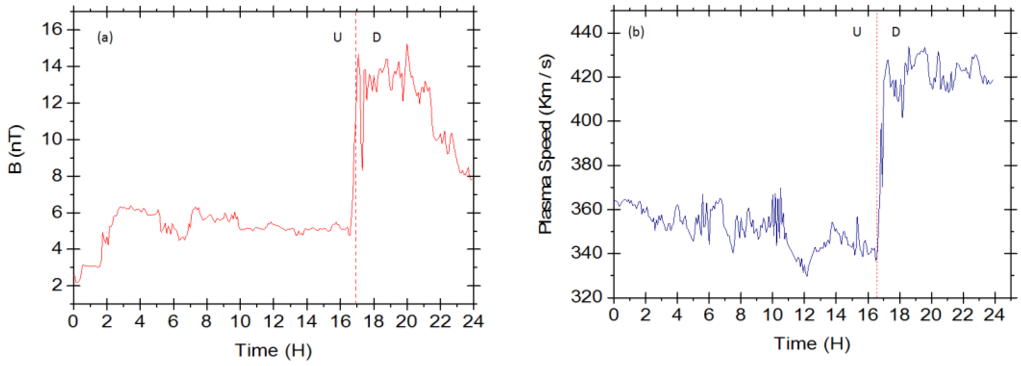


Figure 2. A fast forward interplanetary shock on June 7th 2014, during solar maximum. a) The total magnetic field and b) speed of flow.

Fundamental physical relationships for a plane surface of discontinuity are a set of jump conditions that so-called Rankine-Hugoniot equations:

$$\rho_{mu}U_{nu} = \rho_{md}U_{nd} \tag{1}$$

$$\rho_{mu}U_{nu}^2 + \rho_{mu}\frac{V_{su}^2}{\gamma} + \frac{B_{tu}^2}{2\mu_0} = \rho_{md}U_{nd}^2 + \rho_{md}\frac{V_{sd}^2}{\gamma} + \frac{B_{td}^2}{2\mu_0} \tag{2a}$$

$$\rho_{mu}U_{nu}U_{tu} - B_{nu}\frac{B_{tu}}{\mu_0} = \rho_{md}U_{nd}U_{td} - B_{nd}\frac{B_{td}}{\mu_0} \tag{2b}$$

$$\rho_{mu}U_{nu}\left(\frac{V_{su}^2}{\gamma-1} + \frac{U_{tu}^2+U_{nu}^2}{2}\right) + \frac{B_{tu}}{\mu_0}\left(B_{tu}U_{nu} - B_{nu}U_{tu}\right) = \rho_{md}U_{nd}\left(\frac{V_{sd}^2}{\gamma-1} + \frac{U_{td}^2+U_{nd}^2}{2}\right) + \frac{B_{td}}{\mu_0}\left(B_{tu}U_{nd} - B_{nd}U_{td}\right) \tag{3}$$

$$U_{nu}B_{tu} - U_{tu}B_{nu} = U_{nd}B_{td} - U_{td}B_{nd} \tag{4a}$$

$$B_{nu} = B_{nd} \tag{4b}$$

In above equation, $U_{nu}, U_{nd}, V_{su}, V_{sd}, B_{nu}, B_{nd}$ are the normal propagation of shock speed, the sound speed and the normal of magnetic field in the upstream and downstream regions, respectively. $U_{tu}, U_{td}, B_{tu}, B_{td}$ are the tangential propagation of shock speed, and the normal of magnetic field in the upstream and downstream regions. γ is ratio of heat capacity at constant pressure to heat capacity at constant volume.

By using the Rankine-Hugoniot equations, we can obtain an equation so-called Shock adiabatic equation (Anderson, 1963) as follow:

$$\left(U_{nu}^2 - rV_{Au}^2\cos^2\theta_u\right)^2\left[U_{nu}^2 - \frac{2rV_{su}^2}{r+1-\gamma\left(r-1\right)}\right] - r\sin^2\theta_u U_{nu}^2 V_{Au}^2\left[\frac{2r-\gamma\left(r-1\right)}{r+1-\gamma\left(r-1\right)}U_{nu}^2 - rV_{Au}^2\cos^2\theta_u\right] = 0 \quad (5)$$

It gives the propagation as a function speed of the shock strength and the upstream parameters.

Conclusions

By definition of U_n in terms of Alfven Mach number which is the ratio of the normal component of the Alfven velocity, and sonic Mach number which is the ratio of the normal component of the flow speed to the sound speed, we can obtain an equation for θ_u. Table 1 shows the results of calculating for upstream. After determining, θ_u, the speed of shock can estimated by Eq.(5). From these results, we made a plot of the shock speed as a function of the shock strength and for $\theta_u \approx 71.8^\circ$ as shown in Figure 3. At r =3.88(an estimation of the shock strength for this case), the shock is fast with U_n= 678(km/s). U and B may change direction across the shock, by using the jump conditions such as: $B_{nu} = B_{nd}$, the propagation angle in downstream region is estimated about 82°.
In summary, we used the solar wind parameters (density, speed, temperature, and magnetic field) to estimate other parameters such as Alfven velocity and sound speed, thermal pressure (electron pressure and proton pressure), shock strength, and the angle (θ) between the upstream magnetic field direction and the shock normal.

Table1. The value of Shock strength and the average of calculating parameters correspond to the upstream time window.

Shock strength	Plasma Beta	Alfven velocity (km/s)	Sound speed(km/s	θ_u
3.88	1.41	43.0	47.45	71.8

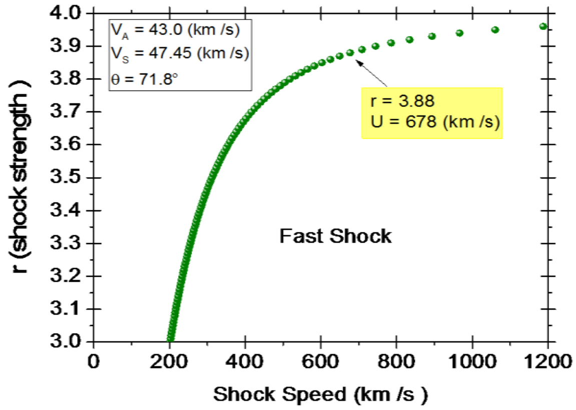


Figure 3. Plot of the shock propagation velocity, as a function of the shock strength and for, $\theta_u = 71.8^{\circ}$, angle between the upstream magnetic field direction and the shock normal. With a shock strength equals 3.88, the shock is fast with U_n = 678 (km/s).

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