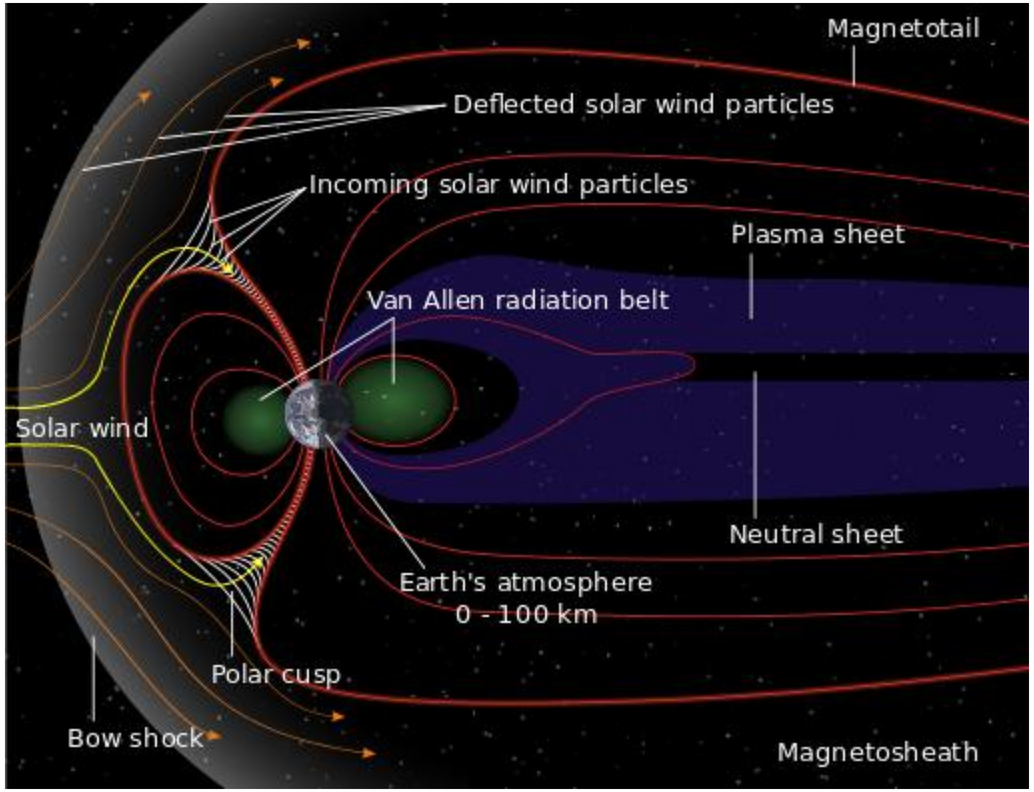
ALFVEN VELOCITY

SOLAR WINDS

SOLAR WIND

- The solar wind is a stream of charged particles released from the upper atmosphere of the Sun.
- This plasma consists of mostly electrons, protons and alpha particles with energies usually between 1.5 and 10 keV; embedded in the solar-wind plasma is the interplanetary magnetic field.
- The solar wind varies in density, temperature and speed over time and over solar longitude.
- Its particles can escape the Sun's gravity because of their high energy, from the high temperature of the corona and magnetic, electrical and electromagnetic phenomena in it.
- The solar winds flow outward supersonically at varying speeds depending on their origin reaching up to around one million miles per hour to great distances, filling a region known as the heliosphere, an enormous bubble-like volume surrounded by the interstellar medium.
- Other related phenomena include the aurora (northern and southern lights), the plasma tails of comets that always point away from the Sun, and geomagnetic storms that can change the direction of magnetic field lines and create strong currents in power grids on Earth.



SOLAR WIND COMPONENTS

The solar wind is divided into two components, respectively termed the slow solar wind and the fast solar wind.

- The **slow solar wind** has a velocity of about 400 km/s, a temperature of 1.4–1.6×106 K and a composition that is a close match to the corona. By contrast, the fast solar wind has a typical velocity of 750 km/s, a temperature of 8×105 K and it nearly matches the composition of the Sun's photosphere.
- The slow solar wind is twice as dense and more variable in intensity than the fast solar wind. The slow wind also has a more complex structure, with turbulent regions and large-scale structures.
- The slow solar wind appears to originate from a region around the Sun's equatorial belt that is known as the "streamer belt". Coronal streamers extend outward from this region, carrying plasma from the interior along closed magnetic loops.

- The **fast solar wind** is thought to originate from coronal holes, which are funnel-like regions of open field lines in the Sun's magnetic field. Such open lines are particularly prevalent around the Sun's magnetic poles. The plasma source is small magnetic fields created by convection cells in the solar atmosphere. These fields confine the plasma and transport it into the narrow necks of the coronal funnels, which are located only 20,000 kilometers above the photosphere. The plasma is released into the funnel when these magnetic field lines reconnect.

SOLAR WIND PRESSURE

The wind exerts a pressure at 1 AU typically in the range of 1–6 nPa ($1–6\times10^{-9}$ N/m2), although it can readily vary outside that range.

The dynamic pressure is a function of wind speed and density. The formula is

$P = 1.6726\times10^{-6} * n * V$

where pressure P is in nPa (nanopascals), n is the density in particles/cm3 and V is the speed in km/s of the solar wind.

SOLAR MAGNETIC FIELD

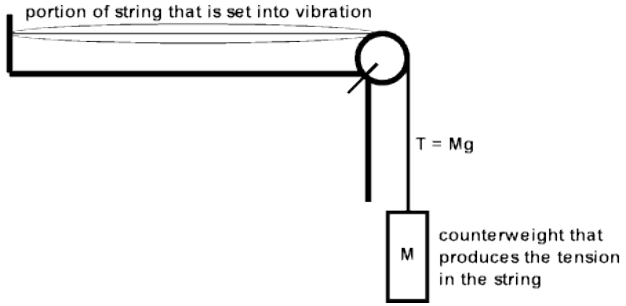
The interplanetary magnetic field (IMF) is the solar magnetic field carried by the solar wind among the planets of the Solar System.

- Since the solar wind is a plasma, it has the characteristics of a plasma, rather than a simple gas.
- It is highly electrically conductive so that magnetic field lines from the Sun are carried along with the wind.
- The dynamic pressure of the wind dominates over the magnetic pressure through most of the Solar System
- The plasma in the interplanetary medium is also responsible for the strength of the Sun's magnetic field at the orbit of the Earth being over 100 times greater than originally anticipated. If space were a vacuum, then the Sun's magnetic dipole field, about 10−4 teslas at the surface of the Sun, would reduce with the inverse cube of the distance to about 10−11 teslas. But satellite observations show that it is about 100 times greater at around 10−9 teslas.
- Magnetohydrodynamic (MHD) theory predicts that the motion of a conducting fluid (e.g. the interplanetary medium) in a magnetic field, induces electric currents which in turn generates magnetic fields, and in this respect it behaves like a MHD dynamo.

WAVE ON A STRING

The speed of a wave pulse traveling along a string or wire is determined by knowing its mass per unit length and its tension.

$$v_w = \sqrt{\frac{tension}{mass/length}}$$



In this formula, the ratio mass/length is read "mass per unit length" and represents the linear mass density of the string. This quantity is measured in kilograms/meter.

Tension is the force conducted along the string and is measured in newtons, N. The maximum tension that a string can withstand is called its tensile strength.

The formula given above tells us that the "tighter" the string (that is, the greater the tension placed on the string) the faster the waves will travel down its length. It also tells us that the "lighter" the string, that is, the smaller its mass/length ratio, the faster the waves will travel down its length.

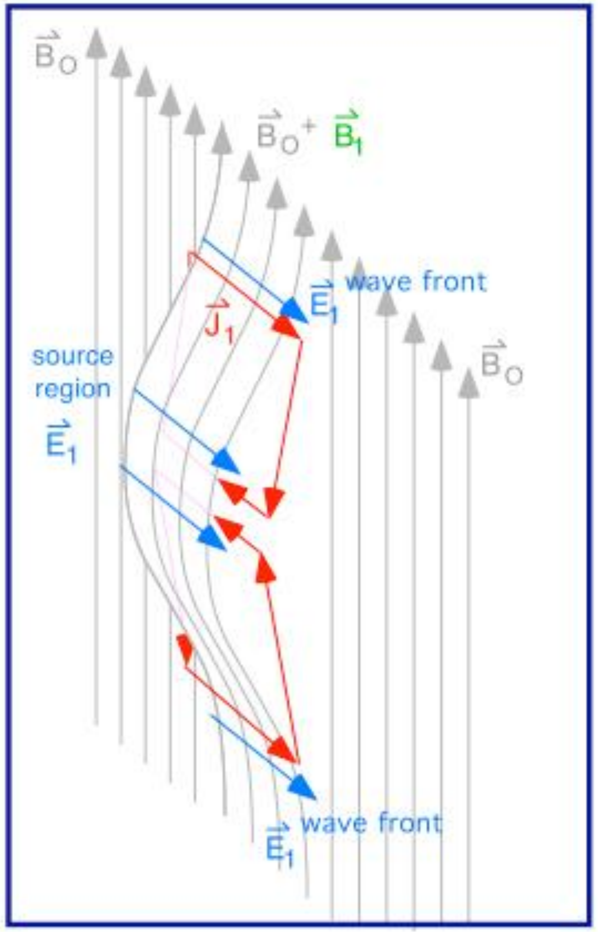
An increase in the tension of a string causes an increase in the velocity that waves travel on the string.

ALFVEN WAVE

Alfvén wave is a fundamental physical phenomenon in all kinds of magnetized plasmas.
Alfvén waves contribute to a variety of physical processes in space plasmas, e.g.:

• heating of solar and stellar coronae,
• solar and stellar wind acceleration,
• wave-particle interaction,
• turbulence,
• generation of geomagnetic perturbations (auroral activity),

A 3-D View of Alfvén wave propagation



ALFVEN VELOCITY

For the solar wind waves travelling between the sun and earth, they behave like waves on a string in tension. In solar wind case, tension is due to magnetic field between sun and earth. The plasma behaves like air except it is affected by magnetic fields.

Within the magnetosphere, however, the dynamics are dominated by the energy density and pressure of the magnetic field. In this case, the appropriate sound speed is the *Alfven speed :*

$$v_A = \sqrt{\frac{B^2}{\rho\mu_o}} = \left(\frac{\text{tension}}{\text{density}}\right)^{1/2}$$

All sound speeds are roughly the square root of the ratio of the energy density of the medium to its inertial mass Density: $v_A \approx (\varepsilon/\rho)^{1/2}$
where ε is the energy density in the medium. Since the magnetosphere is magnetically dominated,

$$\varepsilon = \frac{B^2}{2\mu_0} \quad \text{and hence} \quad v \approx \sqrt{\frac{B^2}{\mu_0\rho}}$$

The exact answer is the Alfven speed quoted above which is the speed at which hydromagnetic waves can be propagated in a magnetically dominated plasma.

VERIFICATION

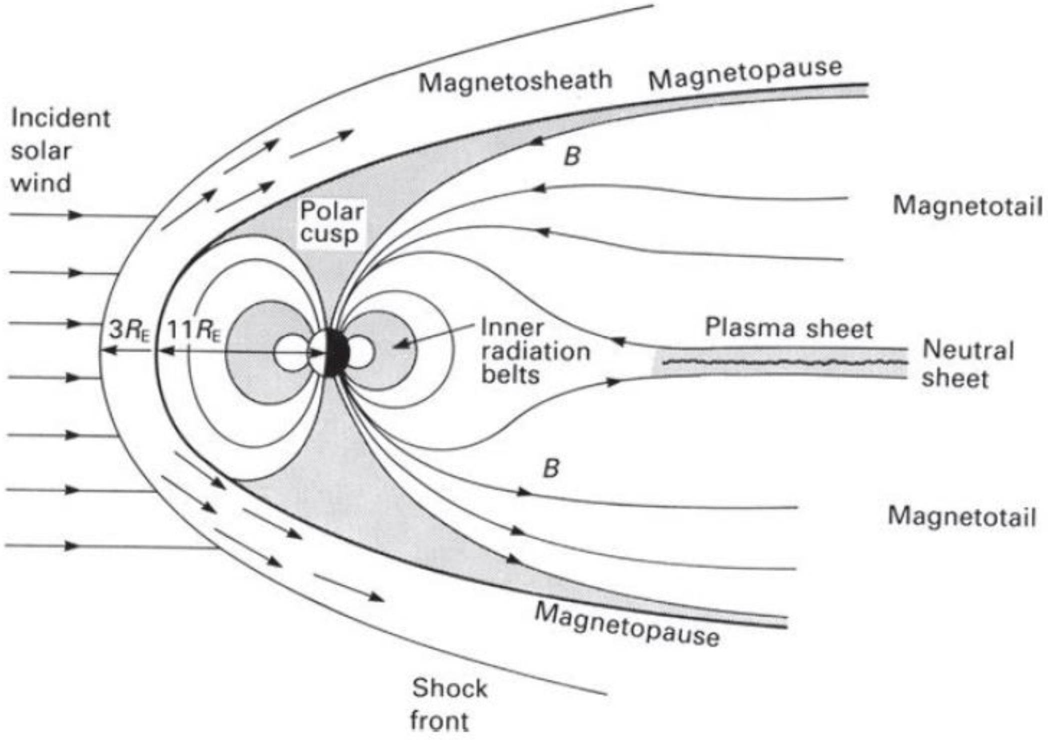
Inserting appropriate values for the earth magnetosphere,

B = 5 nT, n = 107 m−3, we find v_A = 35 km s−1.

Typical speed of Solar Wind leaving the sun is around 350 km/s.

Thus, the flow of the Solar Wind is certainly highly supersonic (Alfven Mach number M_A=10) with respect to the Alfven velocity within the magnetosphere. If any region of space is magnetically dominated, the appropriate sound speed is the Alfven speed rather than the standard sound speed in the gas. Often, the flow of the Solar Wind is described as super-Alfvenic rather than supersonic.

ANALOGY



This is analogous to being supersonic and the behaviour of such a plasma flow will form a bow shock around magnetic field of earth which is magnetopause. The MHD shock equations are also valid here and after shock values can be determined using shock equations.