Solar Wind Acceleration
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Solar Wind Acceleration

Solar wind acceleration is the increase of the flow speed of the solar wind plasma from close to zero in the lower solar atmosphere to the values observed in interplanetary space, which can range from 200 km s\(^{-1}\) for the slowest speeds in the ecliptic plane to 750 km s\(^{-1}\) for streams originating in the large polar coronal holes. The exact height in the solar atmosphere at which the plasma starts its outflow is still being debated. Until recently it was thought that the solar atmosphere was more or less static out to distances of 5 to 10 solar radii. With new observations from both ground and space based instruments, it has become clear that at least the fast solar wind streams accelerate at much lower heights in the solar atmosphere than previously thought, starting their outflows probably even below the transition region.

Properties of solar wind streams

Solar wind streams that differ significantly in speed will also differ in other plasma properties such as density and temperature. Different parts of the global solar magnetic field seem to give rise to streams with different properties. The large-scale magnetic field on the Sun can be approximated to first order by a dipole. Near the dipole equator inside of 1.5 to 3 solar radii the magnetic field is strong enough to withstand the outward plasma pressure, the magnetic field lines are therefore closed, and the plasma is confined in these regions called coronal streamers. Further away from the Sun the magnetic field becomes weak compared with the plasma pressure, and the plasma forces the field lines to open, permitting a steady outflow of plasma into interplanetary space. These open field lines fill the space between the streamer boundaries and the solar poles. Plasma conditions in the open field regions differ from the conditions in the streamers. Observations show that electron densities and temperatures as well as emission at visible, UV and x-ray wavelengths are lower in the open field regions. Regions of extremely low emission are called coronal holes. The fastest solar wind originates from the large polar coronal holes which, particularly during solar minimum activity, might have extensions all the way to the solar equator (see Yohkoh).

Figure 1. Soft x-ray Yohkoh image from 12 April 1993. The image shows a very distinct low-emissivity coronal hole region (large white area surrounding the north pole and stretching all the way to the equator). There is also a coronal hole present at the south pole, but this is veiled by denser material from surrounding regions and is therefore not visible at the time of the observation (see Yohkoh.)
Figure 2. Polarized white light intensity measurements carried out every 3° along the circle shown in figure 1. These ground based measurements are made daily with the Mauna Loa K-coronameter, operated by the High Altitude Observatory (NCAR/HAO). The intensities are normalized to the lowest coronal hole intensity. Position angle 0 corresponds to heliographic north. Shown here are the measurements from 12 March to 19 May 1993. The low intensities from position angle 120° to 220° correspond to the southern coronal hole. Note the large daily intensity variations both inside the hole and in the surrounding regions.

Figure 3. Electron densities derived from polarization brightness measurements in the inner corona (n_e) and estimates of the flow speed (v) derived from the mass flux measured in situ, these densities and the law of mass flux conservation for a radial expansion of the flow tubes (lower limits) and an expansion seven times more than radially.
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The solar wind accelerates very rapidly in the inner corona, and achieves its almost final flow speeds between 5 and 10 solar radii. This is in agreement with the in situ Helios observations which show that there is basically no acceleration of the flow at large distances from the sun. Observations from SOHO indicate that the heavy O$^{5+}$ ions already flow faster than the protons in the inner corona. It seems that, at least in the high-speed wind, the differences between minor ions and protons, seen in the in situ measurements, originate in the inner corona with subsequent modification in interplanetary space.

Solar wind speeds of 200 km s$^{-1}$ can be achieved by the pressure gradient force alone. To accelerate the wind to higher speeds, additional energy is needed that has to be deposited in the corona. At present it is not well understood where this additional energy comes from. It is usually assumed that plasma waves play a significant role (see SOLAR WIND: THEORY and CORONAL HEATING MECHANISMS).

Summary

The acceleration of the solar wind plasma to the speeds measured in interplanetary space happens close to the Sun, below 5 solar radii in the fastest streams and at slightly larger distances in the low-speed wind. During this acceleration process the solar wind passes from subsonic to supersonic speeds. The energy source necessary for the acceleration to happen is not yet known but is thought to be high-frequency plasma waves originating either in the lower solar atmosphere or higher up in the corona via a cascade from lower-frequency waves or via locally generated microinstabilities.

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