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Upstream and downstream waves in subsonic and supersonic flowing plasmas

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The Earth's bow shock generates whistler-mode waves near 1 Hz in the Pc frequency band. In the measurement frame these waves may be right-handed or left-handed with respect to the magnetic field depending on whether component of the solar wind velocity parallel to the phase velocity carries the wave fronts toward the shock or whether the phase velocity can overcome the solar wind velocity and appear in its native right-handed state. Because the group velocity exceeds the phase velocity of whistler mode waves by up to a factor of two, the energy of a bow shock generated whistler can move upstream even while phase fronts are carried back toward the shock. The spectrum of 1 Hz upstream waves often appears to have a slow rise in intensity followed by a sharp upper frequency cutoff. This upper cutoff is in fact the frequency at which the group velocity first exceeds the solar wind speed, and the waves are Doppler-shifted the most. As the wave frequency increases beyond this point the waves are Doppler-shifted less (have lower frequency in the measurement frame) and are weaker in power spectral density. These waves damp with distance from the shock, apparently by Landau damping. They are seen in front of all the bow shocks visited to date.

Ion cyclotron waves are also produced by backstreaming ions in the foreshock. Because of Doppler shifting these waves occur well below the local ion gyrofrequency at frequencies of about 30 mHz in the Earth's frame. The solar wind around Mars is also filled with ion cyclotron waves but these appear very close to the local proton gyrofrequency because these waves are produced by pickup ions that are at rest initially with respect to the observer. Similar waves are produced at Jupiter's moon, Io, at SO2, SO, and S gyro frequencies and in the Saturnian magnetosphere in the E-ring torus at water group gyrofrequencies. These waves are good indicators of neutral gas loss and their Poynting vector can provide quantitative estimates of mass loss rates. There are

many lessons for Earth from such observations.