1.2.2 What mechanisms heat and accelerate the solar wind?

Present state of knowledge

Coronal and solar-wind heating as well as the acceleration of the solar wind are believed to be closely connected phenomena. In Parker's (1958) seminal theory, the acceleration of the solar wind is a direct consequence of the coronal pressure gradient. We now understand, however, that the details of the solar-wind acceleration are more intricate. The kinetic properties of the solar wind give us insight into the heating and acceleration mechanisms (Marsch, 2006). For instance, we observe plasma species with different temperatures, temperature anisotropies, relative drifts between species, heat flux, and beams in the particle distribution functions (Marsch et al., 1982a; Marsch et al., 1982b; Pilipp et al., 1987; Goldstein et al., 2000; Hellinger et al., 2006; Matteini et al., 2007; Bale et al., 2009; Maruca et al., 2012; Tracy et al., 2016). These observations show that it is insufficient to reduce the question about coronal and solar-wind heating to a mere increase in temperature. Instead, it is necessary to determine the processes that create these observed kinetic features in order to understand coronal heating, solar-wind heating, and the acceleration of the solar wind.

In a plasma with low-to-medium collisionality like the solar wind, deviations from thermodynamic equilibrium can drive the plasma unstable (Gary, 1991; Gary, 1993; Gary & Lee, 1994; Stverak et al., 2008; Verscharen et al., 2013). These instabilities create small-scale fluctuations in the electromagnetic fields. Particles scatter on these fluctuations and thereby reduce the deviations from equilibrium that caused the instability in the first place. These processes are thermodynamically relevant since they not only generate electromagnetic fluctuations but also equilibrate the plasma, change the plasma components' temperatures, and regulate the heat flux in the system (Araneda et al., 2002; Matteini et al., 2006; Hellinger & Travnicek, 2013; Verscharen et al., 2015; Riquelme et al., 2018).

We expect that the relevance of the acting mechanisms depends on location, source regions of the solar wind, the magnetic configuration and connectivity, and the solar cycle. It is, therefore, necessary to study the kinetic properties of the solar wind under different conditions in order to quantify the contributions of the relevant heating and acceleration mechanisms.

How Solar Orbiter will address this question

Solar Orbiter will measure the velocity distribution functions of the solar-wind ions and electrons with unprecedented spatial and energy resolutions. By leaving the plane of the ecliptic and sampling the solar wind at different heliocentric distances, Solar Orbiter will allow us to discriminate between the kinetic states of very diverse solar-wind streams. The key strength of Solar Orbiter's in-situ instrument package is its capability to combine particle observations with measurements of the magnetic field (background and fluctuations) with a very high resolution in amplitude/energy and time. This will help us to understand the interactions between particles and fields through global-expansion effects and local interactions. Combining the in-situ observations with remote-sensing observations of the photosphere and the corona will help us to understand the dependence on the source regions of the solar wind. Exploiting these unique synergies offered by Solar Orbiter, we will be able to determine where the main energy deposition occurs in the solar wind, how the distribution functions evolve in different wind streams, and which turbulence/wave-particle interactions are relevant for the overall thermodynamics of the plasma. The unique orbits of Solar Orbit will also allow us to determine radial profiles of the solar wind properties. Based on the measured radial profiles of temperature, density, and magnetic-field strength, we will estimate the required local heating rates to counteract the double-adiabatic expansion in addition to heat flux and collisions for ions and electrons.