the solar plasma environment
the solar wind - steady state

Parker solar wind (1958)
- no angular momentum
- critical points
- no electric field
- entrained magnetic field

Measured by Mariner 2 (1962)

Figure 2. One of the better spectra obtained by the Mariner 2 solar wind spectrometer. The current \( I \) is given in amperes.

Fig 6 — Projection onto the solar equatorial plane of the lines of force of any solar field which is carried to infinity by outward-streaming gas with velocity \( 10^7 \) km/sec.
What’s the source of the mechanical energy?

How and how rapidly does it couple to the coronal plasma?

How is the energy dissipated and converted to heat?

Are exospheric effects important?

collisions (visc, cond, resist, friction) or collisionless
the solar wind - a turbulent plasma

Figure 5. Power spectral density vs. frequency for angle bins centered at \( \theta = 5^\circ \) (bottom), 9, 15, 21, ... 93 deg (top) computed using the 2008 February c in Table 1 by means of Equation (27). The different curves have been offset vertically for easier viewing.

(A color version of this figure is available in the online journal.)

(Podesta, 2009)
the solar wind - a turbulent plasma

- turbulent dissipation proceeds from GS cascade via kinetic Alfvén waves

- wind expansion drives instabilities that generate turbulence - evidence of heating
- may play role in weakly collisional accretion

(Bale et al., 2005)

(Bale et al., 2009)
the solar wind - steady state?

STEREO HI difference images - \(~10^\circ \times 10^\circ\) FOV
solar wind magnetic reconnection

- density isocontours
- 3D PIC simulation
- periodic
- plasmoid formation

(Y. Lin et al., 2008)

(Dungey, 1958 via Hudson archive)
the solar wind - steady state?

STEREO HI difference images - ~10° x 10° FOV
Figure 2 | Detections of the magnetic reconnection exhaust by the ACE, Cluster-3 and Wind spacecraft on 2 February 2002. a, b, The magnetic field and plasma velocity in GSE coordinates measured by ACE; c, d, the magnetic field and velocity measured by Cluster-3; and e, f, the magnetic field and velocity measured by Wind. The x component of the velocity in b, d and f has been shifted by $+300$ km s$^{-1}$. The red horizontal bars in a, c and e indicate the durations of the encounters by the three spacecraft. The magnetic field rotated 140° across the exhaust. The plasma flow in the exhaust was enhanced by $\sim 50$ km s$^{-1}$ relative to the ambient solar wind flow speed. The velocity components were correlated (anti-correlated) with the components of the magnetic field at the leading (trailing) edge of the exhaust, as expected from reconnection sunward and northward of the spacecraft. It is concluded that all three (widely separated) spacecraft detected essentially the same reconnection signature. The abrupt changes in the magnetic field $B_z$ at the two edges and a plateau in the $B_z$ profile in the middle of the current sheet indicate that the current sheet is bifurcated.
solar electron events - flares

FIG. 1. The solar-flare electron event of 8 October 1965.
(Anderson and Lin, 1966)
solar electron events - Moreton waves

Fig. 7.—Compared Moreton wave observations. The temporal evolution of the leading edge of the wave fronts outlined in black are plotted on the SDO/EIT 195 Å image. The six events with the best temporal coverage are shown. The flare sites are marked by circles. The black and white curves give the interpolated wave-front position at the time of the electron release, \( t_q \), whereas the black curves along constant longitudes are the expected footpoint locations of field lines connection the Sun and the spacecraft.

(Krucker et al., 1999)
solar electron events and plasma radio emission

[Diagram showing solar activity and electron distribution]

Ergun et al., 1998

ISEE-3
8 FEB. 1979

(Bale et al., 1998)

Lin et al., 1986
the solar wind - steady state?
coronal mass ejections (CMEs)

- CMEs are enormous, magnetic flux tubes carrying solar plasma
- Responsible for emerging magnetic flux
- May help conserve magnetic helicity

(Gosling et al., 1974)
coronal mass ejections (CMEs)

Magnetic field line lengths and topology are inferred using energetic (collisionless) electron beams (Larson et al., 1997)

Figure 3. Schematic picture of possible magnetic cloud topology. In a magnetic flux rope with constant alpha, magnetic field lines wind around a central core axis in a helix pattern. Two closely spaced field lines of a magnetic flux rope are shown. These two field lines are nearly parallel but one is connected to the Sun along the negative leg, whereas the other is not.
Composite images of COR2, HI1 and HI2 on board STEREO A and B:
• Running difference images of and HI1 and HI2 are used, since the CME signal (K corona) is dominated by the F corona;
• Earth and Venus are visible in HI2;
• The CME produces wave-like structures in HI2 seen all the way to Earth.
coronal mass ejections (CMEs) - STEREO

- Propagation direction shows a small variation but is generally within 5 deg of the Sun-Earth line, so the CME will impact Earth;
- The features can be continuously tracked up to 150 solar radii (without projection);
- Radial velocity also shows a variation with distance and is about 363 km/s for feature 1 and 326 km/s for feature 2 close to Earth.

(Liu et al.)
shock structure and ‘type II’ radio bursts

- type II radio emission is ‘plasma emission’ generated in ‘bays’ on the front of fast CME-driven interplanetary shocks
- Wind spacecraft measurements

Fig. 1.— A cartoon of shock structure consistent with our observations. Electron flux in the \( B \) and \(-B\) direction increases previous to shock arrival, as Wind is connected along the IMF line to an advanced section of the shock front. Langmuir waves and electron beams are observed in the foreshock region.

(Bale et al., 1998)

(Pulupa and Bale, 2007)
collisionless dissipation in shocks

- Collisionless shocks need to ‘heat’ ions and electrons
- However shocks are ‘ion’ scale, so thermal electron motion is nearly adiabatic
- Phase space structure develops and proceeds to dissipation

Wind spacecraft instruments measure microstructure within the shock structure with a large perpendicular wavelength. The electric field vector is roughly parallel to the magnetic field, indicating a shock ramp.

Fig. 1.—The shock crossing. The TNR spectrogram shows broadband wave activity below the electron plasma frequency in panel (a). Panel (b) shows the location and amplitude of the TDS waveform events. Panels (c)-(e) show electron temperature, solar wind speed, and magnetic field magnitude respectively.

Fig. 5.—Turbulent voltage amplitude as a function of observed electron temperature change $\Delta T_e/T_{e,2} = (T_{e,2} - T_{e,1})/T_{e,2}$. Largest observed wave fields occur for a large electron temperature jump. Since $\Delta T_e/T_{e,2}$ may be a proxy for the shock dHT potential $\Delta \Phi_{dHT}$, this indicates a large modification to the electron distribution function by shock DC fields, which may then be unstable.
`fast’ nano-dust with STEREO/WAVES

**FIGURE 2.** Basics of the electric detection of a fast grain impinging on a spacecraft.

**Figure 5** Flux of particles of mass greater than \( m \). Our result, the ISS detection (Carpenter et al., 2007), and the \( \beta \) meteoroids detected by *Ulysses* (Wehry and Mann, 1999) are superimposed to the interplanetary dust flux model (solid line, Grün et al., 1985) and to the model derived from meteor and small solar system object observations (dashed, Ceplecha et al., 1998). The green dotted line is a flux \( \propto m^{-5/6} \), as expected for collisional fragmentation equilibrium (adapted from Meyer-Vernet, 2007).

(Meyer-Vernet et al., 2009)
SSL ‘Heliosphere’ Experiments

NASA IMP 1-6, AIMP 1-2 (1963-1973) - Geiger tubes, SSDs
NASA ISEE3 (1978-1997) - energetic electrons (SSDs), x-rays/γ-rays
ESA Ulysses (1990-2009) - energetic particles (SSDs), x-rays/γ-rays
NASA Wind (1994-date) - thermal plasma (ESA) and energetic particles (SSD)
NASA STEREO (2006-date) - thermal plasma (ESA), energetic particles (SSD), and solar/LF radio astronomy
Future Experiments

ESA Solar Orbiter (2017 launch) - 40 Rs perihelion, co-rotation
NASA Solar Probe Plus (2018 launch) - <10 Rs perihelion, 90 day orbit