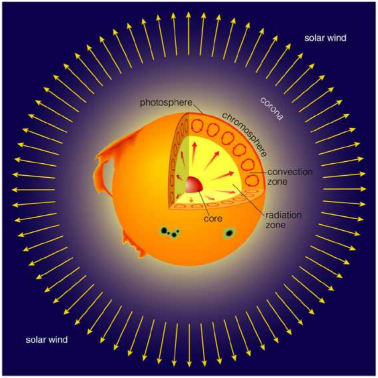
The Solar Wind

SHINE 2014, June 22



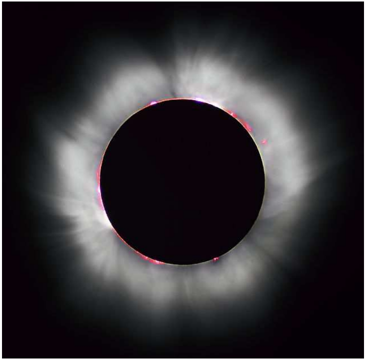
The Solar wind is a Plasma

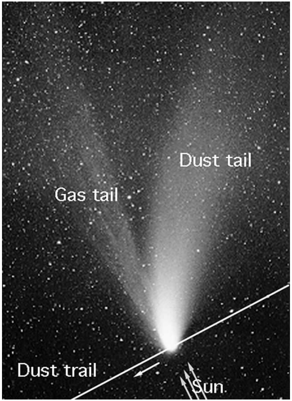
Typical solar wind parameters at 1 AU (Kivelson & Russell 1995)

Proton density	$= 6.6\times10^{6}\ \mathrm{m}^{-3}$
Electron density	$= 7.1\times10^{6}\ \mathrm{m}^{-3}$
He^{2+} density	$= 0.25\times10^{6}\ \mathrm{m}^{-3}$
Speed	$= 450\ \frac{\mathrm{km}}{\mathrm{s}}$
Kinetic energy	$= 6\times10^{-4}\ \frac{\mathrm{W}}{\mathrm{m}^2}$
Proton temperature	$= 1.2\times10^{5}\ \mathrm{K}$
Electron temperature	$= 1.4\times10^{5}\ \mathrm{K}$
Gas pressure	$= 30\ \mathrm{pPa}$
Sound speed	$= 60\ \frac{\mathrm{km}}{\mathrm{s}}$
Alfvén speed	$= 40\ \frac{\mathrm{km}}{\mathrm{s}}$
Magnetic field	$= 7\times10^{-9}\ \mathrm{T}$

Early Observations

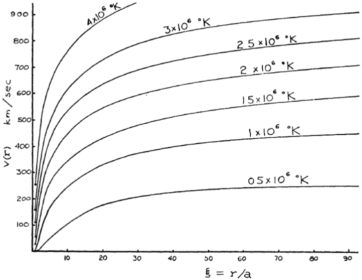
- 1859 “Carrington Event”: solar flare observed by Richard Carrington, followed by a geomagnetic storm
- Biermann (1951) observes that comet tails point radially from sun, suggesting that gas is streaming outward
- Chapman (1954) infers from coronal temperatures that the corona must extend far from sun, past the Earth

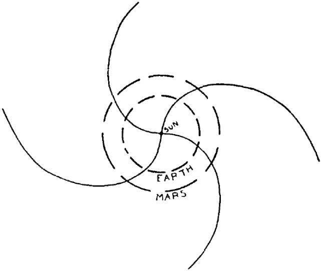




Parker (1958)

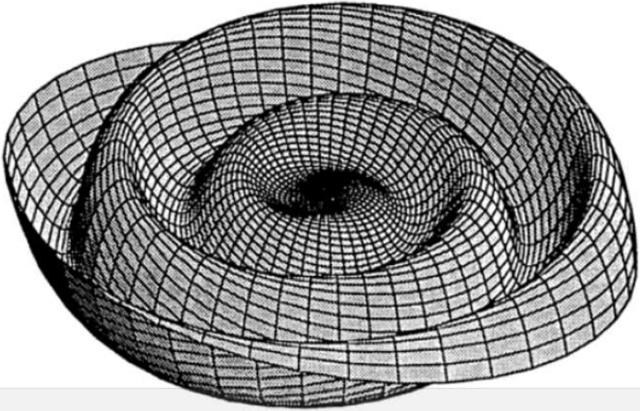
- Assumes steady-state, calculates density n(r) and temperature T(r) profiles
- These profiles give the pressure P(r) = nkT, which accelerates the wind
- Predicts "Parker spiral" B-field, from frozen-in flux condition for conducting plasma





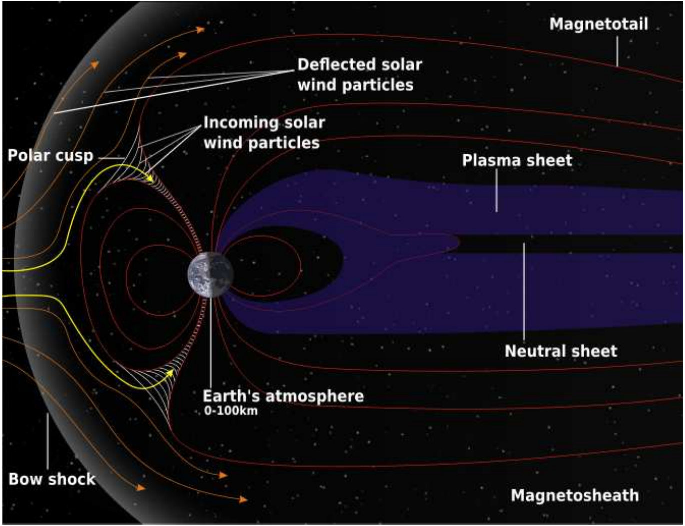
Heliospheric Current Sheet

- Sun's dipole magnetic axis not aligned with rotational axis → ripples in current sheet
- Magnetic field flips direction when crossing the sheet "sector boundaries"



Interaction with Magnetosphere

- Solar wind compresses and drags out Earth's magnetic field.
- Magnetopause: $\rho V_{sw}^2 \approx B^2/(2\mu_0)$

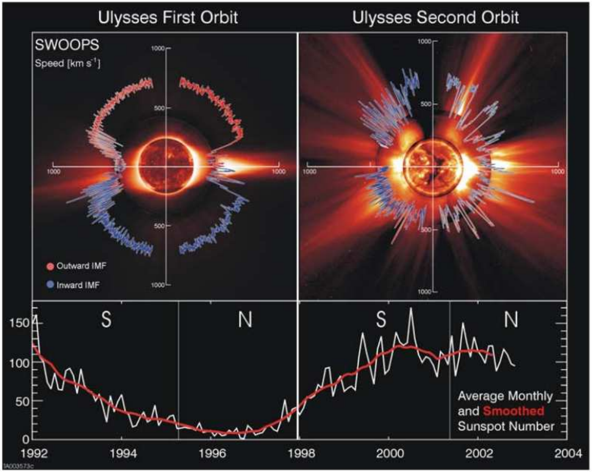


Aurora Borealis ("Northern Lights")

Astronomy picture of the day!

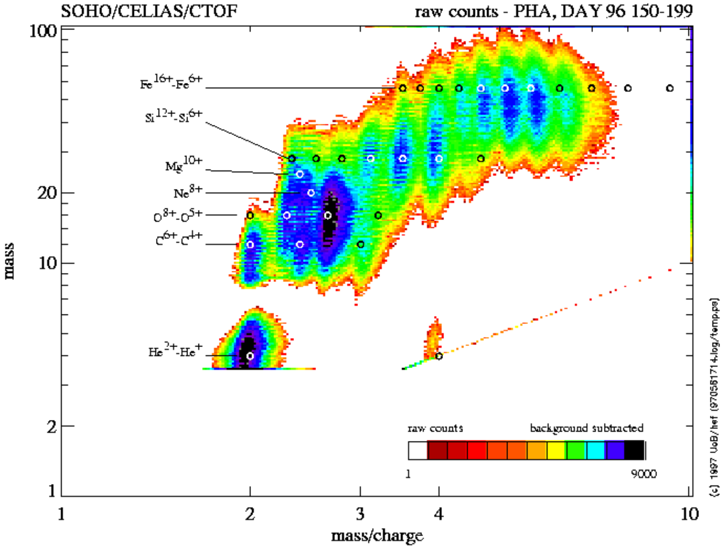
Fast and Slow solar wind (McComas 2003)

- Fast wind: $V_{sw} \approx 600 km/sec$, low density, high temperature, originates from coronal holes, typically seen near poles
- Slow wind: $V_{sw} \approx 400 km/sec$, high density, low temperature, originates from active regions, typically seen in ecliptic



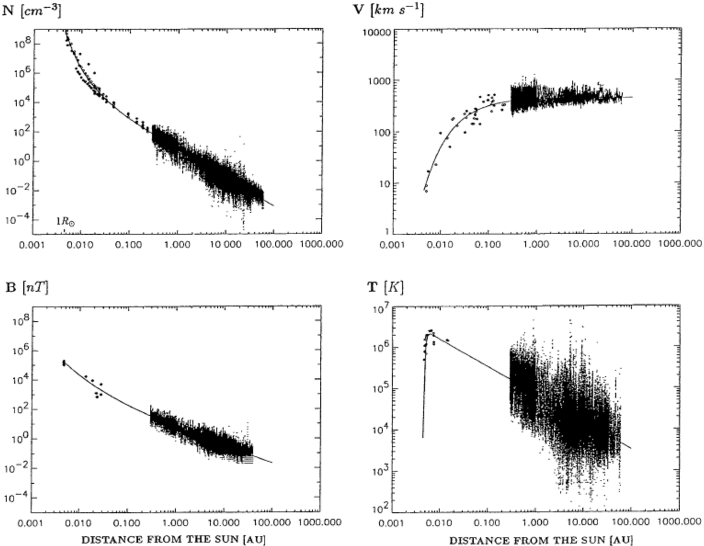
Ion composition

$n_\alpha/n_p \approx 0.01$. Other heavy elements and charge states can be detected (SOHO data)



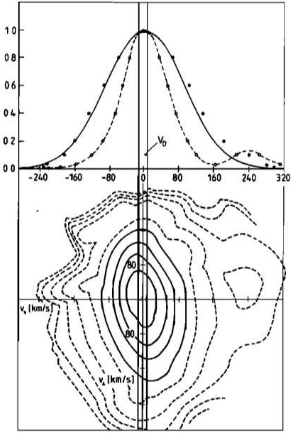
Radial variation of 0.005-60 AU (Koehnlein, 1996)

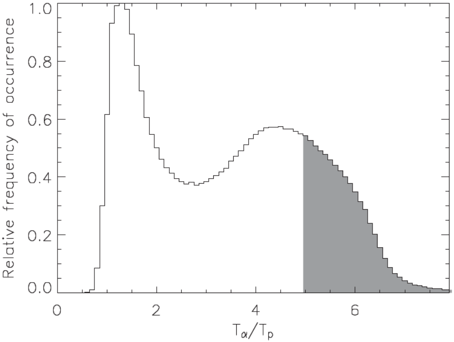
- $n \propto r^{-2}$, V_{sw} =constant
- $T \propto r^{-\alpha}$, $\alpha \approx 1/2$. Implies heating?



Distribution functions: ions

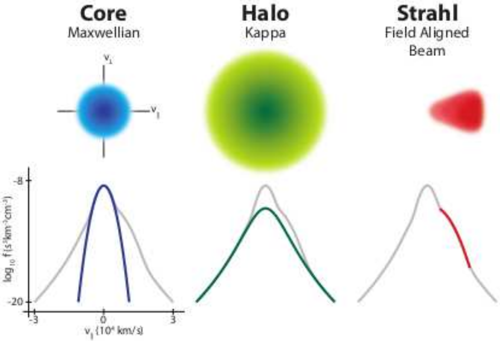
- Large temperature anisotropies $T_{p\perp} > T_{p||}$
- Twin-peaked proton distributions (Marsch & Goldstein 1983)
- Distributions are "gyrotropic": symmetrical about $\hat{B}$ direction
- $T_\alpha \approx 4T_p$? (Kasper 2008)

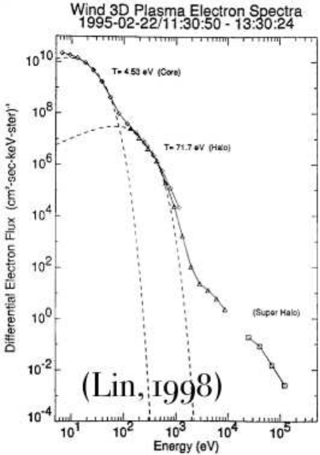




Distribution functions: electrons

- Maxwellian core: "thermal"
- "Suprathermal" populations: halo, strahl, superhalo

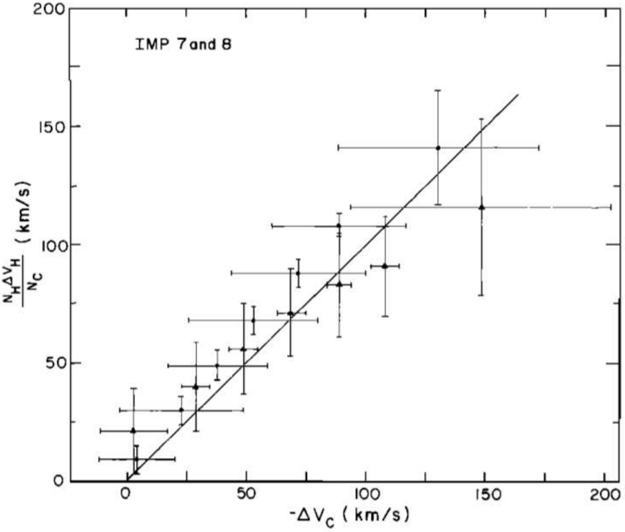




(Lin, 1998)

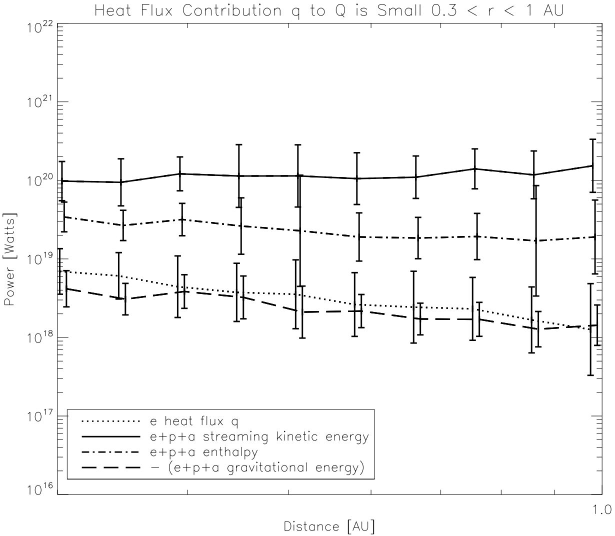
Steady-state: $< \mathbf{j}_{\parallel} >= 0$ (Feldman, 1975)

Core drift balances the strahl: $n_c v_c \approx n_s v_s$



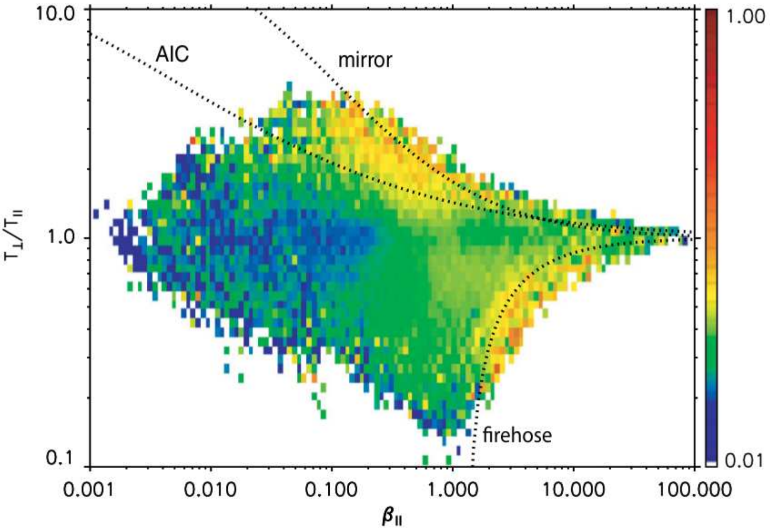
Steady-state: $\nabla \cdot \mathbf{Q} = 0$ (Marsch 1984)

- Energy flow is dominated by kinetic energy of ions
- Total power is constant with radius 0.3-1AU



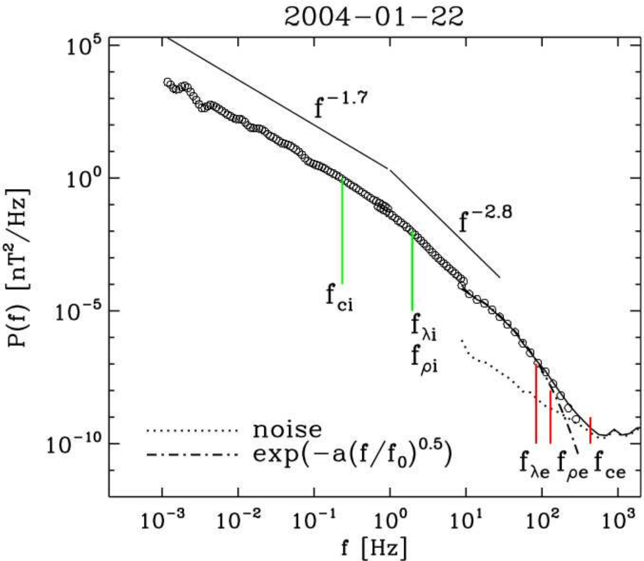
Waves/Instabilities

Enhanced $|\delta B/B|$ at instability thresholds (Bale 2009)



Turbulence

Breaks in turbulence spectrum. Dissipation at electron scales?
(Alexandrova 2009)



The future: Solar Orbiter and Solar Probe Plus

Many important questions still unsolved!

- The coronal heating problem (waves vs magnetic reconnection)
- How is the solar wind accelerated?
- What is the origin of non-thermal distribution functions?
- What heats the solar wind as it expands?