Solar Wind and Heliosphere
Modern Research Frontiers

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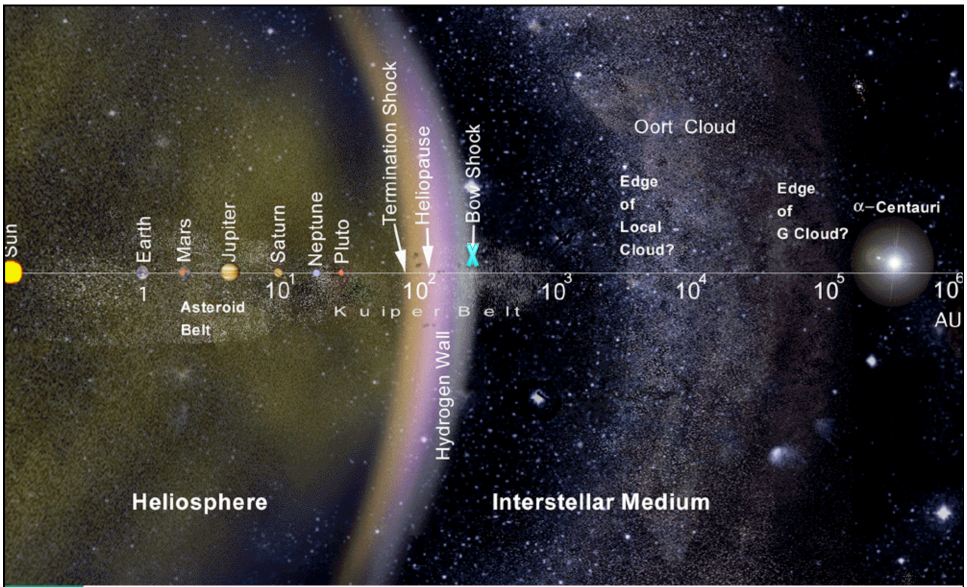
"In my own view, the important achievement of Apollo was a demonstration that humanity is not forever chained to this planet, and our visions go rather further than that, and our opportunities are unlimited."
– Neil Armstrong (Apollo 11 30th Anniversary Press Conference, 1999)



"The Sun and the Interstellar medium compete for control of the interplanetary medium"

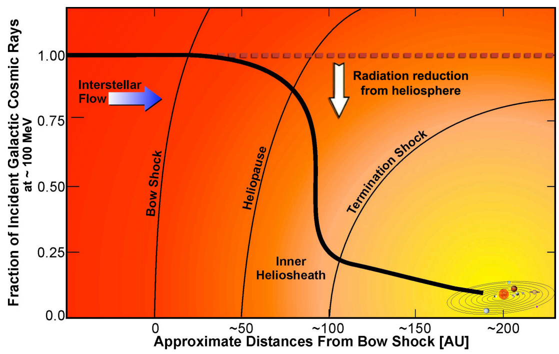
– Leonard F. Burlaga (Interplanetary MHD, 1995)

The Heliosphere

Why it is important: Our first line of defence against cosmic rays and interstellar clouds.

- The heliosphere is the volume of space, enclosed within the *interstellar medium*, formed by, and which contains, the outflowing *solar wind* and the Sun's magnetic field.
- The size of the heliosphere, known to be more than 100 AU, is determined by a balance between the dynamic pressure of the *solar wind* and the pressure of the *interstellar medium*.

Magnetized plasmas cannot mix. The boundary between the solar wind plasma and interstellar plasma is known as the 'heliopause'.

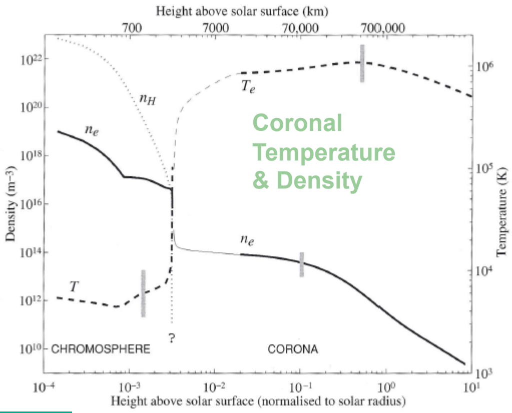


Credit: *Southwest Research Institute*

The Solar Wind

Brief overview

- The solar wind is a plasma, i.e., an ionized gas, that fills the solar system.
- It results from the supersonic expansion of the solar corona (Parker 1958).



Credit: *Meyer-Vernet 2007*

- The solar wind consists primarily of electrons and protons with a smattering of alpha particles and other ionic species at low abundance levels.
- At 1 AU (Earth) average proton densities, flow speeds and temperatures are ~8.7 cm^{-3}, 468 km/s, and 1.2 x 10^5 K, respectively.
- Embedded within the solar wind is a magnetic field having an average strength of ~6 nT at 1 AU.
- The Sun yearly loses ~6.8 x 10^{19} g to the solar wind, a very small fraction $(\dot{M} \sim 10^{-14}\ M_{\odot}\ \mathrm{yr}^{-1})$ of the total solar mass of ~2 x 10^{33} g.

The Solar Wind

Parker's Solar Wind Model (1958)

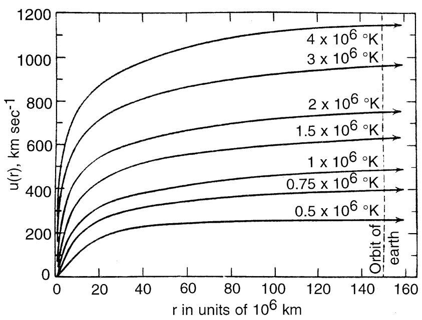
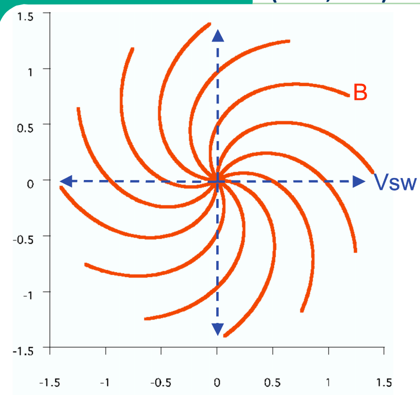


FIGURE 1 E. N. Parker's original solutions for solar wind flow speed as a function of heliocentric distance for different coronal temperatures. Subsequent work has demonstrated that the simple relationship between coronal temperature and solar wind speed illustrated here is incorrect. [From E. N. Parker (1963). "Interplanetary Dynamical Processes." Interscience, New York. Copyright © 1963. Reprinted with permission of John Wiley & Sons, Inc.]

- Motivated by diverse indirect observations, E.N.Parker developed the first fluid model of a continuously expanding solar corona, driven by the large pressure difference between the solar corona and the interstellar plasma.
- This model produced low flow speeds close to the Sun, supersonic flow speeds far from the Sun and vanishingly low pressures at large heliocentric distances.
- This continuous supersonic expansion was called the "solar wind", in view of the fluid character of the model.

Magnetic Field

Parker's Model of the Heliospheric Magnetic Field (1953,1963)



Axes are heliocentric distance in units of AU.

Spiral angle: $\tan\varphi = \frac{r\Omega_S}{u_{sw}}$

• At 1 AU the average field is inclined ~45˚ to the radial direction in the equatorial plane.

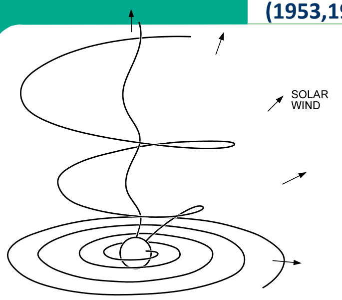
$$\vec{B} = B_S\left(\frac{R_S}{r}\right)^2 \vec{e}_r - B_s\left(\frac{R_S^2}{r}\right)\frac{\Omega_S \sin\Theta}{u_{SW}}\vec{e}_\phi$$

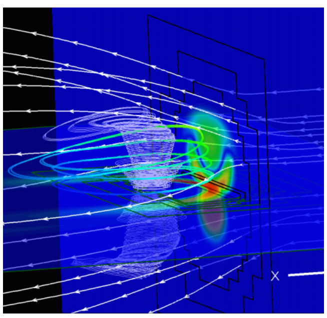
• The electrical conductivity of the solar wind plasma is so high that the solar magnetic field is "frozen into" the solar wind flow as it expands outward from the Sun.

• Because the Sun rotates with a period **Ω_S** of 27 days as observed from Earth, magnetic field lines in the Sun's equatorial plane are bent into (Archimedean) spirals whose inclination to the radial direction depend on heliocentric distance, ***r***, and the speed of the wind, ***U_{sw}***.

Magnetic Field

Parker's Model of the Heliospheric Magnetic Field (1953,1963)




Tornado-like structure (Opher et al. 2003).

$$\vec{B} = B_S\left(\frac{R_S}{r}\right)^2 \vec{e}_r - B_s\left(\frac{R_S^2}{r}\right)\frac{\Omega_S \sin\Theta}{u_{SW}}\vec{e}_\phi$$

• At large distance from the Sun, $r >> R_S$, we can see that

$$B_r \propto r^{-2} \qquad B_\phi \propto r^{-1}$$

As we go outward in the solar system the magnetic field becomes more and more azimuthal.

• The field lines are nearly perpendicular to the radial direction beyond ~5-10 AU.

• Moving away from the equator, field lines gradually become less tightly wound with latitude until a field line originating exactly from the pole remains purely radial.

Magnetic Field

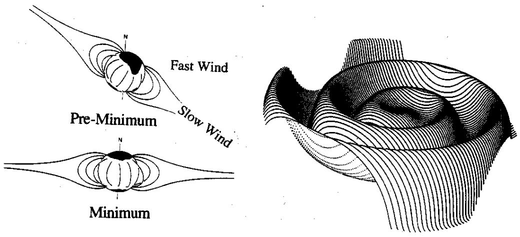
The Solar Dipole and the Heliospheric Current Sheet (HCS)

• The Sun's large-scale magnetic field well above the photosphere is usually well approximated by that of a dipole.

• The dipole generally is tilted relative to the rotation axis of the Sun, the tilt changing with the advance of the 11-year solar activity cycle.

• The heliospheric current sheet (HCS) separates solar wind regions of opposite magnetic polarities and wraps entirely around the Sun. It is the extension of the solar magnetic equator into the heliosphere.

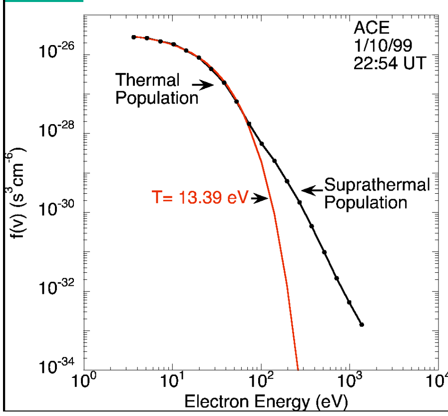
• When the Sun's magnetic dipole is tilted relative to the rotation axis, the heliospheric current sheet is warped and resembles a ballerina's twirling skirt. In this simple picture, each ridge in the skirt corresponds to a different solar rotation; the ridges are separated radially from one another by about 4.7 AU.



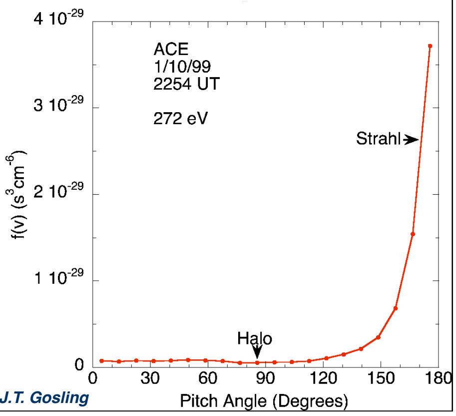
Solar Wind Electrons

Identifying Sector Boundaries

- Measurements of electron energy distributions in the solar wind reveal the presence of both *thermal* and *suprathermal* populations.
- The suprathermal population is nearly collisionless, carries the solar wind heat flux, and includes both a field-aligned "strahl" (or beam) and a roughly isotropic "halo".
- The suprathermal electrons behave as extremely fast test particles and serve as very effective tracers of magnetic field line topology in the solar wind.

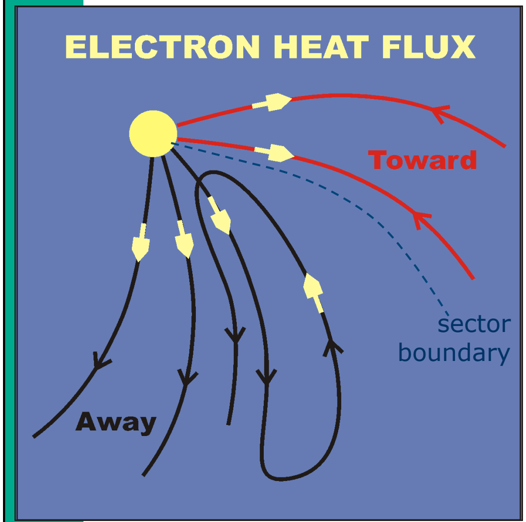


Credit: ***J.T. Gosling***



Solar Wind Electrons

Identifying Sector Boundaries

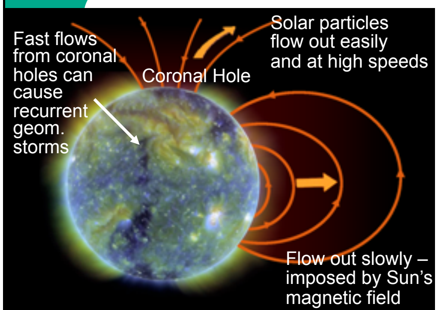


Credit: ***N.U. Crooker***

- Definition: A sector boundary separates fields of opposite solar polarity.
- Direction of electron heat flux relative to the field distinguishes sector boundaries from localized current sheets.
- Some sector boundaries lack a current sheet because adjacent field is inverted.

Stream Structures

Slow and Fast Solar Winds

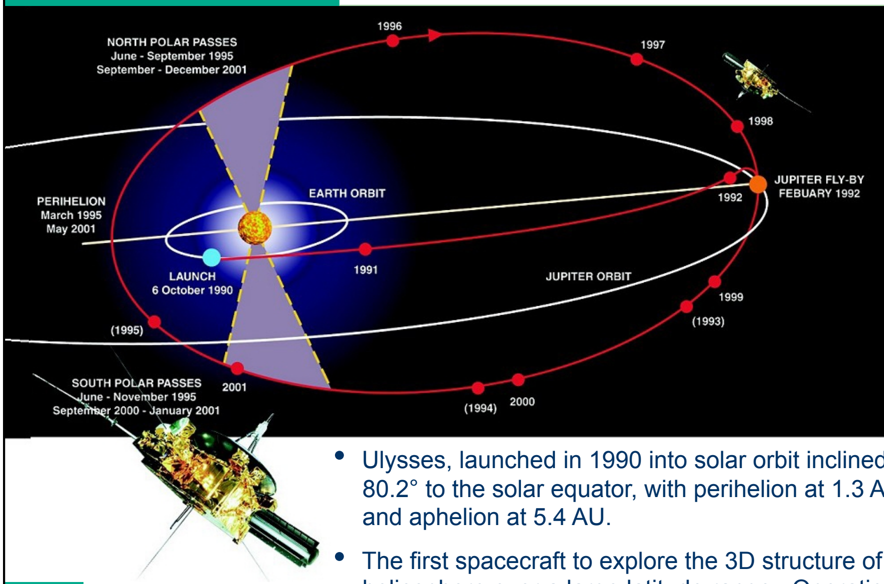


- Two distinct solar wind plasma flows are observed: slow and fast.
- The recurrent high-speed streams originate in coronal holes, which are large nearly unipolar magnetic regions of low plasma density.
- Low-speed flows tend to originate in coronal streamers which straddle regions of field polarity reversals in the solar atmosphere.

Property at 1 AU	**Slow wind**	**Fast wind**
Speed (v)	~400 km/s	~750 km/s
Number density (n)	~10 cm^{-3}	~3 cm^{-3}
Flux (nv)	~3×10^{8} cm^{-2} s^{-1}	~2×10^{8} cm^{-2} s^{-1}
Magnetic field (B)	~6 nT	~6 nT
Proton temperature (Tp)	~4×10^{4} K	~2×10^{5} K
Electron temperature (Te)	~1.3×10^{5} K (>Tp)	~1×10^{5} K (<Tp)
Composition (He/H)	~1 – 30%	~5%

Stream Structures

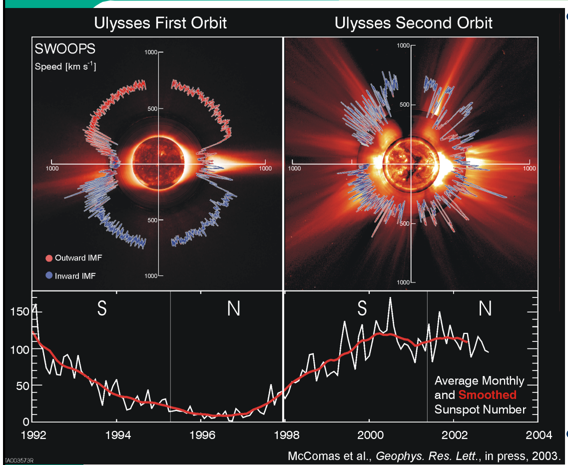
Ulysses observations in latitude.



- Ulysses, launched in 1990 into solar orbit inclined at 80.2° to the solar equator, with perihelion at 1.3 AU and aphelion at 5.4 AU.
- The first spacecraft to explore the 3D structure of the heliosphere over a large latitude range. Operations ceased in 2009 after nearly 3 orbits.

Stream Structures

Ulysses: Solar latitude and solar cycle Effects



Ulysses observations in a 5.5-year solar orbit that took it to heliographic latitudes of +/- 80˚.

(*) Misleading plot of Ulysses speed data: Slow wind does not span 45° near solar minimum, but confined to ~half that span, like width of helmet streamer base. The 45°-sweep created by tilt of streamer belt relative to heliographic equator as Sun rotates through 360°.

- During the decline of solar activity and near solar minimum stream structure is confined to a relatively narrow latitude band centered on the solar equator:

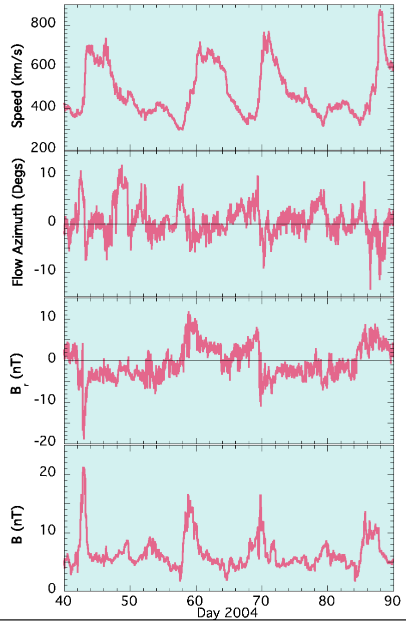
  1) solar wind properties change rapidly as a function of (latitudinal) distance from the heliospheric current sheet (**HCS**);

  2) the HCS is usually found within ~+/- 30˚ of the solar equatorial plane at this phase of the solar cycle (*).
- Near solar activity maximum solar wind variability extends up to the highest solar latitudes sampled by Ulysses, as does coronal structure.

Stream Structures

In-situ measurements of Solar Wind Stream Structures

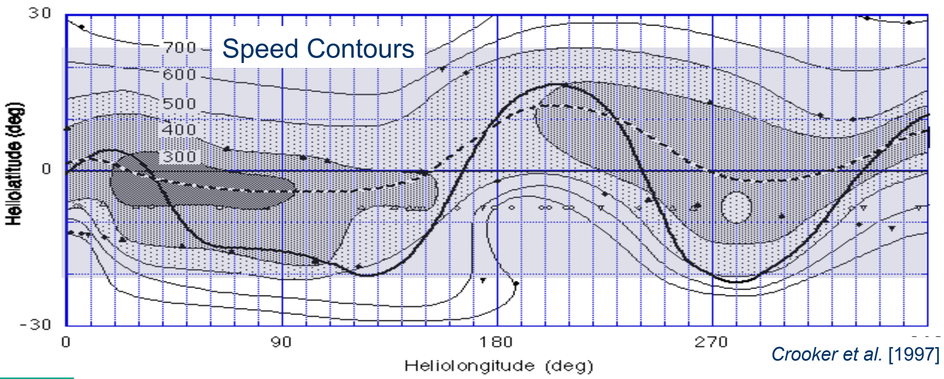
e.g. Advanced Composition Explorer (ACE) observations at L1.



- Each high-speed stream is asymmetric (rapid rise, slower fall) and unipolar (B_r positive or negative) throughout.
- Reversals in B_r occur in the low-speed wind.
- The field strength and plasma density (not shown) peak on the leading edges of the streams, and the flow there is deflected first westward (positive flow azimuth) and then eastward.

Stream Structures

Coronal Streamer Belt: Slow Wind Scale Size Near Minimum



Crooker et al. [1997]

- Synoptic map of solar wind speed
- Based upon Wind (L1) and Ulysses data during fast latitude scan
- Speed is organized by heliomagnetic rather than heliographic coordinates
- Speeds < 500 km/s span ~25° of latitude at any given longitude, even though swath spanning latitudinal extrema covers 45° (Ulysses slide)

Stream Structures

In-situ Composition Signatures

Commonly Observed Ionization States

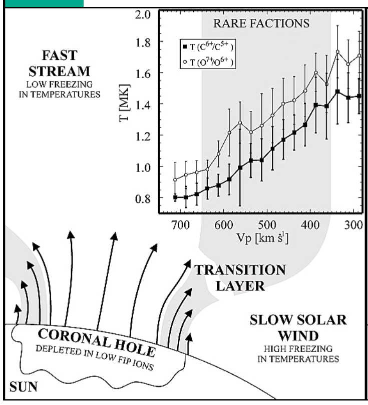
He^{2+}

C^{5+}, C^{6+}

O^{6+} to O^{8+}

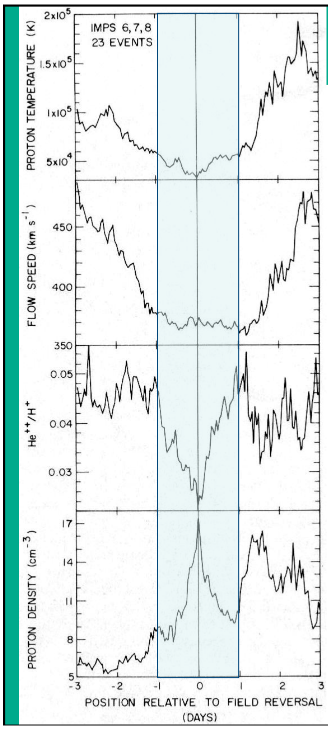
Si^{7+} to Si^{10+}

Fe^{8+} to Fe^{14+}

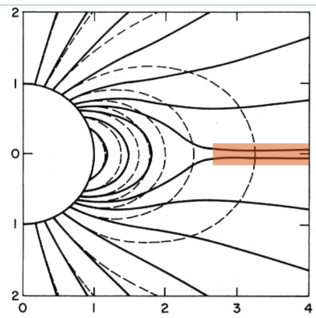


[McComas et al., 2002]

- Ionization states are "frozen in" close to the Sun because the characteristic times for ionization and recombination are long compared to the solar wind expansion time.
- Ionization state temperatures reflect electron temperatures in the solar corona where the ionization states freeze in and are typically 1.4 - 1.6 x 10^6 ˚K in the low-speed wind and 1.0 - 1.2 x 10^6 ˚K in the high-speed wind. Note that this speed/ temperature relationship is opposite to that predicted by Parker.
- At the interface between slow and fast streams, one can characterise Coronal Hole Boundary Layers (CHBLs) : inverse dependence of the solar wind speed on coronal freeze-in temperatures *[e.g. Geiss et al., 1995; McComas et al., 2002].*



The concept of the Heliospheric Plasma Sheet (HPS) Winterhalter et al. (1994)

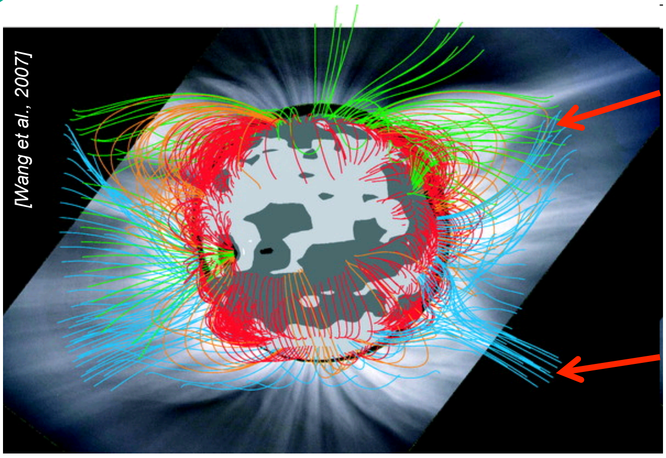


- Concept: HPS is a high-density sheath surrounding the heliospheric current sheet (HCS).
- Superposed epoch analysis centered on heliospheric current sheet (Winterhalter et al. 1994) gave the first identification of high-density plasma sheet separate from compressive stream interaction.
- Temperature, speed, He^{++}/H^{+} minima at density maximum
- Superposed epoch analysis hides substantial variablility.

Credit: ***N.U. Crooker***

Stream Structures

Coronal Structures



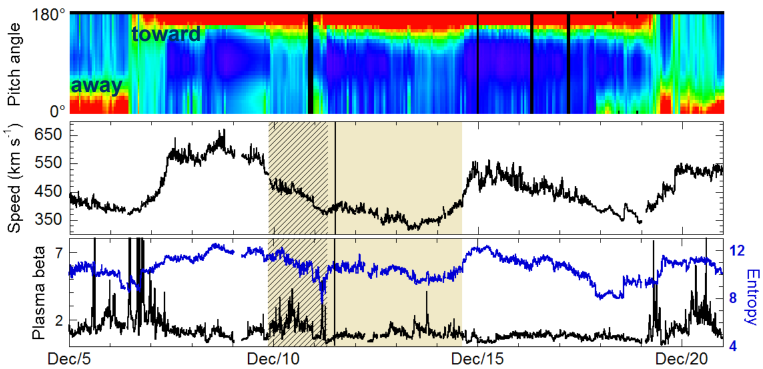
The corona is highly non-uniform, being structured by the interplay between the complex solar magnetic field and the outflow of the solar wind.

It is thus not surprising that the solar wind also is highly structured.

Stream Structures

Heliospheric Plasma Sheet with no HCS

- Arises between streams with like polarity *[Neugebauer et al., 2004]*
- Has both large- and small-scale plasma sheet characteristics
- No heliospheric current sheet required
- Can be traced back to pseudo-streamers *[Wang et al., 2007a,b]*

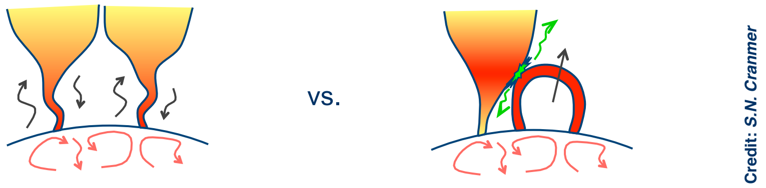


Credit: ***N.U. Crooker***

Entropy $\propto T_p/n^{\gamma-1}$, first proposed as HPS by *Burlaga et al.* [1990]

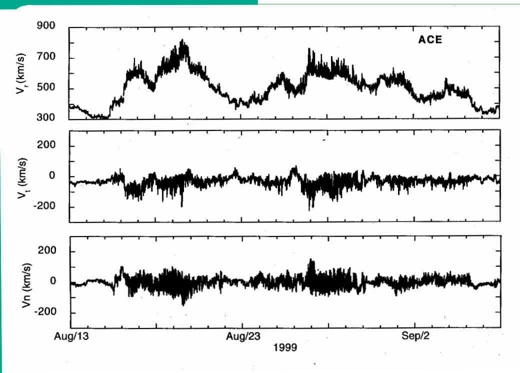
Two broad paradigms — What processes drive solar wind acceleration?

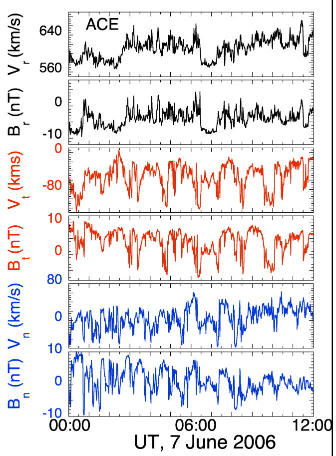
Two broad paradigms have emerged . . .



- Wave/Turbulence-Driven models, in which flux tubes stay open.
- Reconnection/Loop-Opening models, in which mass/ energy is injected from closed-field regions.

1. Wave/Turbulence — In-situ characterisation





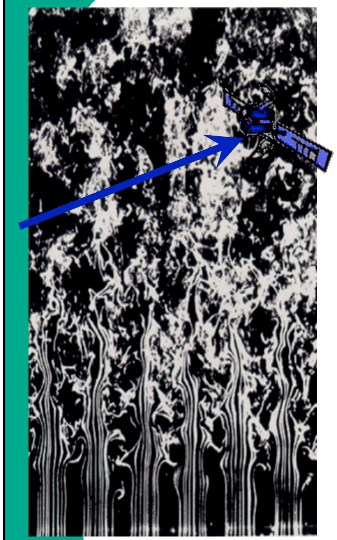
The solar wind is filled with fluctuations that have their largest amplitudes in the high-speed wind.

Many of these fluctuations are Alfvenic in nature (coupled changes in flow velocity and magnetic field vectors, Belcher & Davis 1971).

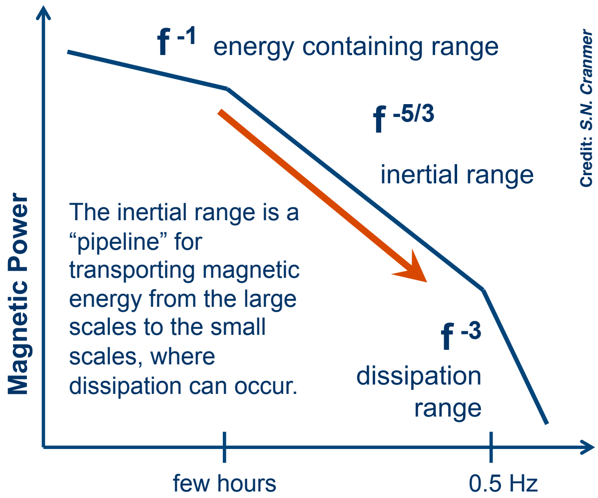
$$\delta \mathbf{u} = \mp \frac{\delta \mathbf{B}}{\sqrt{4\pi\rho}}$$

1. Wave/Turbulence

In-situ characterisation



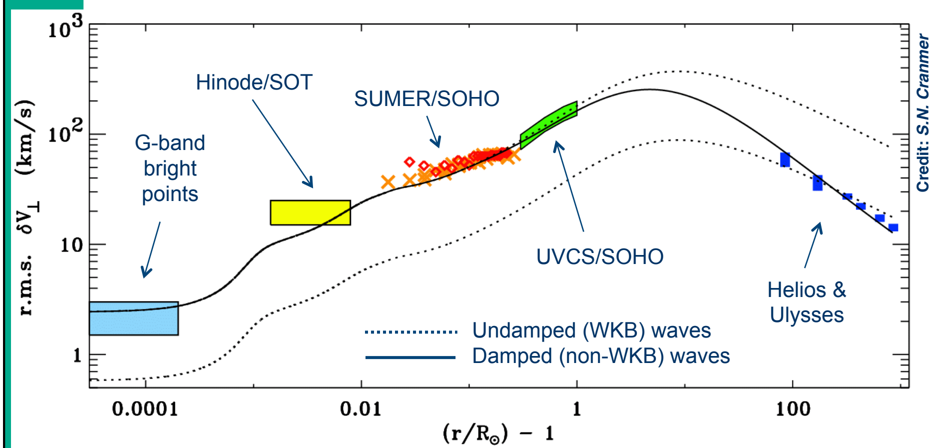
Fourier transform of B(t), v(t), etc., into frequency:



1. Wave/Turbulence

Alfvén waves: from photosphere to heliosphere

- The Alfvenic fluctuations are probably remnants of waves and turbulence that heat the corona and accelerate the solar wind.
- Fluctuation amplitudes decrease with increasing heliocentric distance; their dissipation heats the wind far from the Sun.

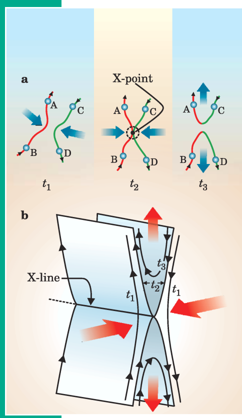


Some of the existing data assembled *[Cranmer & van Ballegooijen, 2005]*

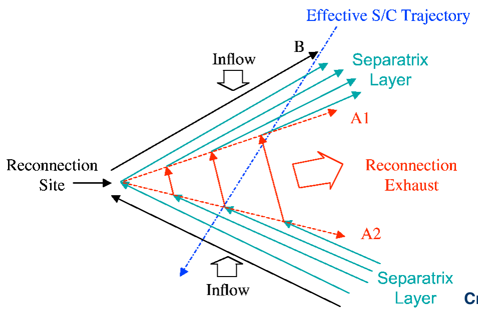
2. Reconnection

Local Magnetic Reconnection in the Solar Wind

[Borovsky, 2008]



- The solar wind contains numerous current sheets where the magnetic field orientation changes abruptly. Large angular changes are usually attributed to spaghetti-like flux tubes (Borovsky, 2008).
- When magnetic reconnection occurs at these current sheets the magnetic topology changes and oppositely directed jets of plasma are produced.
- Observations of this jetting plasma and the related magnetic field structure in the solar wind provide important information about the reconnection process and its after-effects in collisionless plasmas.



Credit: ***J.T. Gosling***

2. Reconnection

Formation of plasmoids: Slow solar wind high variability and reconnection-like signatures

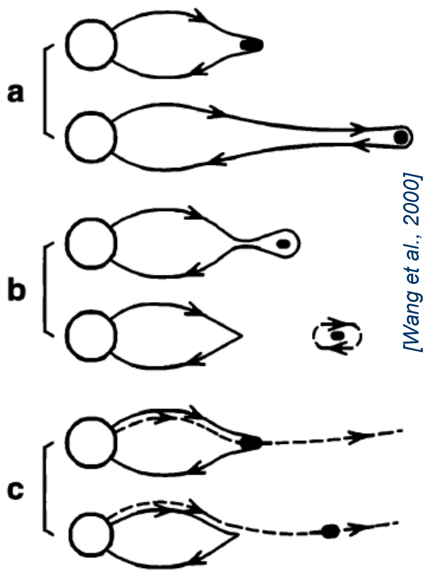
Three possible mechanisms

a) Outward pressure of the trapped material, stretching the loop to infinity.

b) X-type neutral point pinching off detached plasmoid→ *in 3D: cross-section of flux rope with both ends still attached to the Sun.*

c) Interchange reconnection.

Slow solar wind (at least in part): transient events from **magnetic reconnection** generated **either at the cusps** of streamers **or between the coronal hole boundaries and the cusps of streamers**.



[Wang et al., 2000]

Summary

Solar Wind Properties

Property (1 AU)	Slow wind	Fast wind
Speed	430 ± 100 km/s	700–900 km/s
Density	$\simeq 10$ cm^{-3}	$\simeq 3$ cm^{-3}
Flux	$(3.5 \pm 2.5) \times 10^8$ cm^{-2}s^{-1}	$(2 \pm 0.5) \times 10^8$ cm^{-2}s^{-1}
Magnetic field	6 ± 3 nT	6 ± 3 nT
Temperatures	$T_p = (4 \pm 2) \times 10^4$ K	$T_p = (2.4 \pm 0.6) \times 10^5$ K
	$T_e = (1.3 \pm 0.5) \times 10^5$ K $> T_p$	$T_e = (1 \pm 0.2) \times 10^5$ K $< T_p$
Anisotropies	T_p isotropic	$T_{p\perp} > T_{p\parallel}$
Structure	filamentary, highly variable	uniform, slow changes
Composition	He/H$\simeq 1 - 30\%$	He/H$\simeq 5\%$
	low-FIP enhanced	near-photospheric
Minor species	n_i/n_p variable	n_i/n_p constant
	$T_i \simeq T_p$	$T_i \simeq (m_i/m_p)T_p$
	$v_i \simeq v_p$	$v_i \simeq v_p + v_A$
Associated with	streamers and transiently open field	coronal holes

[Hansteen 2009]

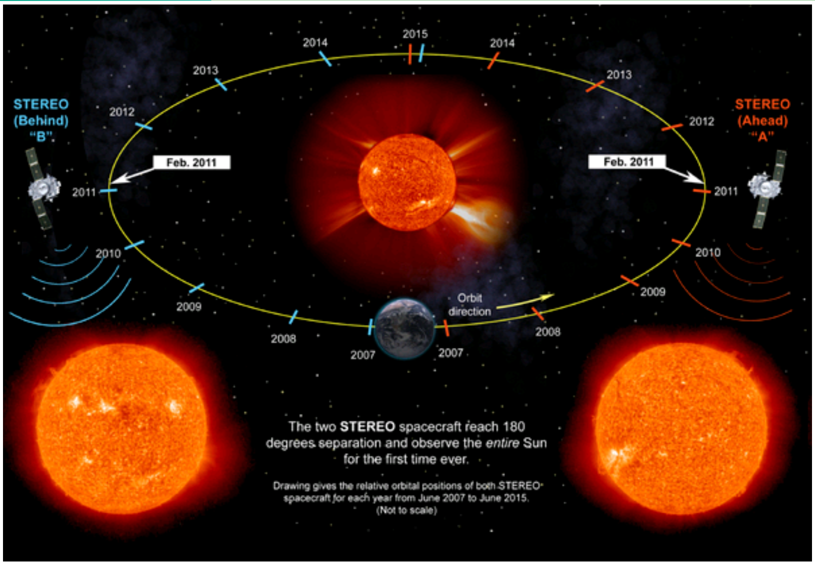
More on the Solar Wind and Heliosphere


Credit: S. Deiries/ESO.

Comet McNaught viewed over the Pacific in 2007.

STEREO

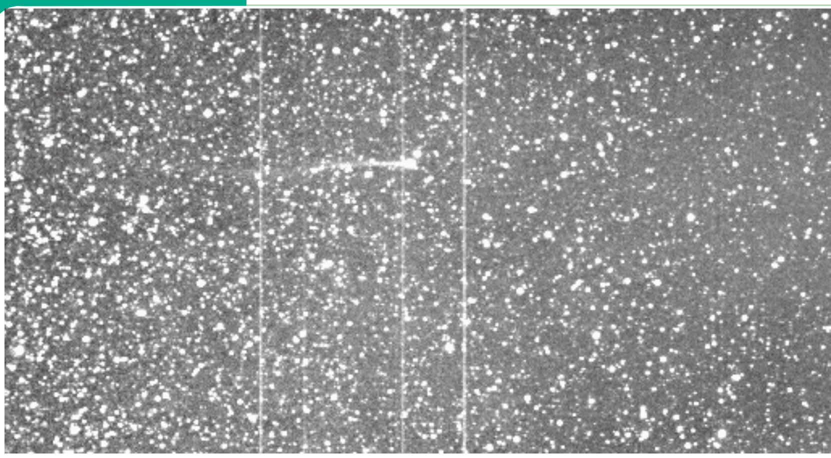
Launched in 2006, STEREO consists of two spacecraft at 1 AU separating in solar longitude ahead of and behind the Earth.



STEREO-A and -B carry instrumentation aimed at obtaining stereoscopic views of the Sun and to make multi-point in-situ measurements of the solar wind.

STEREO

Comets



STEREO-A Heliospheric Imager (HI) captured the first images ever of a collision between a coronal mass ejection (CME), and a comet. The collision caused the complete detachment of the Encke comet's plasma tail.

Movies: http://apod.nasa.gov/apod/ap071003.html

http://www.nasa.gov/mission_pages/stereo/news/encke.html

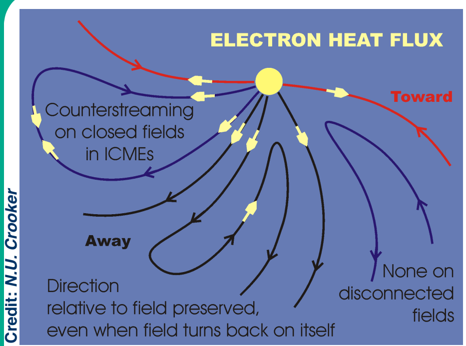
STEREO

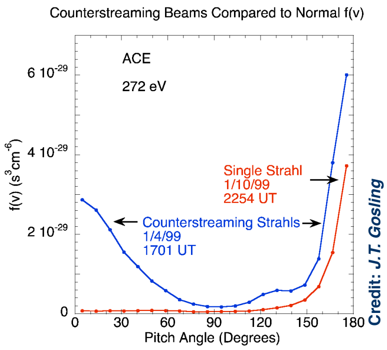
Comets

Movies: http://stereo.gsfc.nasa.gov/gallery/stereoimages_other.shtml

ICMEs

Counterstreaming Suprathermal Electrons as Tracers of Closed Magnetic Field Lines in ICMEs





- In the normal solar wind, field lines are open to the outer boundary of the heliosphere and a single field-aligned, anti-sunward-directed strahl is observed.
- CMEs originate in closed field regions in the corona and field lines within CMEs are at least initially connected to the Sun at both ends.
- Counterstreaming strahls are commonly observed on closed field lines and help identify the solar wind counterparts of CMEs (Interplanetary CMEs).

ICMEs

List of characteristics of Interplanetary Coronal Mass Ejections (ICMEs) at 1 AU

Common signatures:

- Counterstreaming (along the field) suprathermal electrons (energy > 70 eV)
- Counterstreaming (along the field) energetic (energy > 20 keV) protons
- Helium abundance enhancement
- Anomalously low proton and electron temperatures
- Strong magnetic field
- Low plasma beta (ratio of gas pressure to magnetic field pressure)
- Low magnetic field strength variance
- Anomalous field rotation (flux rope)
- Anomalous ionic composition (for example, Fe^{16+}, He^{+})
- Cosmic ray depression

Average radial thickness: 0.2 AU

Range of speeds: 300 - 2000 km/s

Single point occurrence frequency:

- ~72 events/yr at solar activity maximum
- ~8 events/yr at solar activity minimum

Magnetic field topology: Predominantly closed magnetic loops rooted in Sun

Fraction of events driving shocks: ~1/3

Fraction of earthward-directed events producing large geomagnetic storms: ~1/6

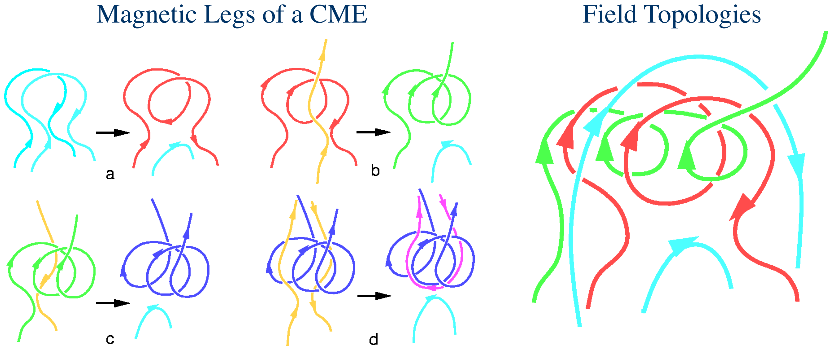
Credit: *J.T. Gosling*

ICMEs

The Magnetic Field Topology of ICMEs and the Problem of Magnetic Flux Balance

3D Magnetic Reconnection Within the Magnetic Legs of a CME

Possible mixture of Resulting Field Topologies

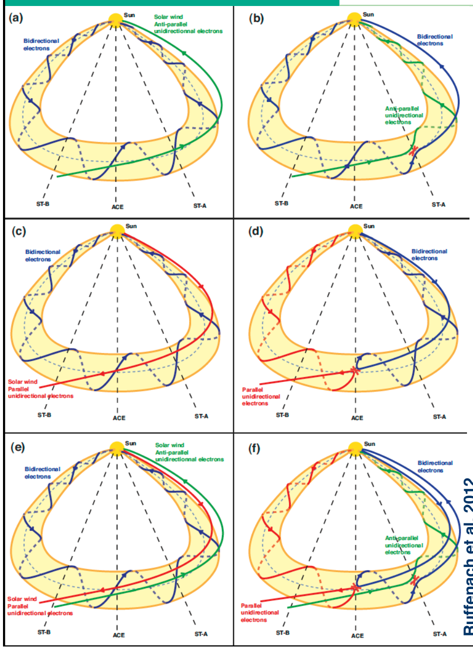


Credit: *J.T. Gosling*

- Every CME carries new magnetic flux into the heliosphere.
- Magnetic reconnection in the footpoints serves to open up the closed field loops associated with a CME, produces helical field lines within it, and helps to maintain a roughly constant magnetic flux in the heliosphere.

ICMEs

Magnetic Cloud Erosion by magnetic reconnection

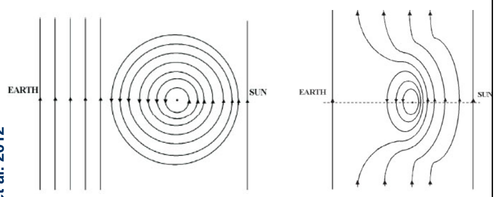


Ruffenach et al. 2012

A Magnetic Cloud (MC) can be distinguished by *[Burlaga et al. 1981]*:

- •Relatively strong magnetic field
- •Large and smooth B-field rotation
- •Lower temperature than average

Magnetic reconnection proposed as a mechanism to erode MC flux *[Dasso et al., 2006]*:

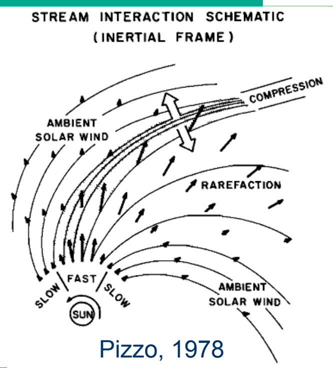


MC without erosion

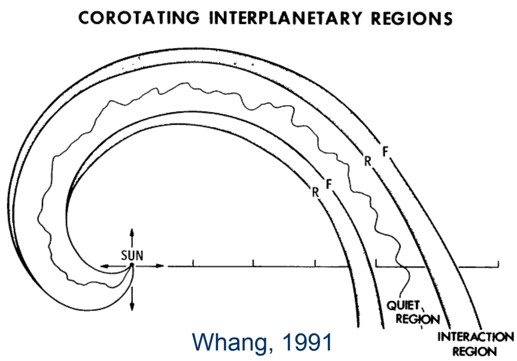
MC eroded

Formation of Shocks

Evolution of Stream Structures with Heliocentric Distance



Pizzo, 1978



Whang, 1991

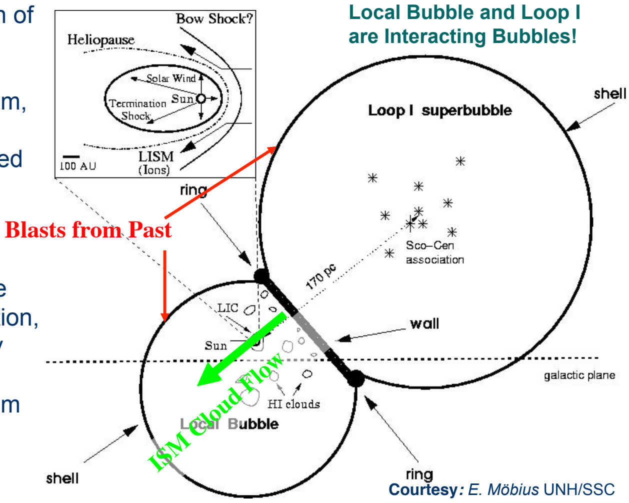
- Origin of shocks: ICME/CME, high-speed streams, corotating interaction regions (CIRs), solar flares
- Shocks: Forward and Reverse
- Shock strength and shock speed change as the shocks propagate in the solar wind;
- Shock-shock interaction: Collision, merging, generation of new discontinuities, e.g. merging of two adjacent CIRs produces a Corotating Merged Interaction Region (CMIR) - dominant dynamical structures between a few AU and 30 AU *[Burlaga et al. 2003]*.

ISM: Interstellar Medium

Outer boundaries of the heliosphere

- Sun is inside hot local bubble formed by supernova explosions.
- The bubble has small denser cooler clouds, perhaps breaking off bubble boundaries. The Sun is in one of these clouds.
- Due to the motion of the heliosphere through the interstellar medium, the interstellar plasma is deflected to flow round the outside of the heliopause.
- Depending on the speed of this motion, a bow shock may form in the interstellar medium upstream of the heliopause.

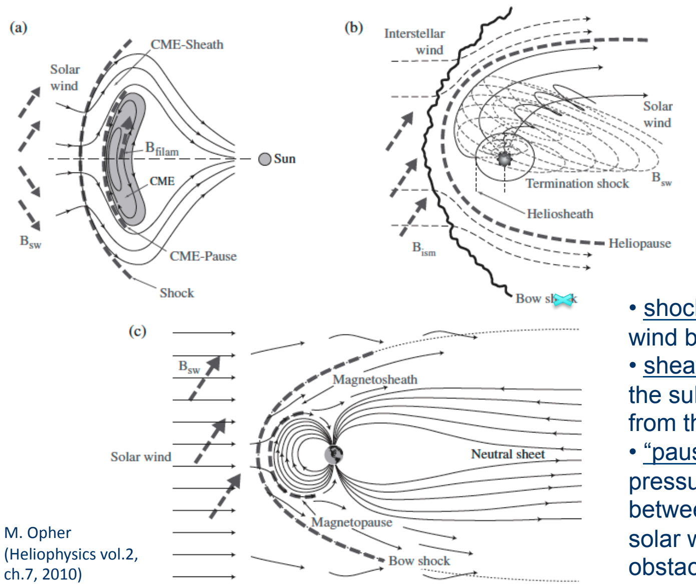
Local Bubble and Loop I are Interacting Bubbles!



Courtesy: *E. Möbius* UNH/SSC

Basic structures

Schematic comparison around CMEs, the heliosphere, and the magnetosphere.



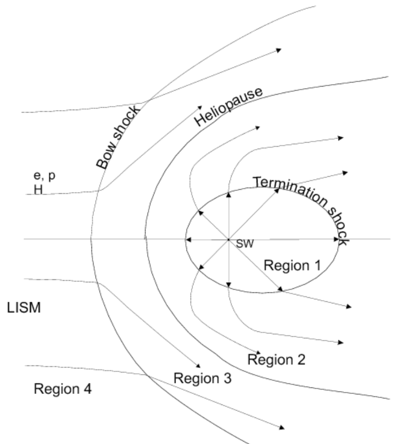
M. Opher (Heliophysics vol.2, ch.7, 2010)

- shocks where the solar wind becomes subsonic;
- sheaths that separate the subsonic solar wind from the obstacle ahead;
- "pause" where there is a pressure equilibrium between the subsonic solar wind and the obstacle's environment.

Termination Shock

Structure inferred from hydrodynamic models

- Because the solar wind flow is supersonic it cannot 'sense' that it is approaching the heliopause. Thus a standing shock wave, the 'termination shock', must form at some distance inside the heliopause so that the flow is slowed to subsonic speeds.
- The solar wind plasma can then be deflected in the region between the termination shock and the heliopause to flow down the 'heliotail'.



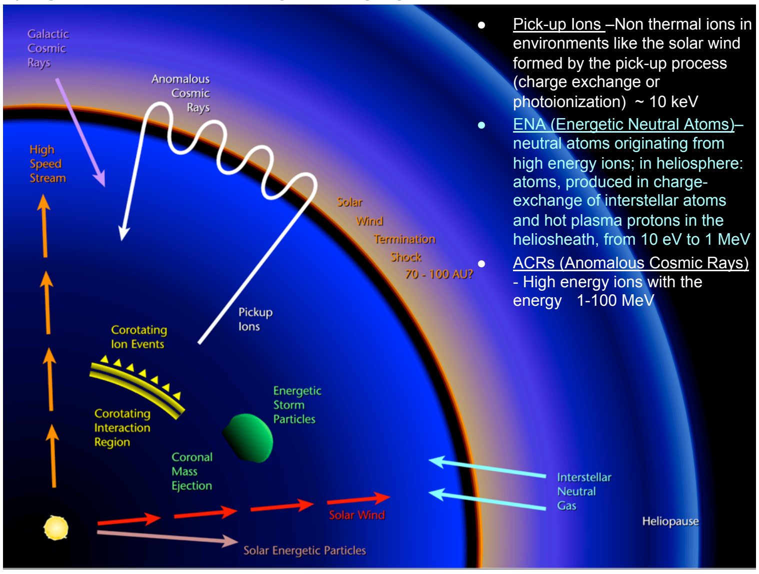
[Izmodenov et al. 2002]

4 regions with significantly different plasma properties.
Region 1: supersonic solar wind;
Region 2: subsonic solar wind;
Region 3: disturbed interstellar gas and plasma; and
Region 4: undisturbed interstellar medium.

Energetic Particles

Most of these energetic ion populations are the result of particle acceleration at shocks.

The heliosphere is filled with a variety of energetic ion populations of varying intensities with energies ranging from ~1 to 10^8 keV/nucleon.



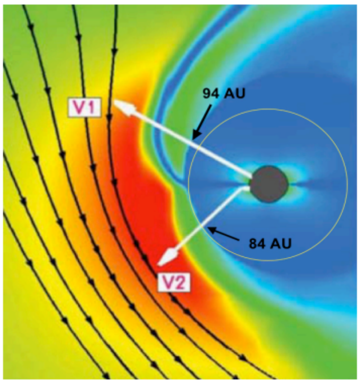
Termination Shock

Asymmetric Structure/Heliosphere Predicted and Observed

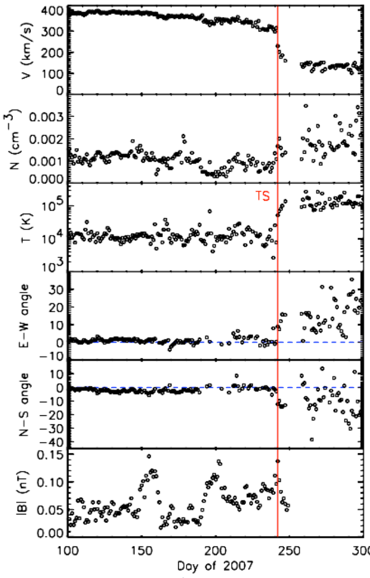
[Opher et al., 2006, 2007]

Voyager 1 and 2 were launched in 1977.

Observed Termination Shock:
Voyager 1: 94 AU in Dec. 2004
Voyager 2: 84 AU in Aug. 2007



Simulation with tilted LIC magnetic field gives asymmetry: TS and HP closer in South than North.



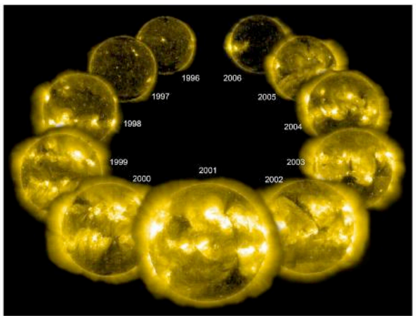
Credit: *J.D. Richardson*

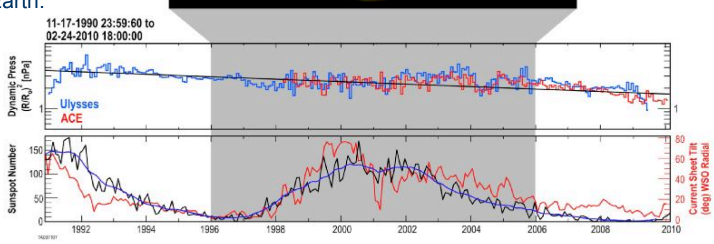
V2 crosses the TS in Aug. 2007 at 84 AU, 10 AU closer than at V1

Time-dependent effects

Solar wind dynamic pressure during Solar cycle 23

- Measurements from the ACE and Ulysses spacecraft show that the force exerted by solar wind is falling with time.
- Solar wind dynamic pressure varies by factor of ~2 from solar maximum to solar minimum.
- As the solar wind becomes weaker, the boundaries surrounding the heliosphere may begin to fall in toward the Sun and Earth.





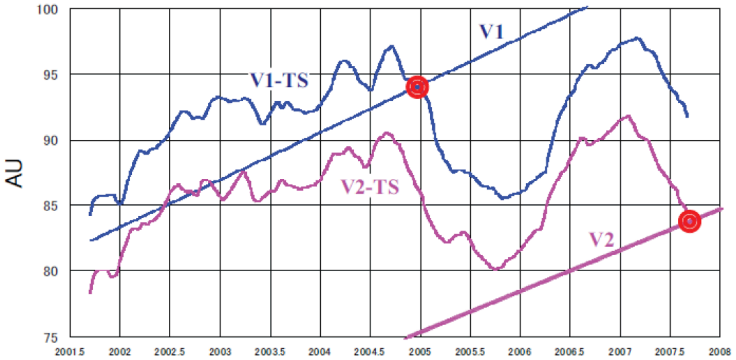
Credit: *SwRI/Ulysses and ACE data/SOHO EIT images*

Time-dependent effects

Breathing heliosphere

• TS location changes as solar wind pressure changes.

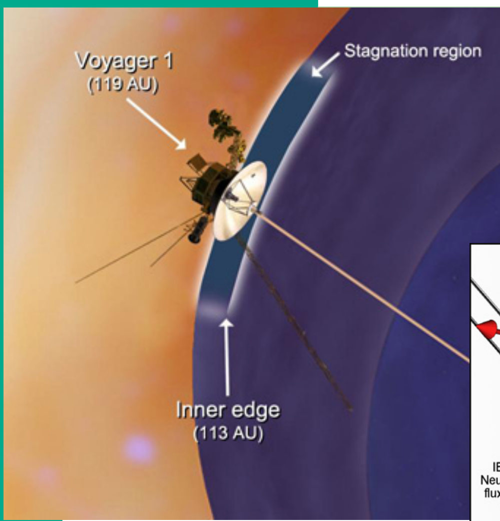
• The TS motion can be predicted by using the V2 interplanetary plasma and magnetic field data as a moving inner boundary while ensuring that the V1 and V2 crossing times and locations constrain the model [Washimi et al. 2010, 2011].



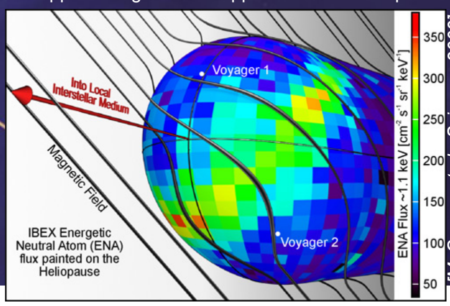
Credit: *G. Zank*

Voyager 1 & IBEX

The first glimpse of the edge of our Solar System



• April-June 2010, Voyager 1 entered a finite transition layer of zero-radial-velocity plasma flow called the 'stagnation region', before sampling a flow pattern consistent with a boundary layer of deflected plasma flow. The negligible flow velocity of the in situ particles suggested proximity to the heliopause *[Krimigis et al., Nature, 2011]*.
• Starting in May 2012 at 120 AU, Voyager 1 detected a sudden increase in cosmic rays, an apparent signature of approach to the heliopause.

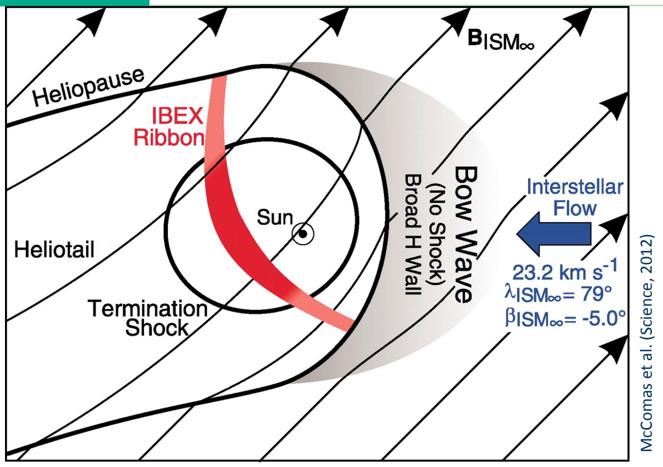


[McComas et al., Science, 2009]

Interstellar Boundary Explorer (IBEX): Remote sensing of the heliosheath proton population using ENA images by IBEX revealed stunningly unexpected structures on a variety of scales. IBEX data show a relatively narrow "ribbon" of atomic hydrogen emission (in the range 200eV to 6keV) that may be ordered by the local interstellar magnetic field interacting with the heliosphere.

The Heliosphere

No Bow Shock & a Broadened "Hydrogen wall"

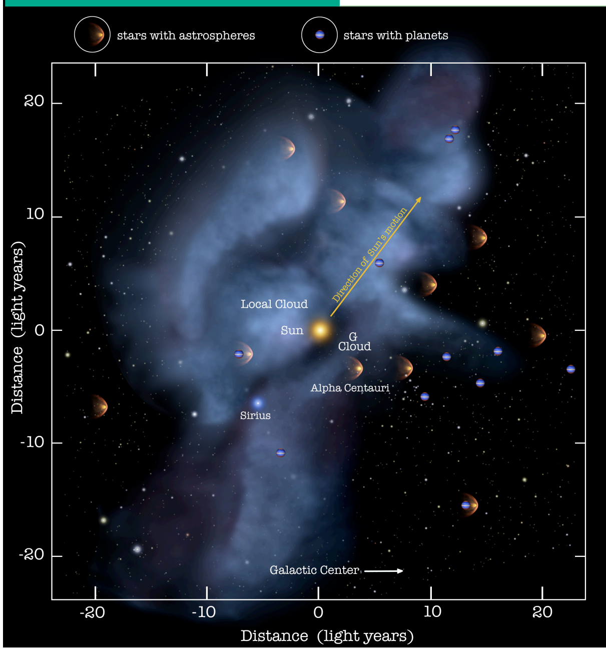


- **bow wave** instead of a shock *[McComas et al., 2012]*;

  Movie http://www.nasa.gov/mission_pages/ibex/news/nobowshock.html
- **a broadened H wall** - The strong plasma interactions heat and compress local ISM protons in between the HP and BS/BW, and thanks to charge exchange processes these high temperatures and densities are transmitted to the neutral H, forming the "hydrogen wall" region, where densities of the hot H I are particularly high *[Zank et al., 1996]*.

Cosmic Neighborhood

Astrospheres do not exist in the absence of a stellar wind



- The first clear detections of winds around other solar-like stars have come from UV spectra of nearby stars from the Hubble Space Telescope (HST). Stellar H I Ly lines at 1216 Å are always contaminated by very broad, saturated H I absorption. Part of the excess absorption comes from the "hydrogen wall".
- Over the last 15 years, we have been able to detect the first astrospheres and planets around other stars (exoplanets).
- The nearest star, alpha Centauri, has an astrosphere.
- At least two cases of astrosphere with exoplanets: analogous to our system in which the heliosphere shields a diverse planetary system.

Credit: *NASA/Goddard/Adler/ U. Chicago/Wesleyan*

Stars travelling through the galaxy surrounded by Astropheres.