The heliosphere, structure and dynamics

- Solar corona, structure and evolution
- The heliosphere, structure and dynamics
- Solar wind (heliospheric) magnetic field
- Corotating interaction regions
- Interplanetary shock waves
- The outer heliosphere and LISM

Electron density in the corona

- Current sheet and streamer belt, closed
- Polar coronal hole, open magnetically

Heliospheric temperatures

- Halo (4%)  
- Core (96%) 

Rotation of the sun and corona

Heliospheric current sheet

Stack plot of Carrington rotations from 1983 to 1994, showing the location of the heliospheric current sheet (HCS) on the source surface at 2.5 Rs

Negative polarity, dark, neutral line, bold


McComas et al., 1998

Hoeksema, Space Sc. Rev., 72, 137, 1995
Coronal magnetic field and density

Dipolar, quadrupolar, current sheet contributions

Polar field: \( B = 12 \text{ G} \)

Current sheet is a symmetric disc anchored at high latitudes!

LASCO C1/C2 images (SOHO)

Banaszkiewicz et al., 1998; Schwenn et al., 1997

Solar wind stream structure and heliospheric current sheet

Current sheet is a symmetric disc anchored at high latitudes!

Alfvén, 1977

Solar wind fast and slow streams

Helios 1976

Alfvén waves and small-scale structures

Marsch, 1991

Stream interaction region

Dynamic processes in interplanetary space

• Wave amplitude steepening (\( n \sim r^{-2} \))
• Compression and rarefaction
• Velocity shear
• Nonlinearity by advection (\( V \cdot \nabla V \))
• Shock formation (co-rotating)

Stream interaction region (Helios)

Forward shock FS
Reverse shock RS
Stream interface SI, tangential discontinuity with T jump

Scheweim, 1990

Solar wind stream interactions

Corotating interaction region (CIR)

Hundhausen, 1973; Pizzo, 1978
Model of coronal-heliospheric field

Heliospheric magnetic field direction

Heliospheric magnetic field

Conservation of radial magnetic flux

Latitudinal variation of the heliospheric magnetic field
Solar wind speed and density

- B outward
- B inward

McComas et al., GRL, 25, 1, 1998

Polar diagram

\( V \)

Density
\( n \, R^2 \)

Ecliptic

Polar diagram crossings

Borrini et al., JGR, 1981

Dense

Slow

Cold

Less Helium

Speeds equal

Temperatures close

Current sheet crossings

Polar plot of density and He/H ratio

\( n_p(r/1AU)^2 \)

\( n_\alpha/np \)

McComas et al., 1998; Geiss et al., 1998

Ulysses SWOOPS/SWICS

Polar diagram of solar wind

Woch, 2000

Ecliptic

Near solar max/min: Slow wind at - 65°

Polar plot of mass/momentum flux

\( n_p/m_p V(r/1AU)^2 \)

\( n_\alpha/m_\alpha V(r/1AU)^2 \)

McComas et al., 1998

Ulysses SWOOPS/SWICS

Heliosphere and local interstellar medium

Kausch, 1998

- 0.3 > \( \log(n_\alpha/cm^3) \) > - 3.7 (blue)

\( V = 25 \) km/s

Bohm, 2000

Ecliptic

Swonis SWICS

Proton density

Current sheet crossings

Borrini et al., JGR, 1981

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Slow

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Polar diagram of solar wind

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Kausch, 1998

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**Structure of the heliosphere**

- Basic plasma motions in the restframe of the Sun
- Principal surfaces (wavy lines indicate disturbances)

**Heliospheric termination shock**

2-3 kHz radio emission generated at the heliopause (compression region); radiation is trapped in heliospheric cavity; source: largest CMEs of solar activity maximum in 1983 and 1993

**The outer frontier**

Termination shock at about 100 AU and Voyager at 80 AU

**The interstellar neighbourhood**

**Changing corona and solar wind**

1. **Fast wind in high-speed streams**
   - High speed: 400 - 800 km/s
   - Low density: 3 cm$^{-3}$
   - Low particle flux: $2 \times 10^{8}$ cm$^{-2}$ s$^{-1}$
   - Helium content: 3.6%, stationary
   - Source: coronal holes
   - Signatures: stationary for long times (weeks!)

2. **Low-speed wind near activity minimum**
   - Low speed: 250 - 400 km/s
   - High density: 10 cm$^{-3}$
   - High particle flux: $3.7 \times 10^{9}$ cm$^{-2}$ s$^{-1}$
   - Helium content: below 2%, highly variable
   - Source: helmet streamers near current sheet
   - Signatures: sector boundaries embedded
**Speed profile of the slow solar wind**


**Solar wind types II**

3. Low speed wind near activity maximum

- Helium content: 4%, highly variable
- Source: related to active regions
- Signatures: shock waves often imbedded

4. Ejecta following interplanetary shocks

- High speed: 400 - 2000 kms$^{-1}$
- Helium content: up to 30%
- Other constituents: often Fe$^{+}$ ions; in rare cases He$^{+}$
- Signatures of magnetic clouds: in about 30% of cases
- Sources: erupting prominences

**Coronal mass ejections**

Schwenn et al., 1998, 2000

LASCO on SOHO, helical CME

**Statistics of CME properties**

Howard et al., 1985

- About 1000 CMEs observed by SOLWIND

**Speeds of CMEs (1996 to 1998)**

St.Cyr et al., 2000

- Flare-associated fast CMEs with 0.3 ms$^{-2}$ and initial V > 700 km/s
- Eruptive slow CMEs with 0-50 ms$^{-2}$ and initial V = 10-20 km/s

**Speed profile of balloon-type CMEs**

Srivastava et al., 1999

- Wide range of initial acceleration: 5-25 ms$^{-2}$
**Field variation in magnetic cloud**

Burlaga, 1980

- Rotation of field vector
- Speed enhancement
- Lower density
- Higher Helium content
- Cooler protons

**Interplanetary CME**

Philipps, 1997

- Magnetic loop or flux rope

**Daily number of interplanetary shocks in a typical solar cycle**

Khalisi, 1995

- The daily shock rate, based on 400 shocks observed by the Helios solar probes in 12 years.

Shock rate in the ecliptic plane is about 10% of the total CME rate: every tenth CME shock hits the earth!

**Interplanetary shock waves**

Richter et al., 1986

- Quasiparallel (190) transient fast-mode shock
- Quasiparallel (120) corotating fast-mode shock

Note the strong jumps in all parameters!

**Solar wind stream dynamics**

Schwenn, 1990

- Fast streams <----- > slow streams
- Coronal holes (open) - streamers (closed)
- Sharp transitions = 2° - 8° (20 - 80) kms⁻¹/degree

- Stream collisions <----- interaction regions
- Advective <----- compression

- Colliding transient flows form corotating interaction regions (CIRs)
- Compound streams: - two corotating streams
  - stream and transient ejection
  - two ejecta or clouds or shocks

- (V·∇) V = - ∇(p + B²/8π)

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Corotating interaction region CIR

Corotating shocks
Schematic showing how the tilted streamer belt leads equatorward forward (FS) and poleward reverse (RS) shock propagation

Ulysses shock statistics for northern (right) and southern (left) hemisphere

Schematic showing how the tilted streamer belt leads equatorward forward (FS) and poleward reverse (RS) shock propagation

In-situ observation at 1 AU
MHD simulation at 2 AU

Large-scale 3-D structure of CIRs is intimately linked with slow/fast wind source geometry in solar corona

Global merged interaction region

Inventory of the heliosphere

- Interplanetary magnetic field (sun)
- Solar wind electrons and ions (corona)
- Solar energetic particles (solar atmosphere)
- Anomalous cosmic rays (planets, heliopause)
- Cosmic rays (galaxy)
- Pick-up ions (solar wind, dust, surfaces)
- Energetic neutrals (heliopause)
- Dust (interstellar medium, minor bodies)
Gravitational focussing of interstellar gas

Interstellar neutral gas

View from Ulysses, in ecliptic coordinates: $\lambda \approx 225^\circ$, $\beta \approx 5^\circ$.