The Dependence of the Plasma Sheet on the Solar Wind

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1. The GEM Global-Interactions Campaign
2. Why the Plasma Sheet Is Important
3. Basic Properties of the Plasma Sheet
4. The Sources of the Plasma Sheet
5. The Dependence on the Properties of the Solar Wind
6. What We Don't Know

The GEM Global Interactions Campaign

Ultimate Goal of the Campaign:

To determine the processes controlling plasma entry and circulation within the magnetosphere.

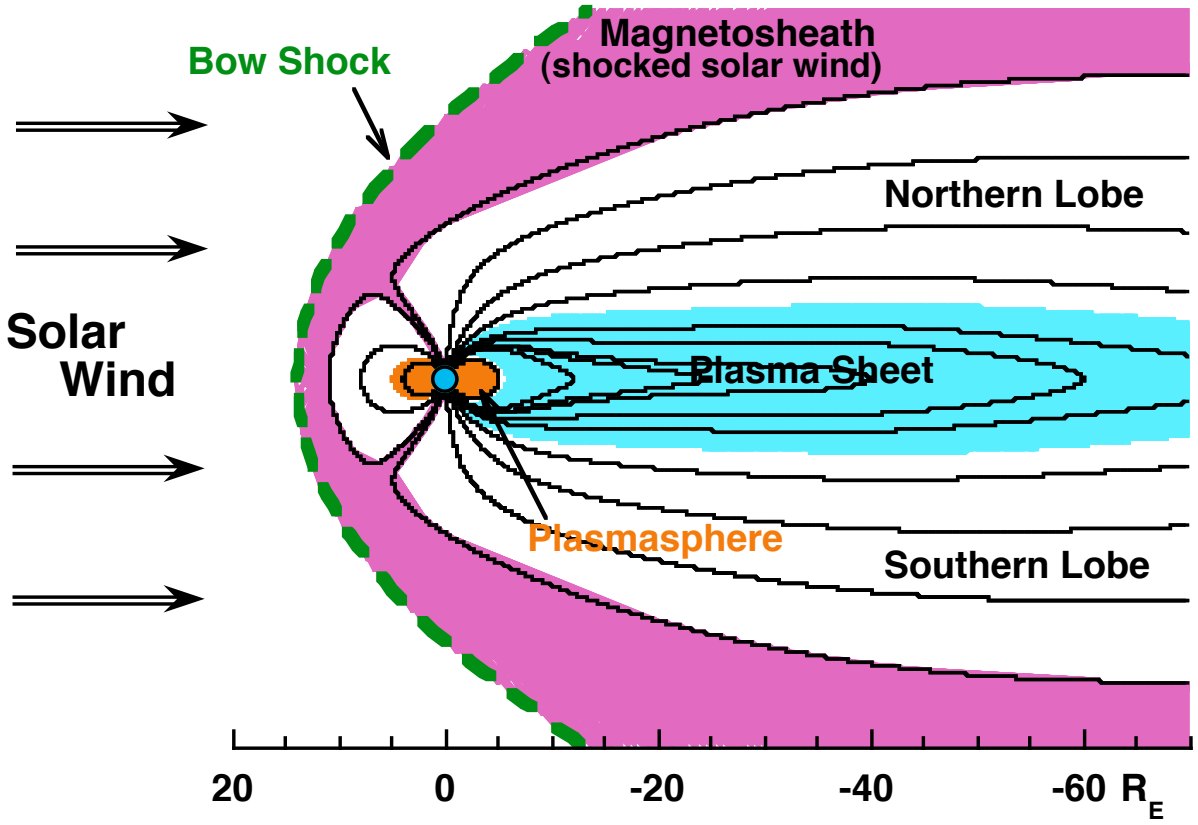
This Talk:

Look at one important pathway of the "entry and circulation" picture-- The solar wind making its way into the plasma sheet and through the magnetosphere.

¿Why Is the Plasma Sheet Important?

- **Feeds plasma into the inner magnetosphere**
  - **Ring-current/partial-ring-current source**
  - **Auroral-particle-precipitation source**
  - **Energetic-particle source**
- **Transports magnetic flux into the inner magnetosphere**
- **Site of auroral currents and auroral Poynting flux**
- **Site of nightside reconnection**
- **Partakes in magnetospheric energy storage and release**

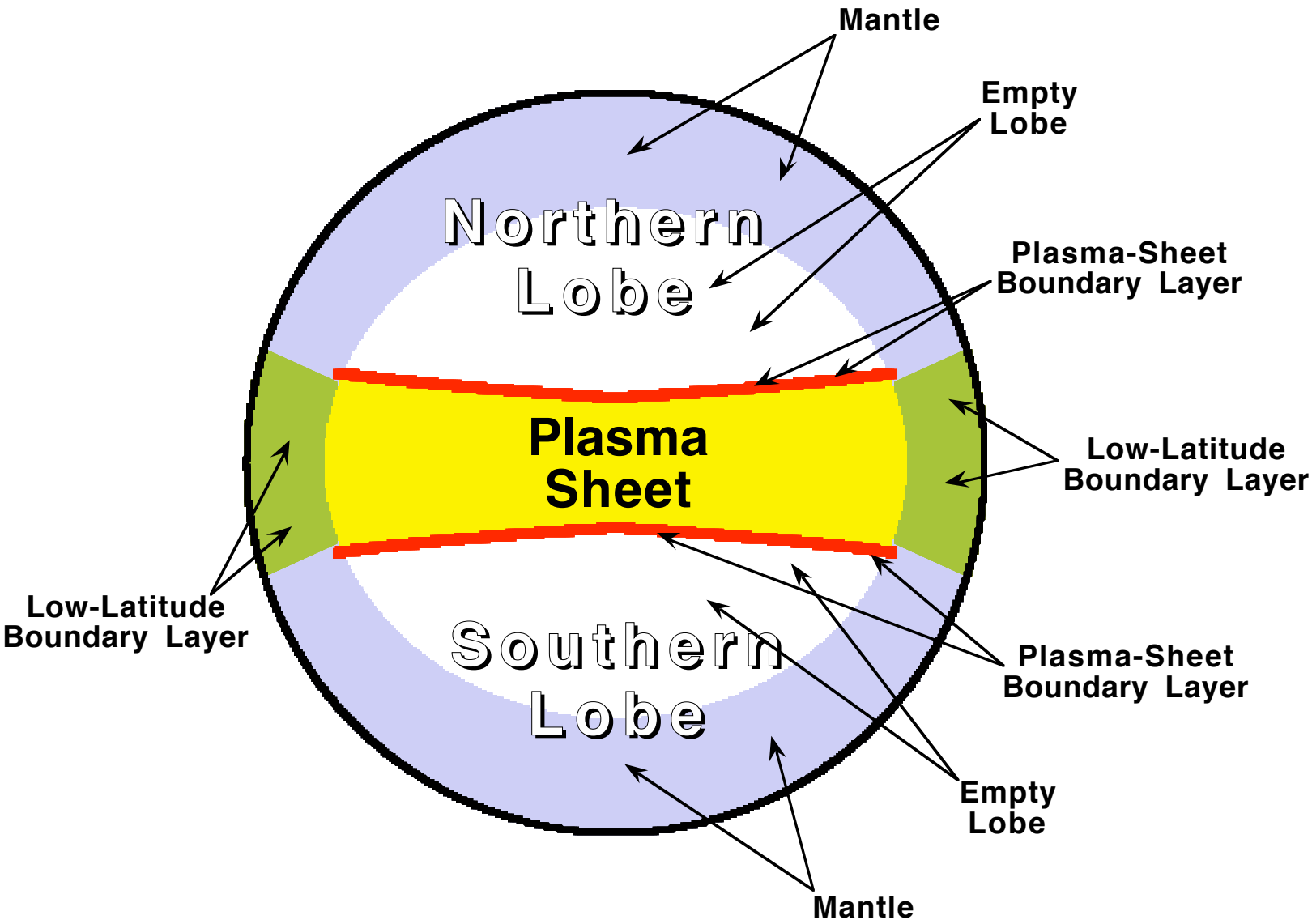
What Is the Plasma Sheet?



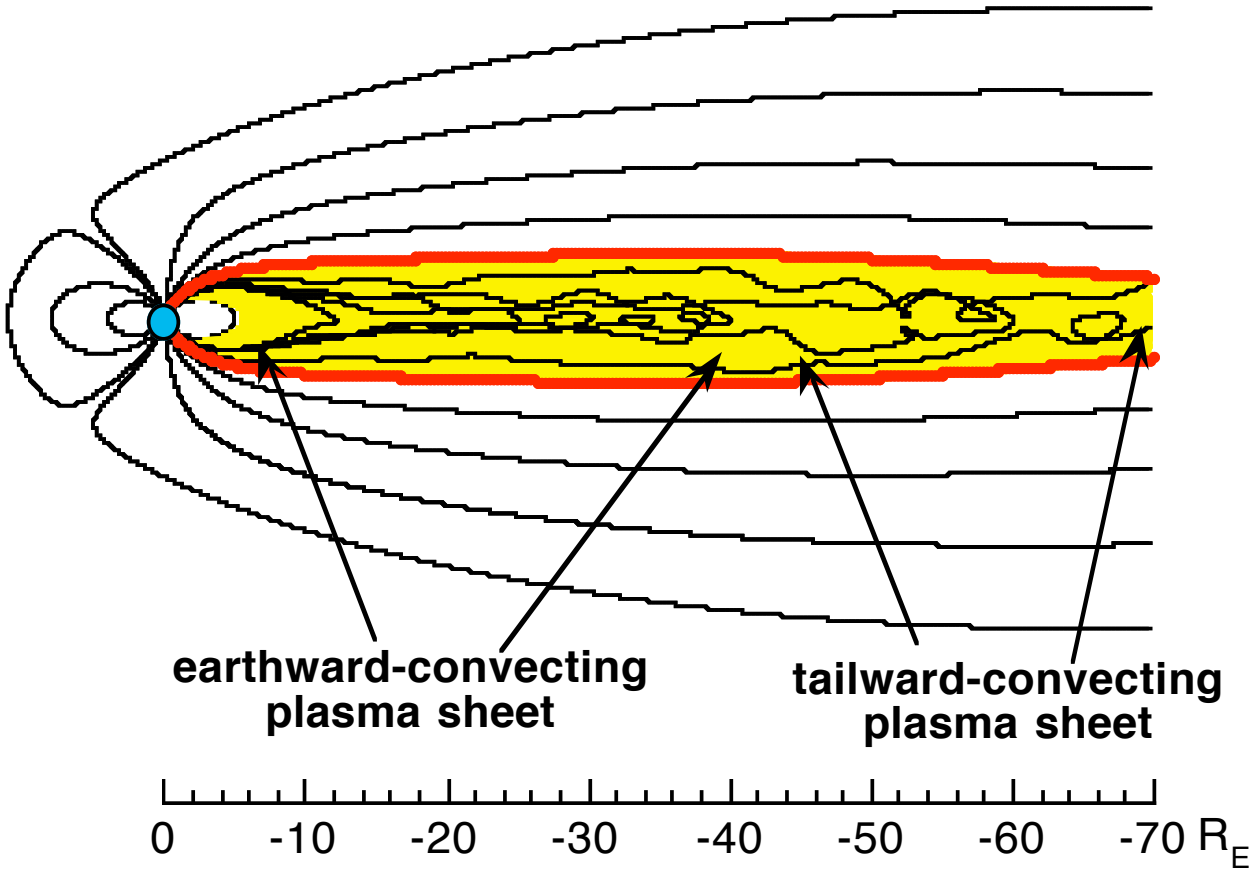
Dipole	*Magnetotail*	*Solar Wind*
$n = 0.5\text{-}1.5\ cm^{-3}$	$n = 0.1\text{-}0.5\ cm^{-3}$	$n = 3\text{-}17\ cm^{-3}$
$T_i = 5\text{-}20$ kev	$T_i = 2\text{-}10$ kev	$T_i = 2\text{-}20$ eV
$T_i/T_e > 6$	T_i/T_e □ 6	$T_i/T_e \sim 0.3$

Mass of protons on nightside ~ 1 Tor

Cross Section of Magnetotail



Convection in the Plasma Sheet



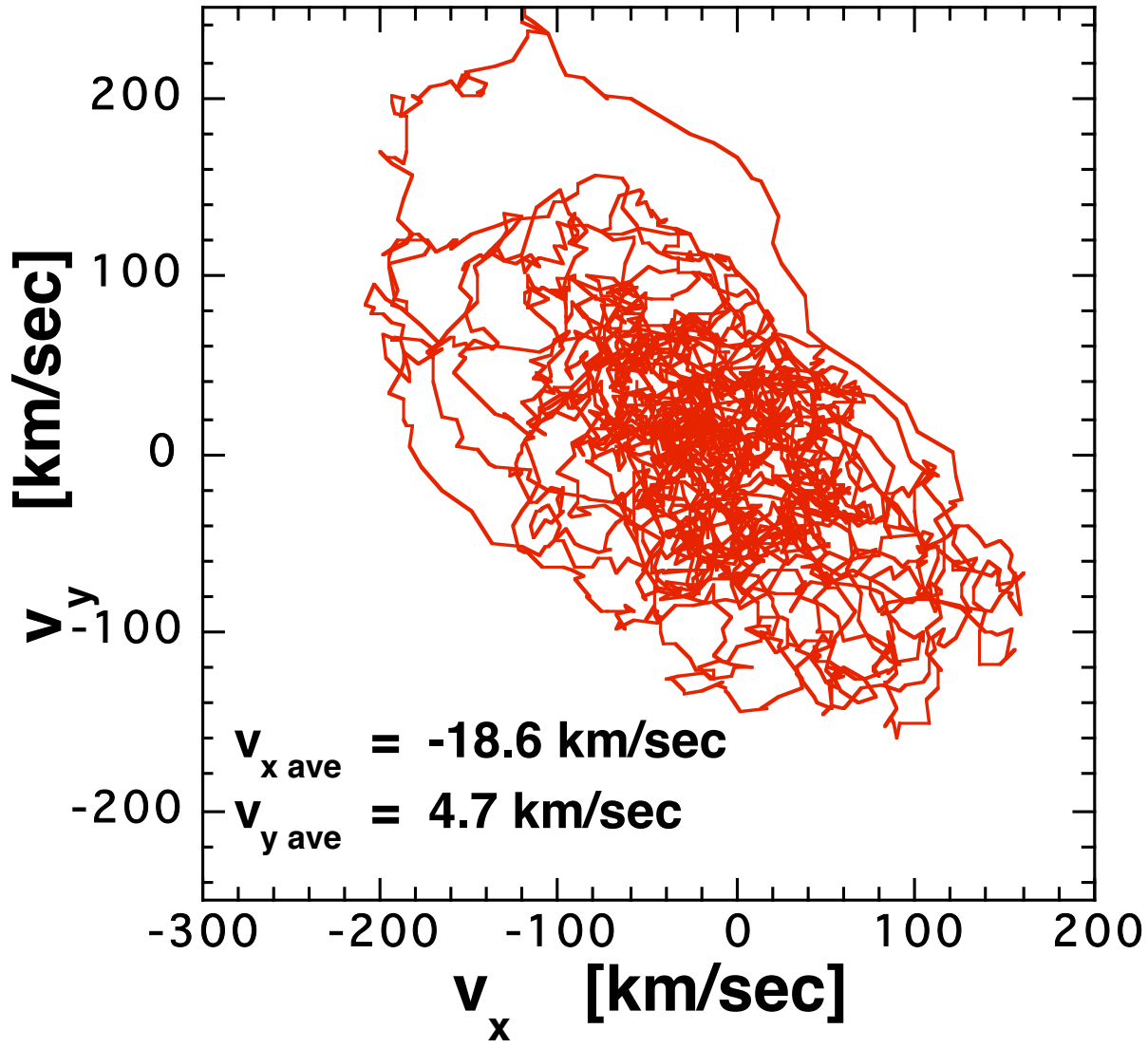
Magnetotail convection is decoupled from the ionosphere

Flows are turbulent

Magnetic field is tangled

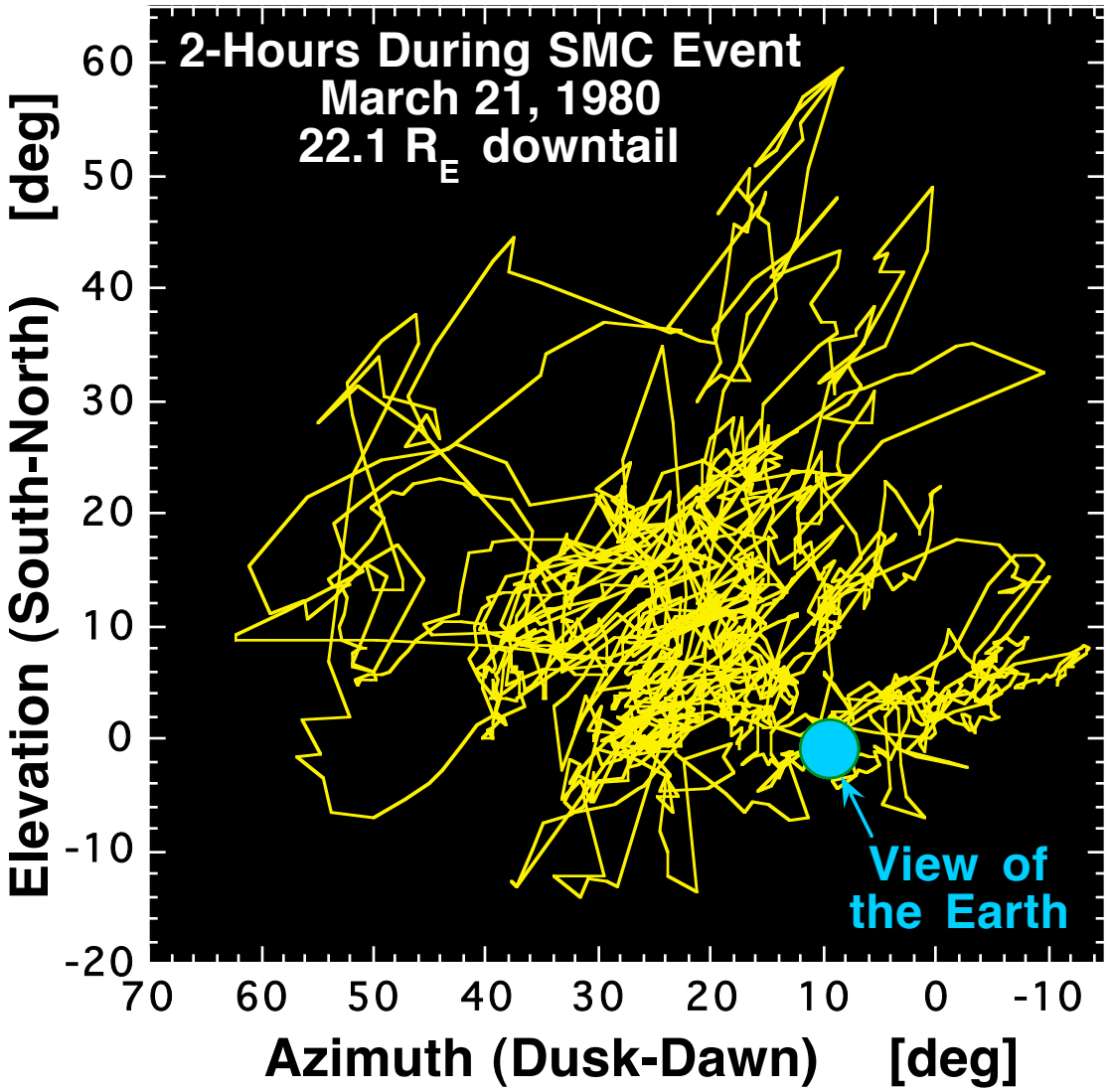
Sporadic reconnection events with BBFs

Plasma-Sheet Flows



Flow during a 2-hour interval

Fluctuations in the Magnetic-Field Direction



Suspected Plasma Sources for the Plasma Sheet

- **Solar Wind Via the LLBL**
- **Solar Wind Via the Mantle**
- **Ionospheric Outflows**
- **Recirculation of the Outer Plasmasphere**

Clues that the Solar Wind Is the Dominant Source

1) Correlations

Properties of the plasma sheet temporally track the properties of the solar wind [e.g. this talk].

2) Composition Measurements

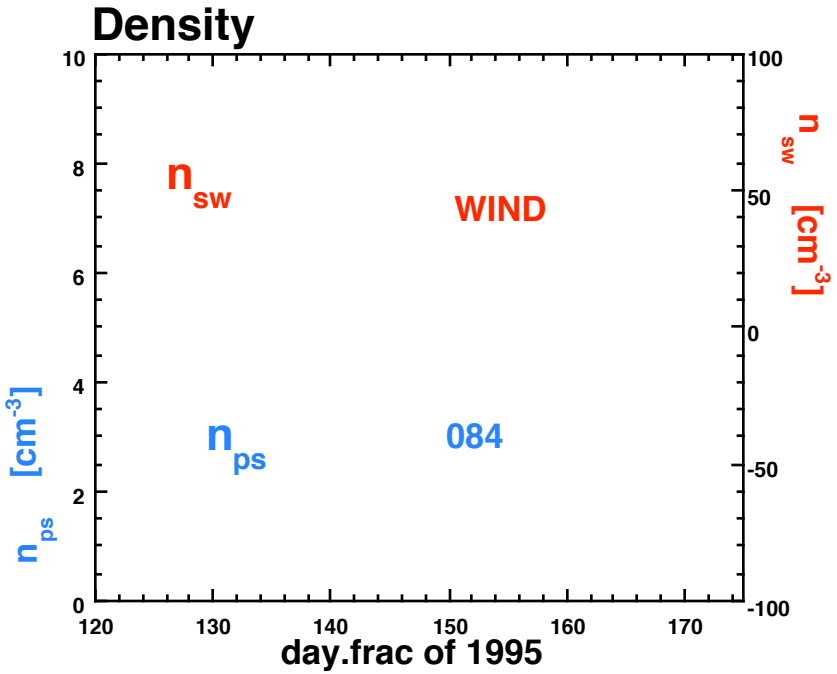
Except when geomagnetic activity is very high, the plasma sheet has solar-wind composition [e.g. *Lennartsson and Shelley, J.G.R., 91, 3061, 1986*].

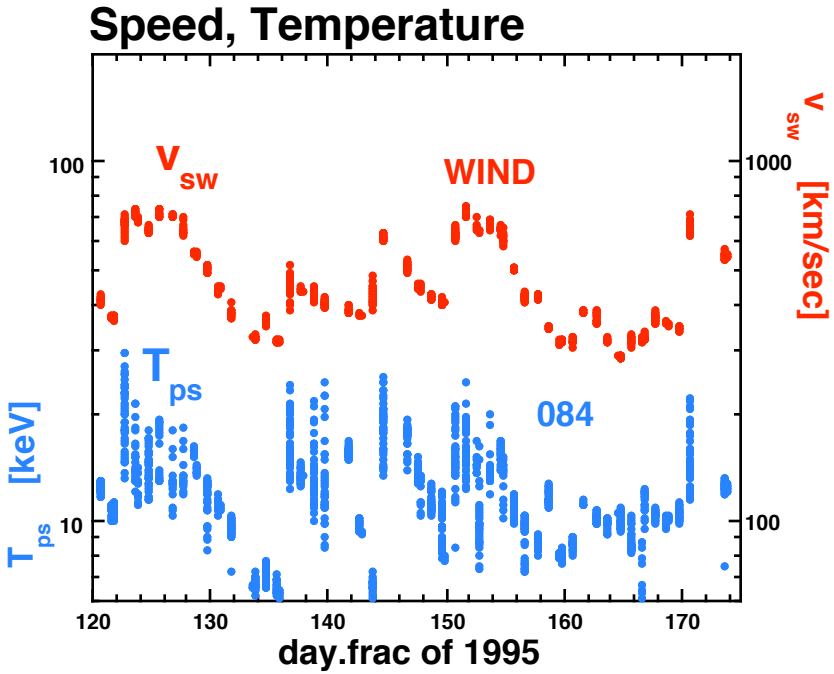
3) Temperature Ratio

In the magnetotail plasma sheet $T_i/T_e \approx 7$ [e.g. *Baumjohann, Space Sci. Rev. 64, 141, 1993*] (as in the magnetosheath), and T_i and T_e track each other (as in the magnetosheath).

The Properties of the Solar Wind and the Plasma Sheet Vary from Day to Day

(the flows vary from minute to minute)





Some Statistical Studies of Solar-Wind/Plasma-Sheet Coupling

Magnetic Field

Lui, A. T. Y., in *Magnetospheric Currents*, p. 158, AGU, 1984.

Tsurutani et al., *Geophys. Res. Lett., 11*, 1082, 1984.

Sergeyev, *Geomag. Aeron., 27*, 528, 1987.

Plasma

Terasawa et al., *Geophys. Res. Lett., 24*, 935, 1997.

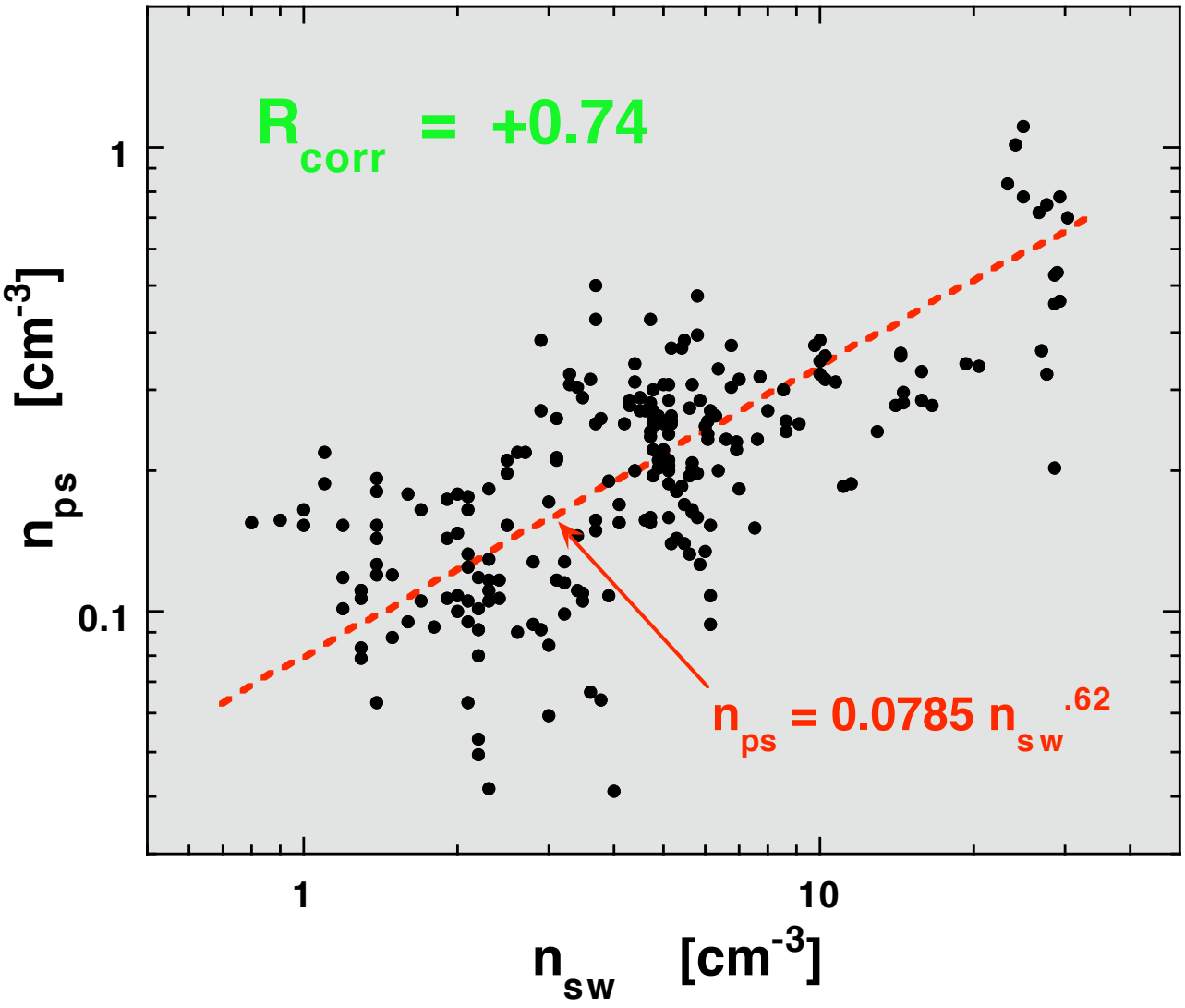
Borovsky et al., *J. Geophys. Res., 102*, 22089, 1987.

Kletzing et al., *J. Geophys. Res., 108*, 1360, 2003.

Plasma & Fields

Borovsky et al., *J. Geophys. Res., 103*, 17617, 1998.

Example Correlation: n_{sw} ? n_{ps}



magnetotail neutral-sheet crossings
zero time lag

Correlations between the Solar-Wind and the Plasma Sheet in the Magnetotail

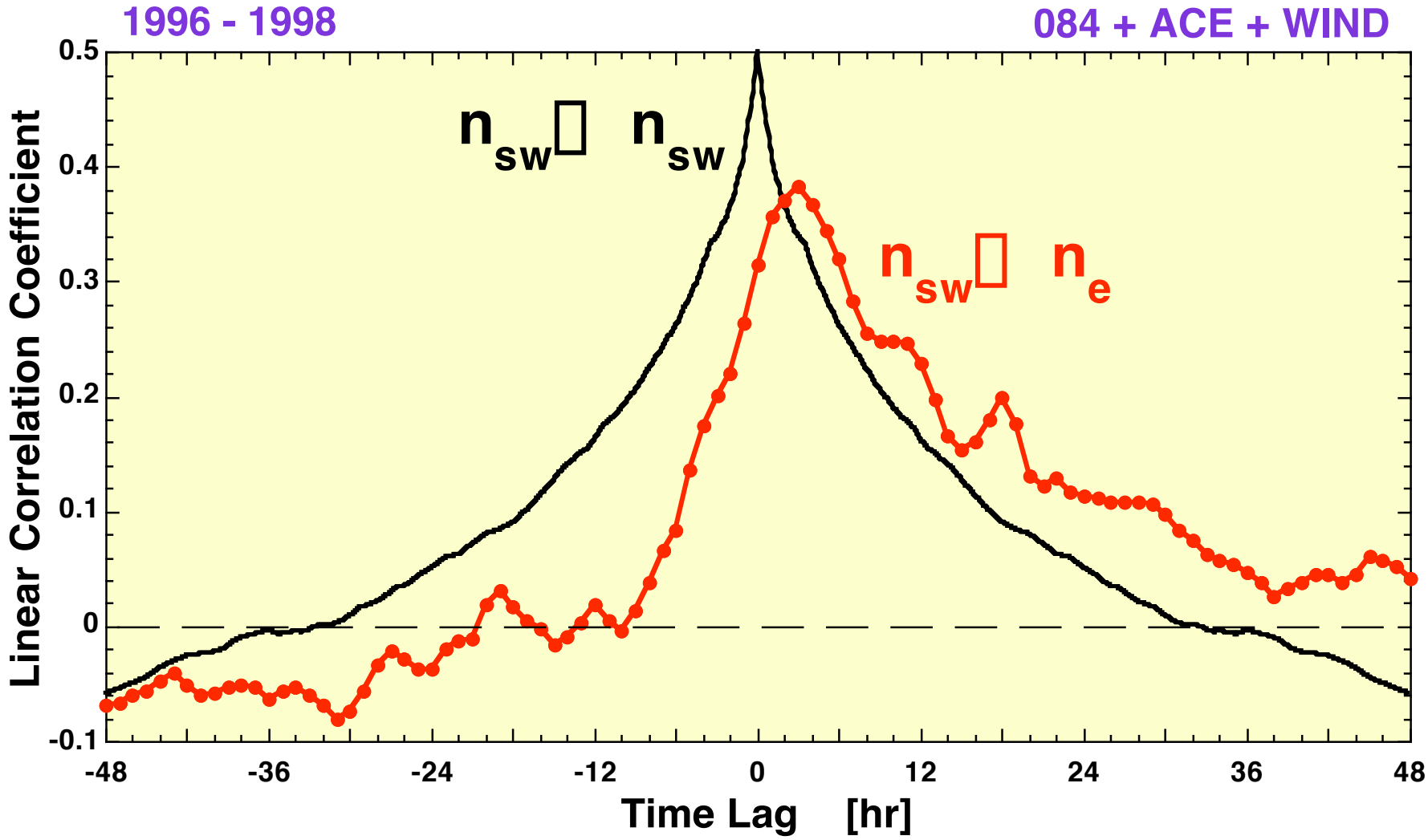
Relationship	R_{corr}	R_{corr}/R_{rand}	*Function*
$n_{sw} \rightarrow n_{ps}$	+74%	5.6	n_{ps} $n_{sw}^{.62}$
$v_{sw} \rightarrow T_{i\ ps}$	+54%	3.8	$T_{i\ ps}$ v_{sw}^{1}
$(\rho v^2)_{sw} \rightarrow (nkT)_{ps}$	+82%	6.1	$(nkT)_{ps}$ $(\rho v^2)_{sw}^{.73}$
$B_{y\ sw} \rightarrow B_{y\ ps}$	+66%*	3.6	$B_{y\ ps}$ $B_{y\ sw}$
$E_{y\ sw} \rightarrow E_{y\ ps}$	+36%*	1.6	?

zero time lag
**calm field*

Solar-Wind/Plasma-Sheet Coupling Is Via the Magnetosheath

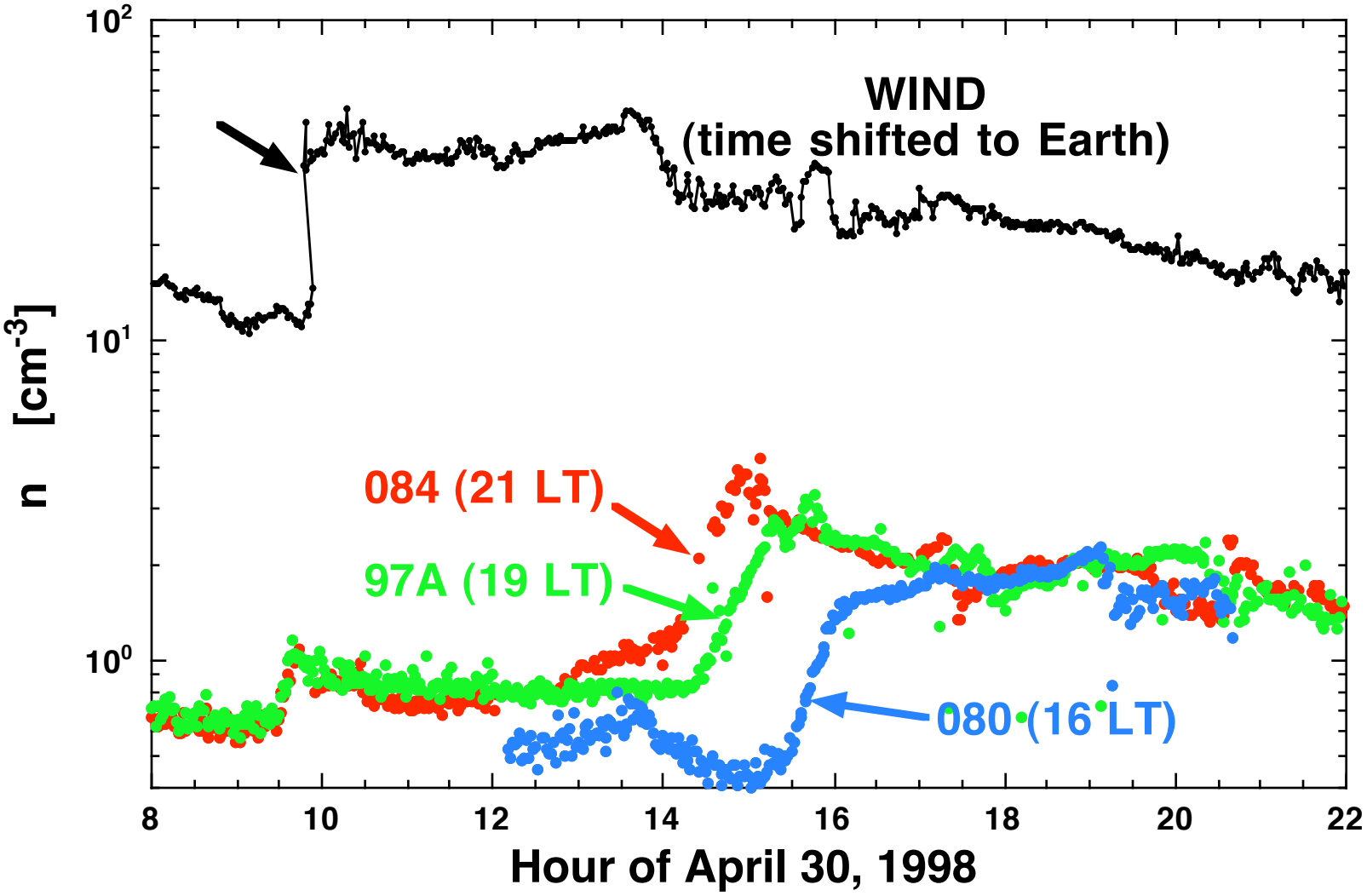
1. $n_{sw} \rightarrow n_{ms} \rightarrow n_{ps}$
2. $v_{sw} \rightarrow T_{i\,ms} \rightarrow T_{i\,ps}$
3. $B_{y\,sw} \rightarrow B_{y\,ms} \rightarrow B_{y\,ps}$
4. $E_{y\,sw} \rightarrow E_{y\,ms} \rightarrow E_{y\,ps}$
5. $v_{sw} \rightarrow T_{e\,ms} \rightarrow T_{e\,ps}$
6. Bow shock $\rightarrow (T_i/T_e)_{ms} \rightarrow (T_i/T_e)_{ps}$

Examining the Time Lag for Solar-Wind/Plasma-SheetCoupling

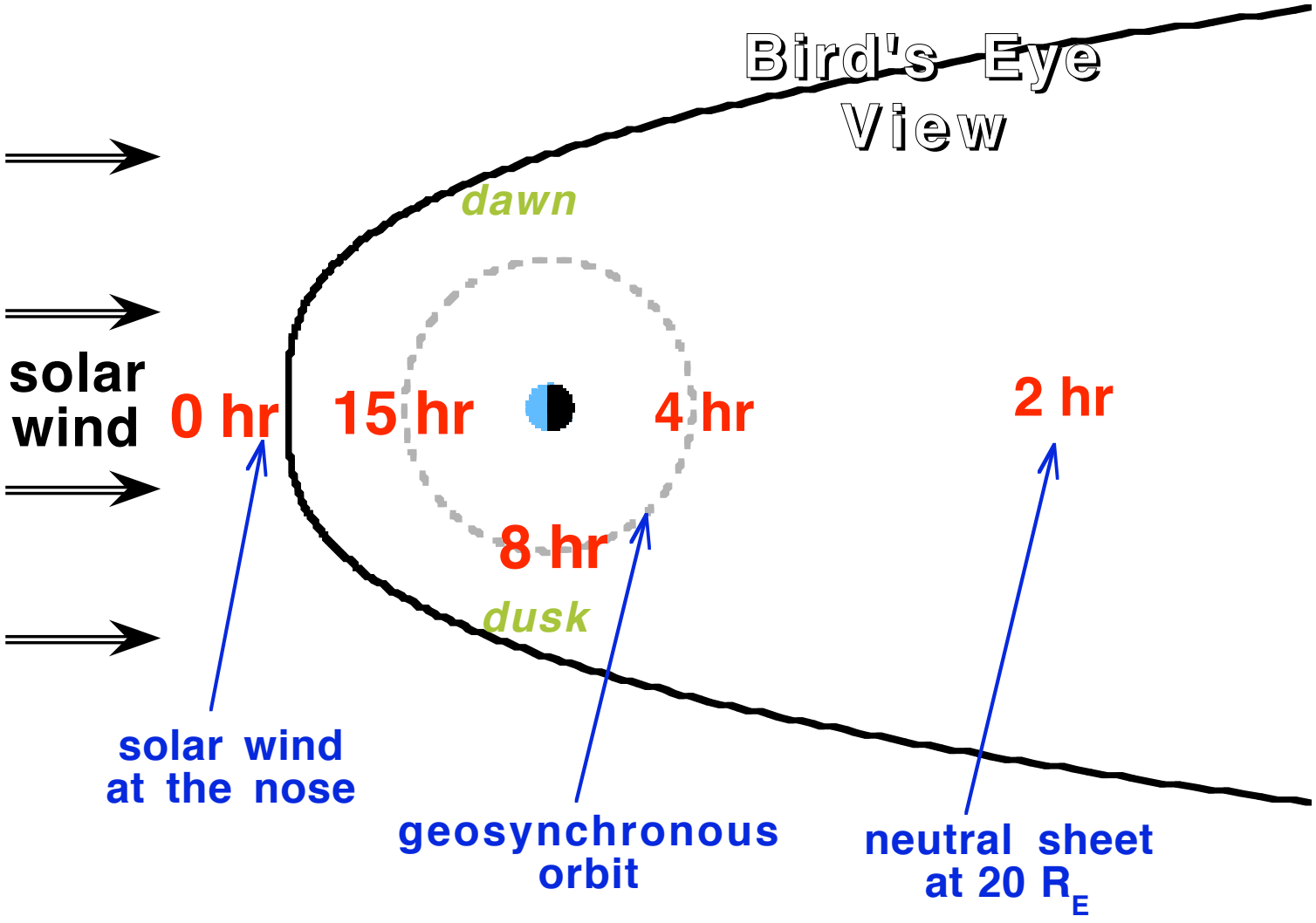


geosynchronous-orbit midnigh

Density Pulses Can Be Seen Moving from the Solar Wind into the Plasma Sheet



Mass-Transport Timescales from the Solar Wind into the Plasma Sheet



Rate of Flow of Solar-Wind Plasma through the Magnetosphere

Estimate 1:

1.1 tons of protons replaced every 4 hours:

4.6×10^{25} protons/sec

Estimate 2:

15 km/s earthward flow of 0.5 cm^{-3} over 6×20 R_E^2 cross section:

3.6×10^{25} protons/sec

Estimate 3:

Transport rate through the dipole is twice the loss rate

Global proton aurora is 9×10^{24} protons/sec

Global charge-exchange rate is $>1 \times 10^{23}$ protons/sec

(thanks to Kunihiro Keika and Pontus Brandt

1.8×10^{25} protons/sec

Earth's Effective Cross Section for Capture of Solar-Wind Plasma

Proton transport rate through the magnetosphere is

4×10^{25} protons/sec

Solar-wind proton flux at 1 AU is

3×10^{8} protons/cm^2/sec

Effective entry area is

1.3×10^{7} km^2 **(about twice the area of Australia)**

This is one proton in 4000

****Note that the flow of plasma downtail may be**
twice the flow through the magnetosphere

Summary (So Far)

- **Correlations between the plasma sheet's properties and the solar wind are well established.**
- **Plasma sheet is largely magnetosheath plasma.**
- **Transport times from solar wind are (normal activity)**

  2 hours to center of the tail

  4 hours to the nightside of the dipole

  15 hours to dayside magnetosphere
- **Rate of solar-wind-plasma flow through magnetosphere is ~4□10^{15} protons/sec.**

What We Don't Know

- **Entry mechanisms: magnetosheath to plasma sheet**
- **Pathways of magnetosheath entry**
- **Understanding of solar-wind control of magnetosheath entry**
- **Quantification of magnetosheath entry and transport from first principles**
- **Whether the T_i/T_e=7 ratio is (a) preserved through capture or (b) recreated in the plasma sheet**
- **Where the plasmaspheric plasma goes**

We Have Not Discussed

The Cold Dense Plasma Sheet

A northward-IMF interval, followed by southward IMF.

Magnetosheath builds up in outer magnetosphere, then is convected in

Fujimoto et al., Space Sci. Rev., 80, 325, 1997

Thomsen Talk Today

Solar-Wind Control of Ionospheric Outflows

vB_z (geomagnetic-activity) dependence

Yau and Andre, Space Sci. Rev., 80, 1, 1997

Solar-wind-pressure dependence

Elliott et al., J. Geophys. Res., 106, 6067, 2001

To Get the Role of the Plasma Sheet Right, What Does a Model Need to Get Right?

First Order:

- Location
- Density profile
- Temperature profile
- Convection pattern
- Density-pulse movements

Second Order:

- Field disorder
- Flow fluctuations*

*If flow fluctuations prove to be fundamental for transport then getting their properties right becomes "First Order"