什麼是電漿?

加熱　　加熱　　加熱

固體 →→→ 液體 →→→ 氣體 →→→ 電漿

當氣體被高能光源或其他高能粒子撞擊後游離(ionization)，形成一種完全游離或部份游離的氣體，稱之為電漿態(plasma)。

帶電粒子的數量必須夠多到具有統計上的意義，因而可測其密度、溫度，正、負電荷數量幾乎相等，使得電漿整體呈現近似電中性(quasi-neutrality)的狀態，並使得遠距離的作用力成為影響電漿集體行為(collective behavior)的主因，但其密度須夠低或碰撞頻率要夠低，使得游離後的氣體不易重新結合(recombination)成為中性粒子，而能保持游離狀態。

紫外線、X光、伽馬射線等短波的電磁波能量，可提供中性粒子的游離能，造成光游離現象。但不論可見光的強度多強，都無法游離氣體。

電漿是物質的第四態，宇宙中99%的物質是電漿態。

霓虹燈招牌

http://upload.wikimedia.org/wikipedia/en/2/2a/PikePlaceMarket.jpg

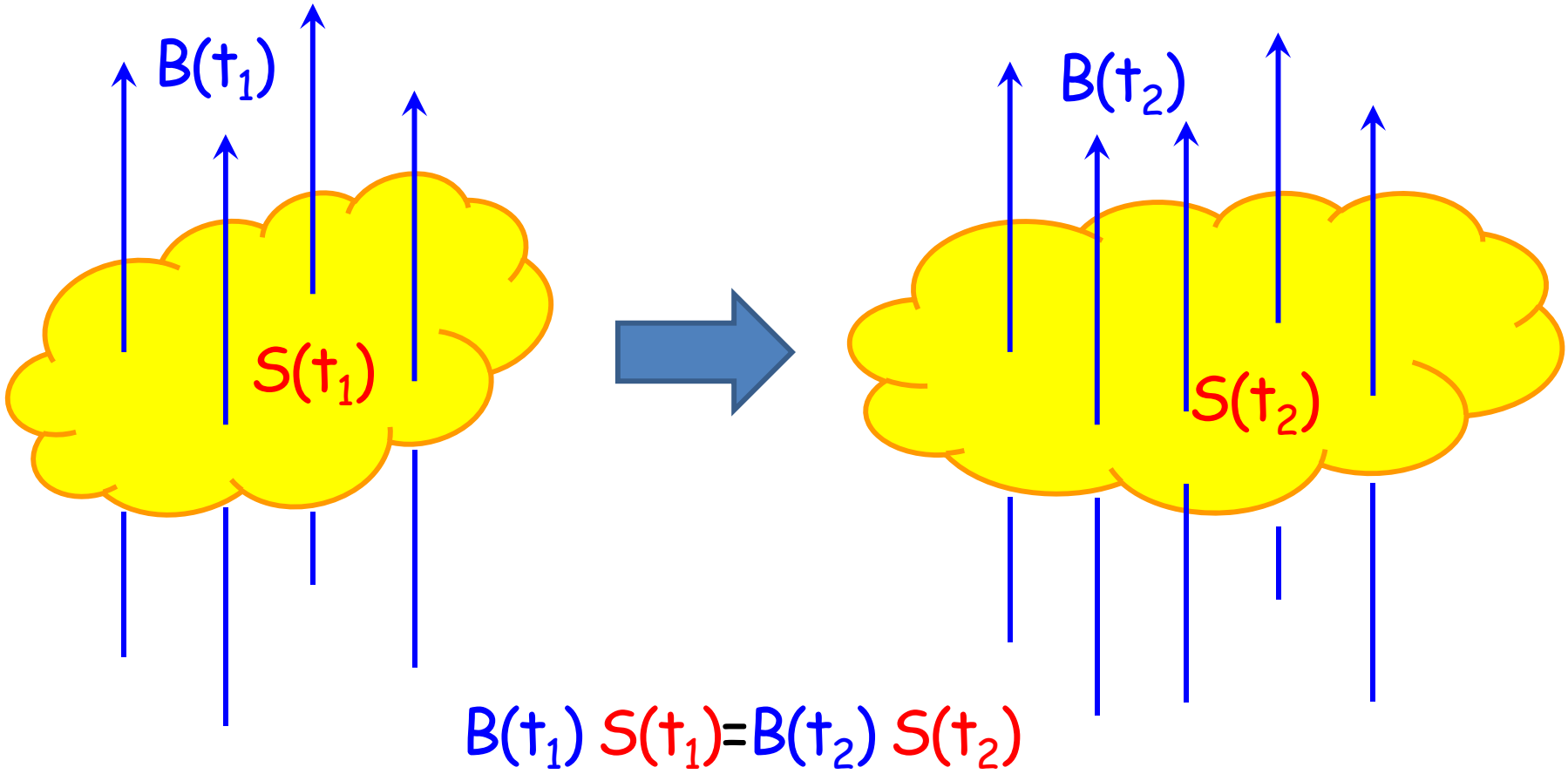

閃電

http://upload.wikimedia.org/wikipedia/commons/4/4b/Lightning3.jpg


極光

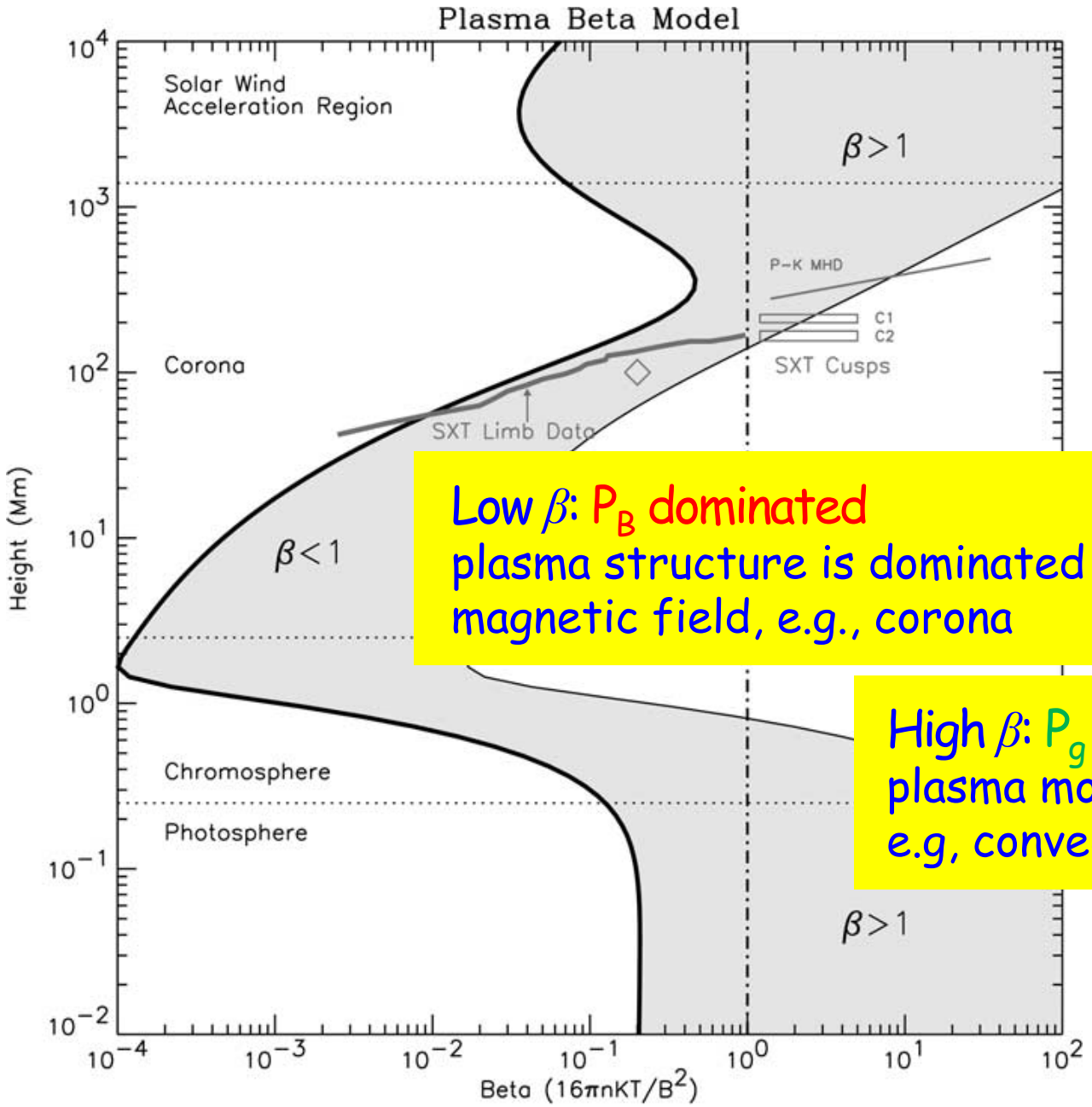
http://upload.wikimedia.org/wikipedia/commons/a/a9/Polarlicht.jpg

Frozen-in Magnetic Flux



由不同fluid elements所圍繞的磁通量，雖然fluid elements在流動後，可能變形或圍繞的面積有很大的改變，但是所圍繞的磁通量不變，這就好像這些磁力線被凍結(frozen-in)在每個電漿團上。成立條件:導電率非常高的電漿。

Plasma Beta



plasma thermal pressure P_g

$$\beta = \frac{nkT}{\frac{B^2}{2\mu_0}}$$

magnetic pressure P_B

Low β: P_B dominated
plasma structure is dominated by the topology of magnetic field, e.g., corona

High β: P_g dominated
plasma motion drags the magnetic field, e.g, convection zone, solar wind

β<<1: cold plasma

β>=1: warm plasma

Gary G. A. (2001) SoPh, 203, 71

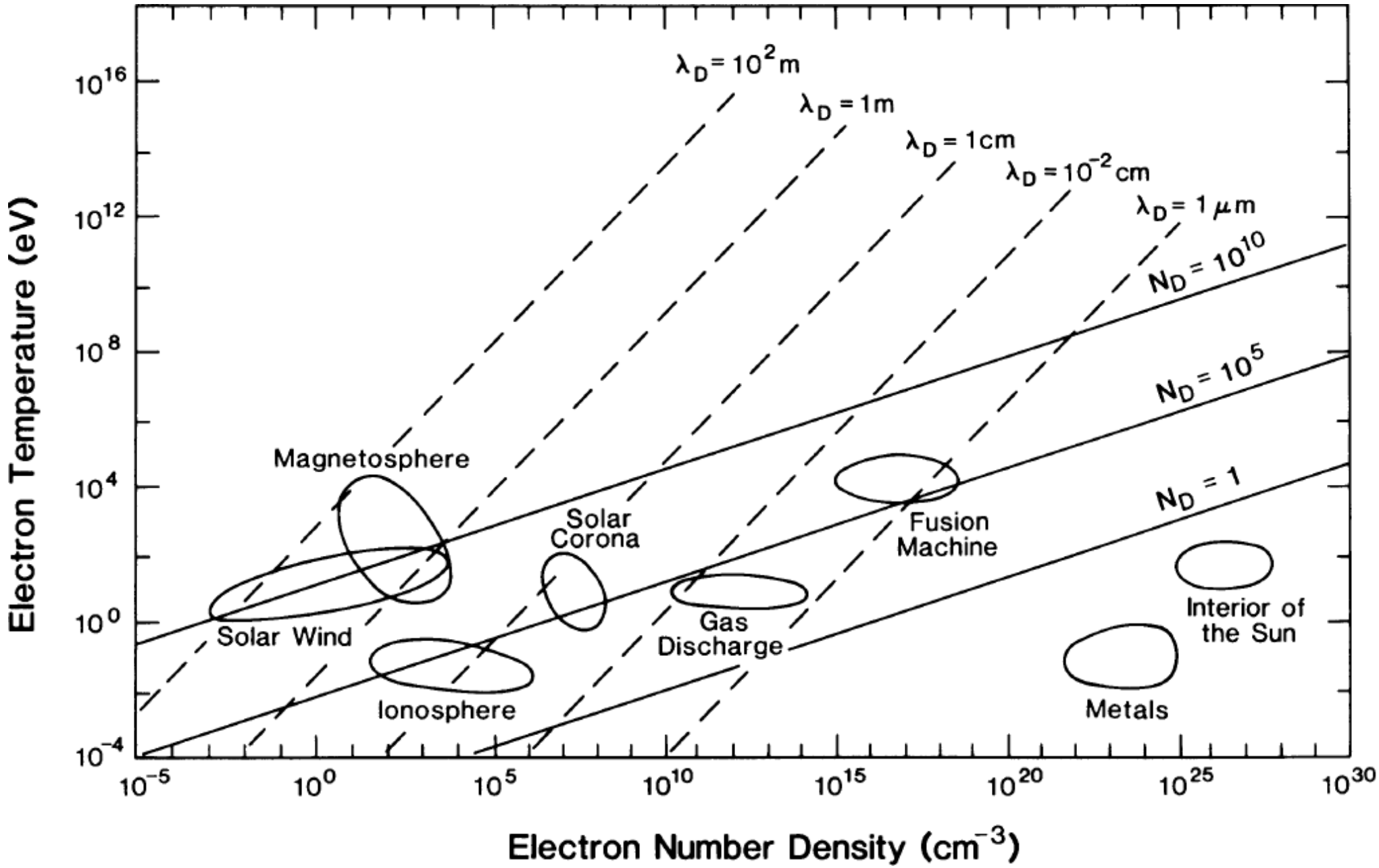


Fig. 2.4 in M. G. Kivelson and C. T. Russell (1995)

太陽風

太陽風是一種由太陽表面吹出來的電漿流，電子、質子與各類帶電原子核或離子雖然各自分開運動，但其整體還是保持電中性。太陽風可說是太陽大氣的延伸，其平均速率約為400 km/s。

太陽風中不但有電漿，由於太陽本身具有磁場，當太陽風吹出時，磁場亦會被太陽風帶著跑，即所謂的行星際磁場(IMF; Interplanetary Magnetic Field)。

太陽風大約在距離太陽不到0.1 AU處就已經加速成為超音速的電漿流，因此當太陽風吹過各行星時，會在行星的向陽面形成一激震波，稱之為艏震波(Bow Shock)。

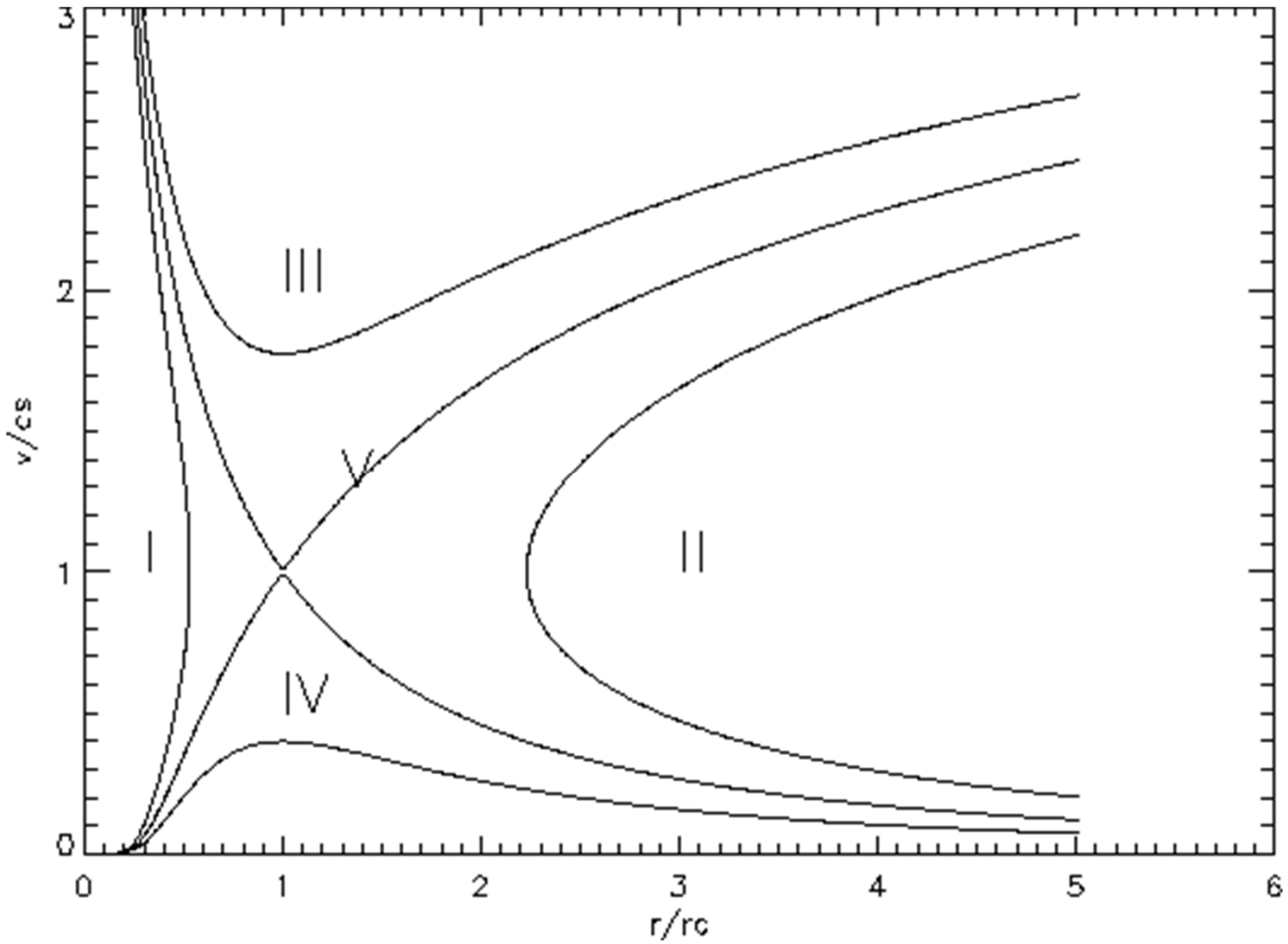
Table 1. Statistical Properties of the Solar Wind at 1 AU

Parameter	Mean	STD	Most Probable	Median	5-95% Range
n (/cm^3)	8.7	6.6	5.0	6.9	3.0 – 20.0
V_{sw} (km/s)	468	116	375	442	320 – 710
B (nT)	6.2	2.9	5.1	5.6	2.2 – 9.9
A(He)	0.047	0.019	0.048	0.047	0.017 – 0.078
T_p (x10^{5}K)	1.2	0.9	0.5	0.95	0.1 – 3.0
T_e (x10^{5}K)	1.4	0.4	1.2	1.33	0.9 – 2.0
T_α (x10^{5}K)	5.8	5.0	1.2	4.5	0.6 – 15.5
T_e/T_p	1.9	1.6	0.7	1.5	0.37 – 5.0
T_α/T_p	4.9	1.8	4.8	4.7	2.3 – 7.5
nV_{sw} (x10^8/cm^{2}s)	3.8	2.4	2.6	3.1	1.5 – 7.8
C_s (km/s)	63	15	59	61	41 – 91
C_A (km/s)	50	24	50	46	30 - 100

n is proton density, V_{sw} is solar wind speed, B is magnetic field strength, A(He) is He^{++}/H^+ ratio, T_p is proton temperature, T_e is electron temperature, T_α is alpha particle temperature, C_s is sound speed, C_A is Alfven speed.

The Sun yearly loses ~6.8 x 10^{19} g to the solar wind, a very small fraction of the total solar mass of ~2 x 10^{33} g.

Parker's Solar Wind Model



Solution I & II are doubled valued and thus are unphysical.

Solution III has supersonic speed at the Sun which is not observed.

Observations show that Solution V is correct.

http://www-solar.mcs.st-andrews.ac.uk/~alan/sun_course/Chapter6/img51.gif

Parker's Solar Wind Model

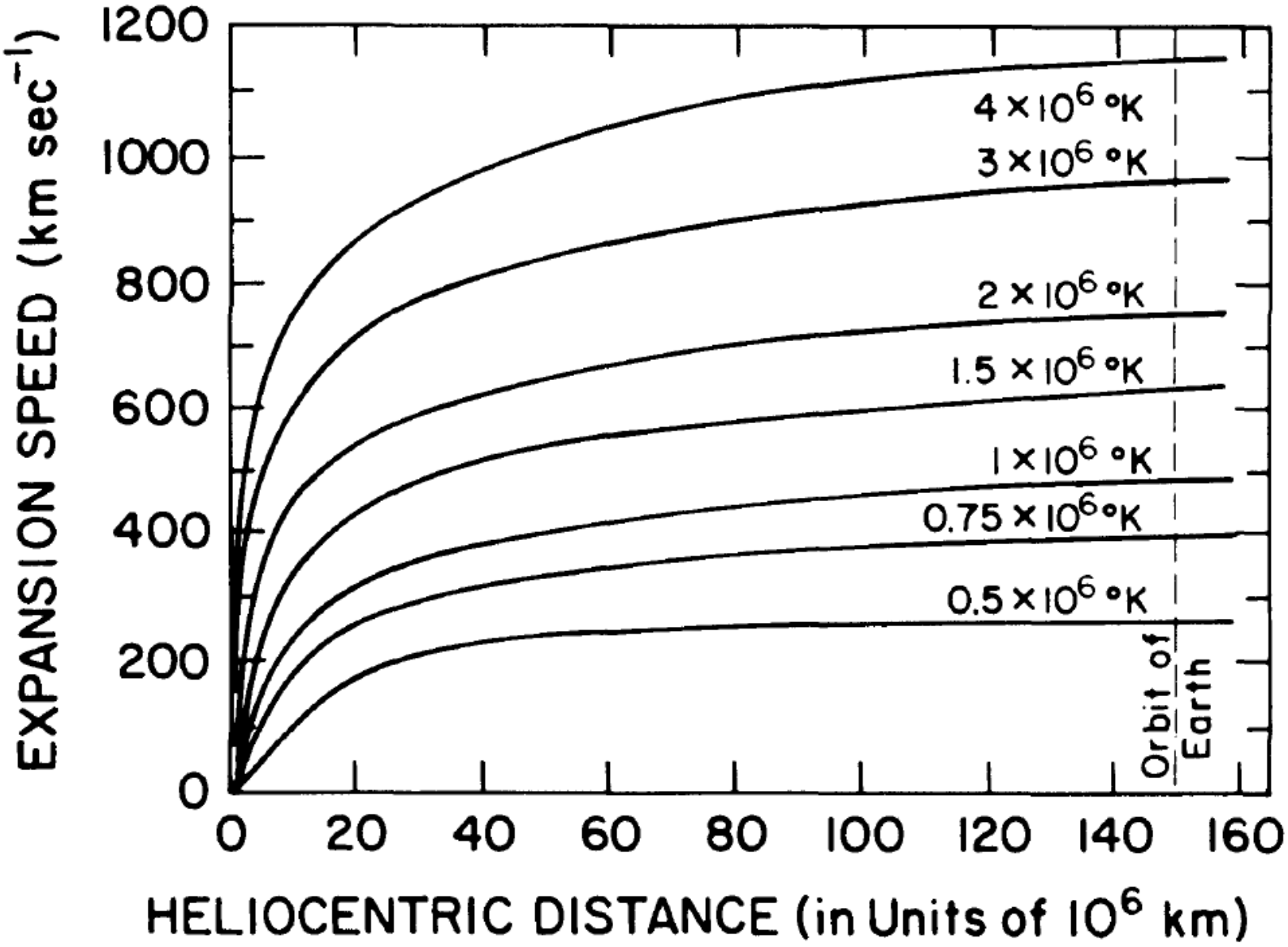
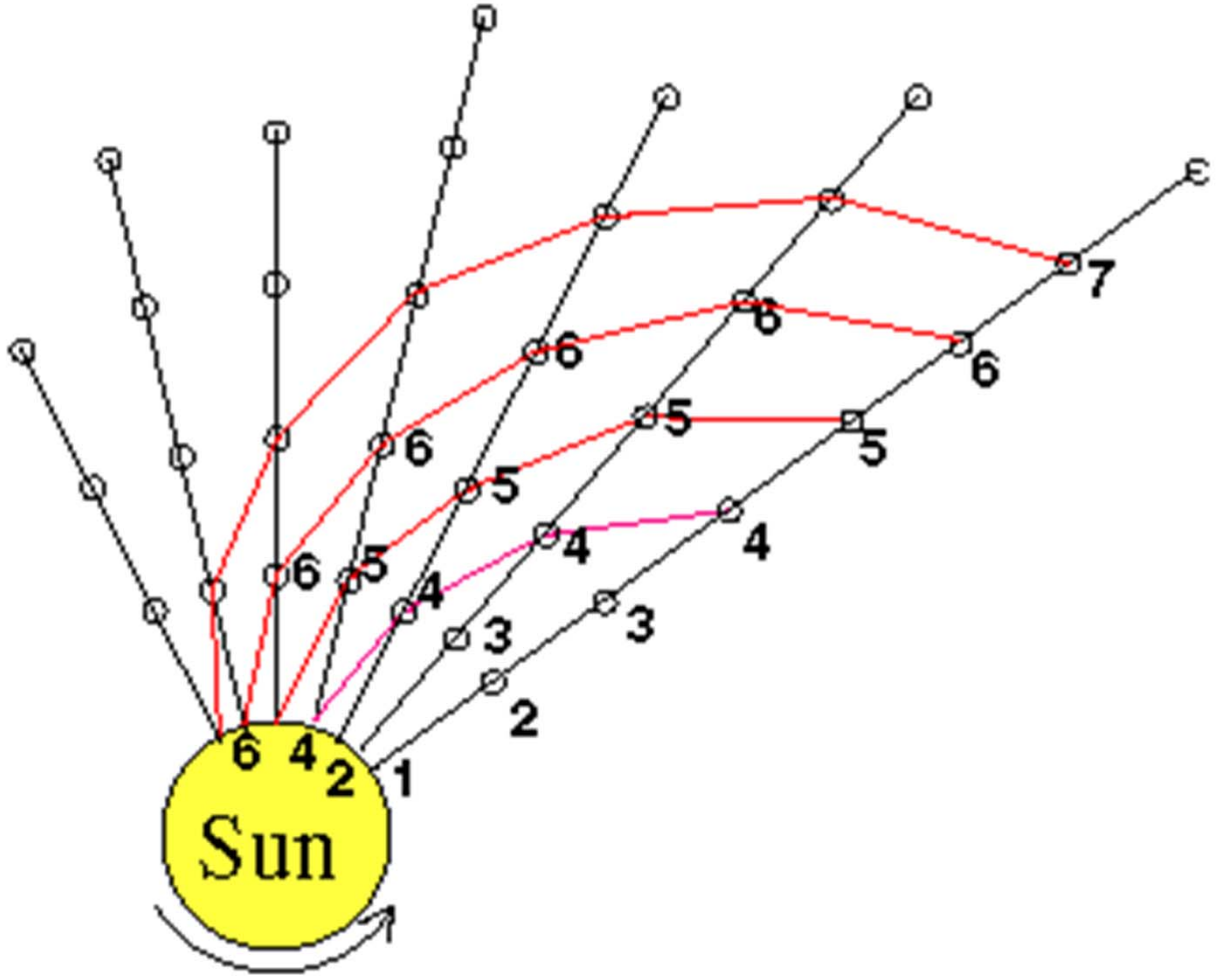


Fig. 4.3 in M. G. Kivelson and C. T. Russell (1995)

Parker Spiral

當太陽風吹出時，磁場會被太陽風拉著跑，由於太陽自轉，太陽磁場會以螺旋結構(稱之為Parker Spiral)分佈於太陽系中。



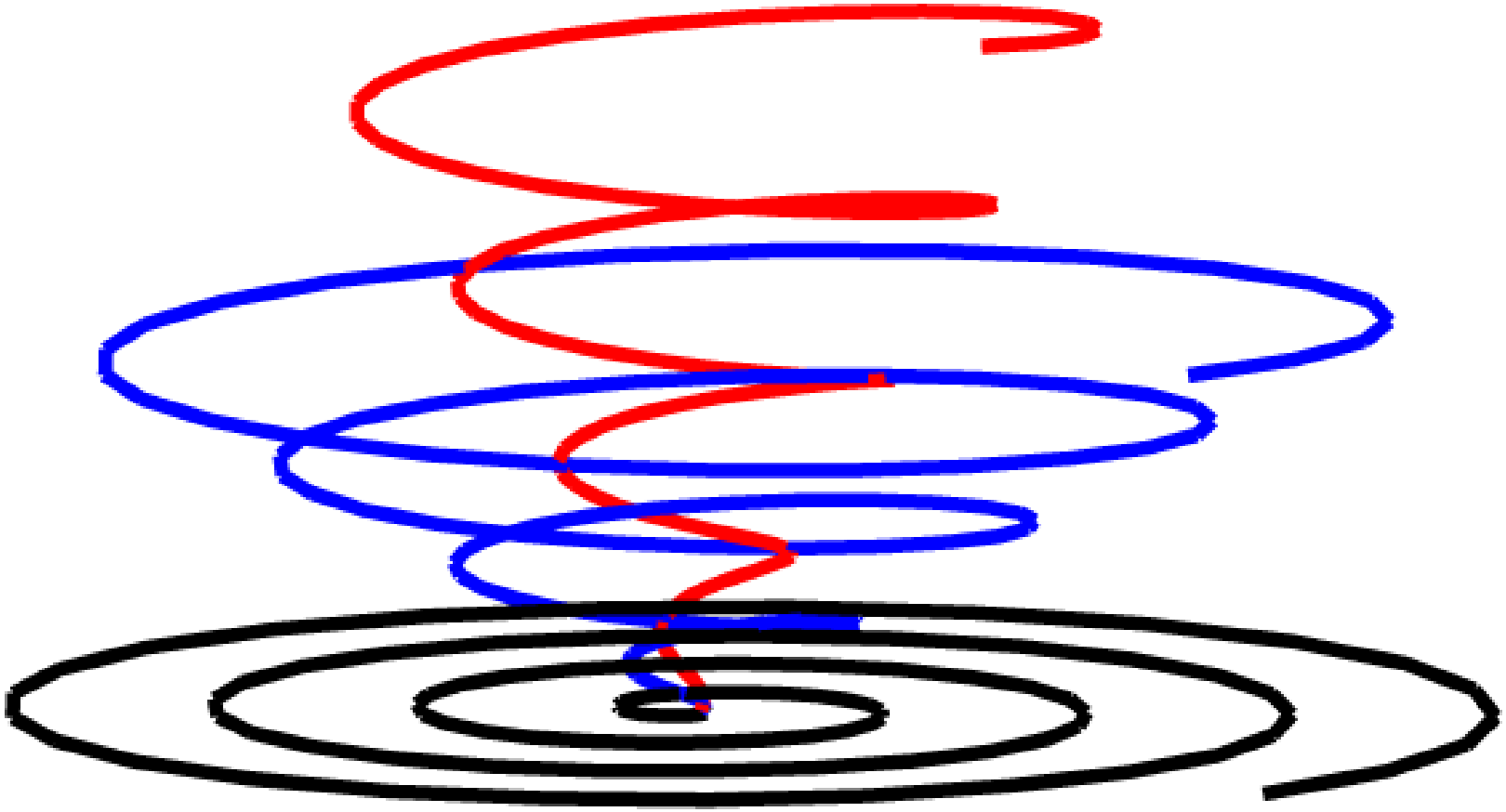
http://www.phy6.org/Education/wimfproj.html

低速太陽風

高速太陽風

Parker Spiral

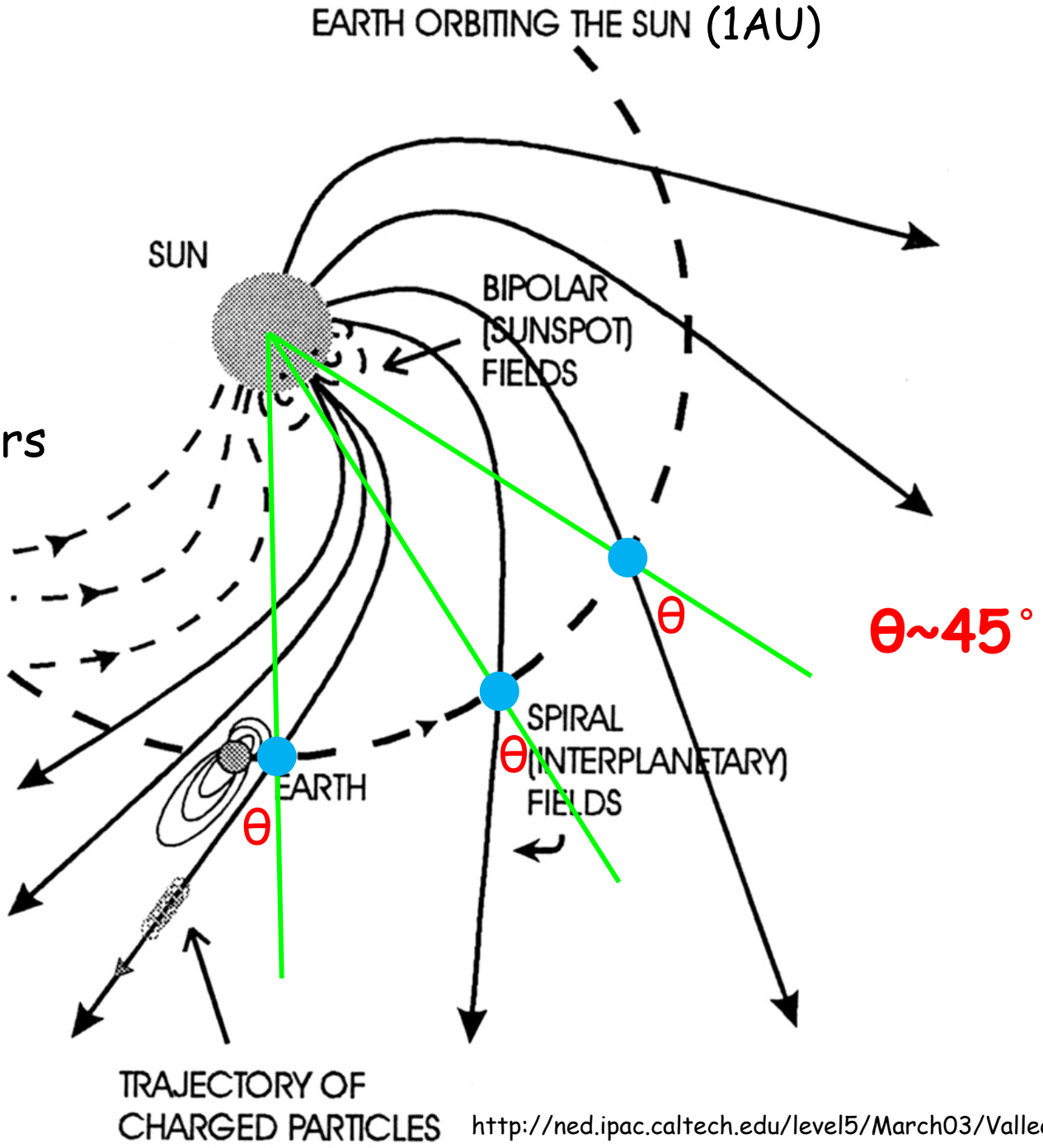
Ideal Parker spiral magnetic field lines between 0 and 25 AU for a solar wind speed of 450 km s^{-1}. Black, blue, and red lines show heliographic latitudes of 0, 30, and 60 degrees, respectively.



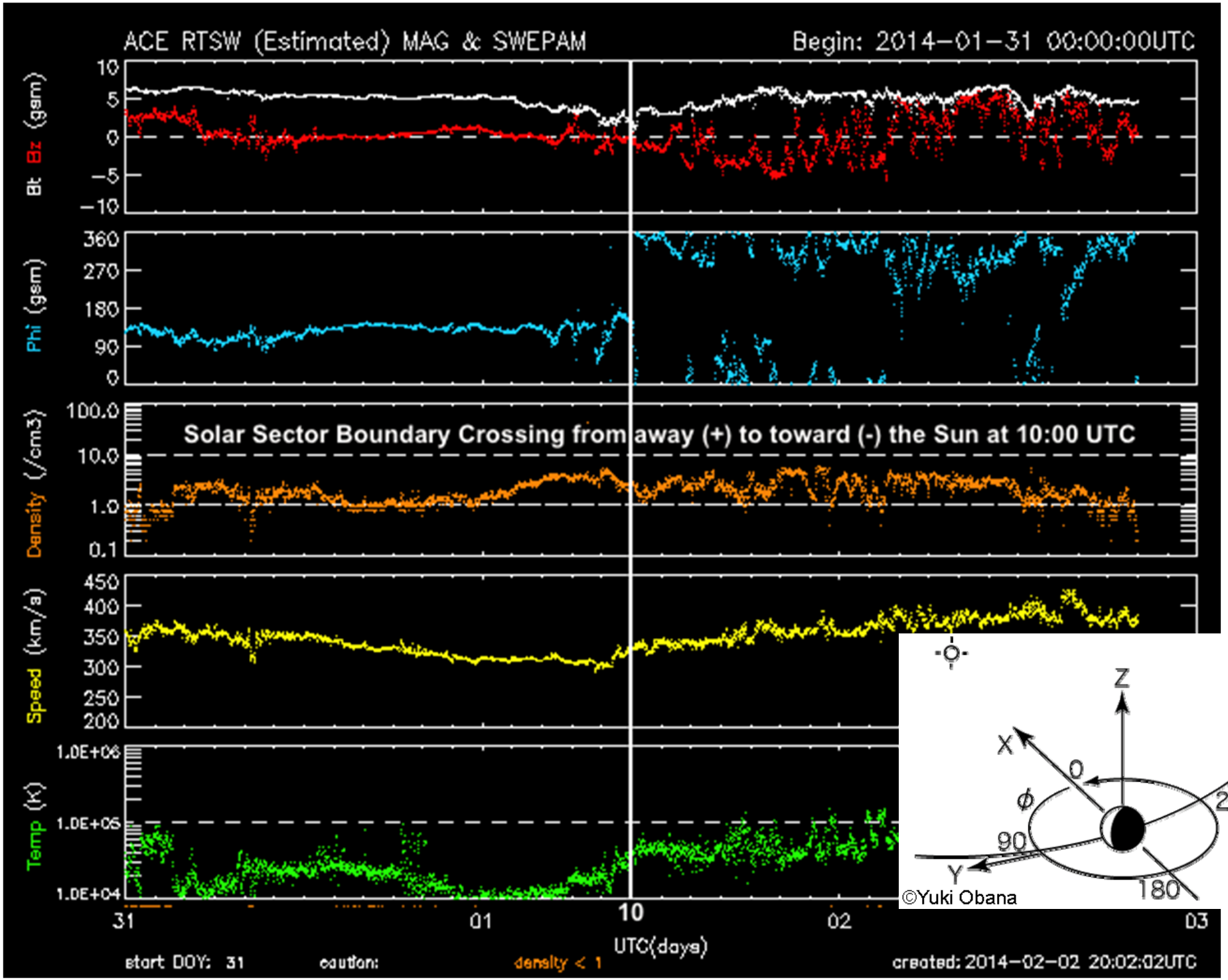
http://solarphysics.livingreviews.org/Articles/lrsp-2013-5/fig_3.html

Magnetic Sector Structure

magnetic sectors

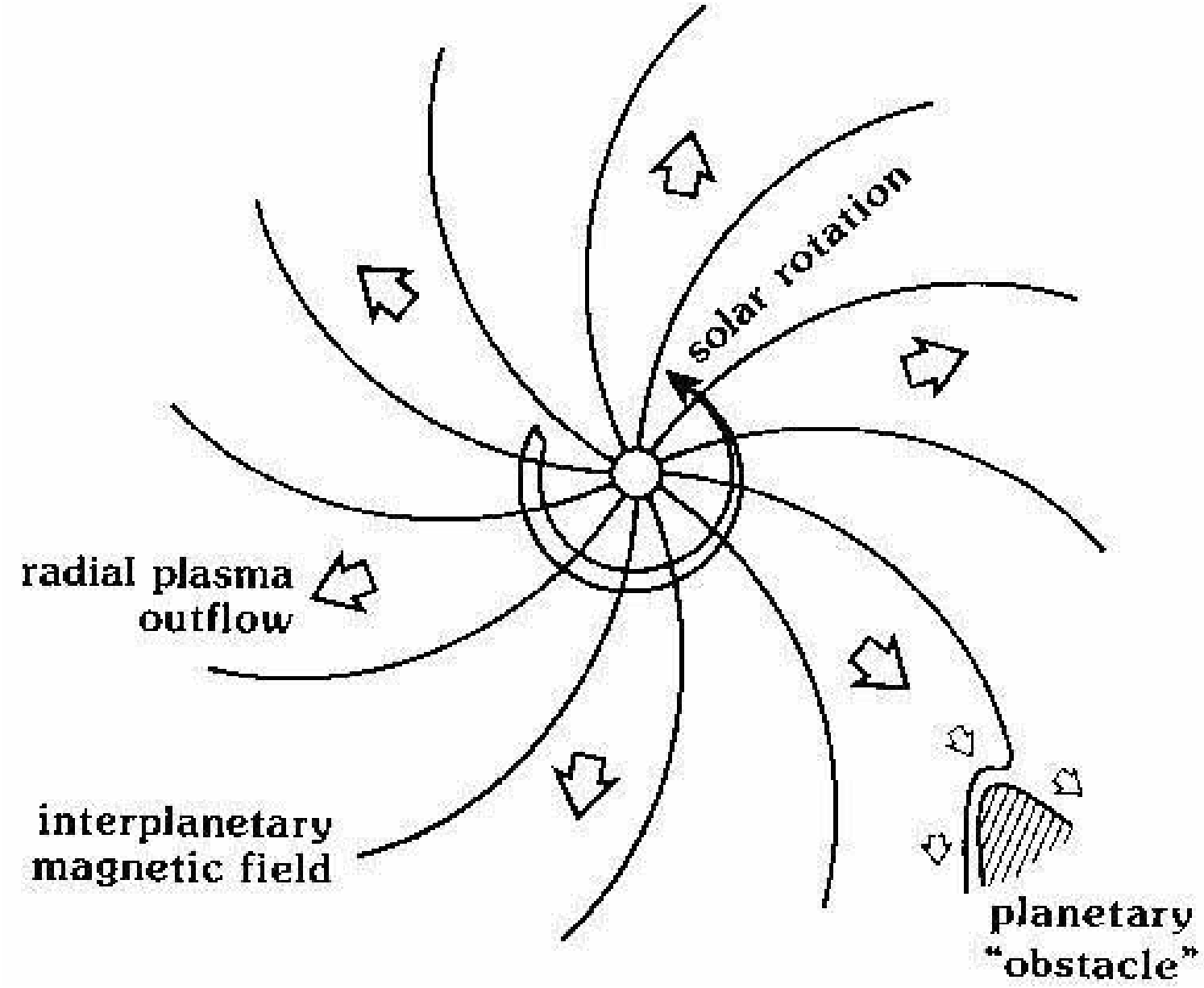


http://ned.ipac.caltech.edu/level5/March03/Vallee2/Figures/figure5.jpg



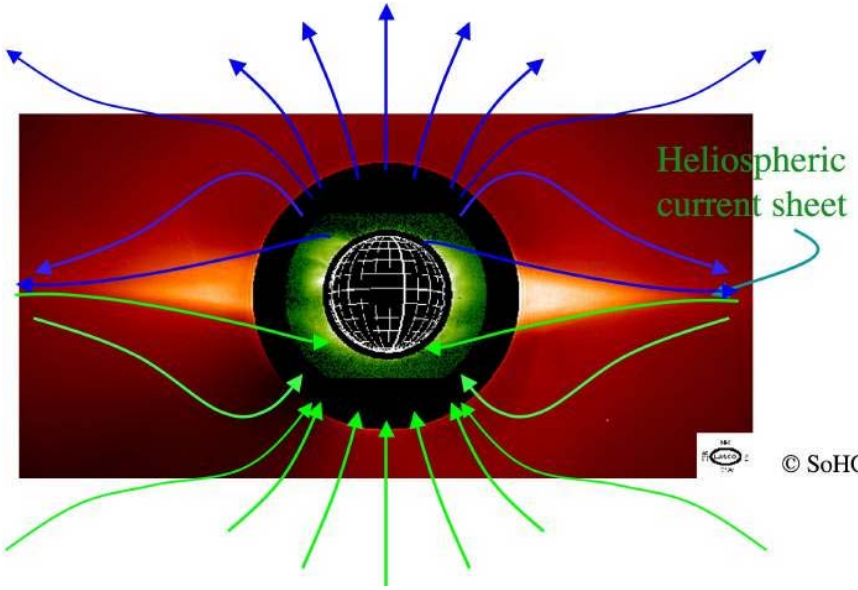
http://www.suspiciousObserverscollective.org/1/post/2014/02/solar-sector-boundary-crossing-on-february-1st-2014-research-notes.html

SOLAR WIND

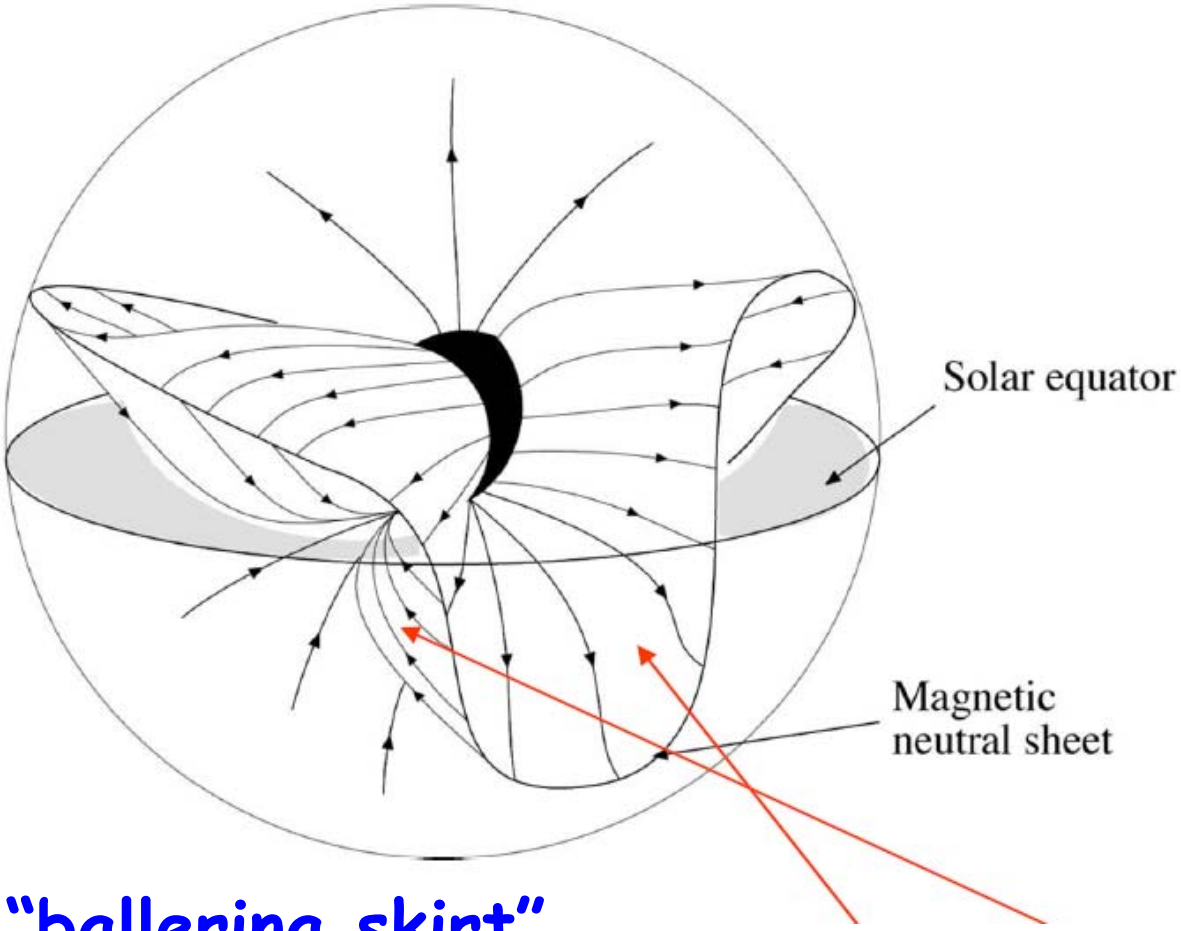


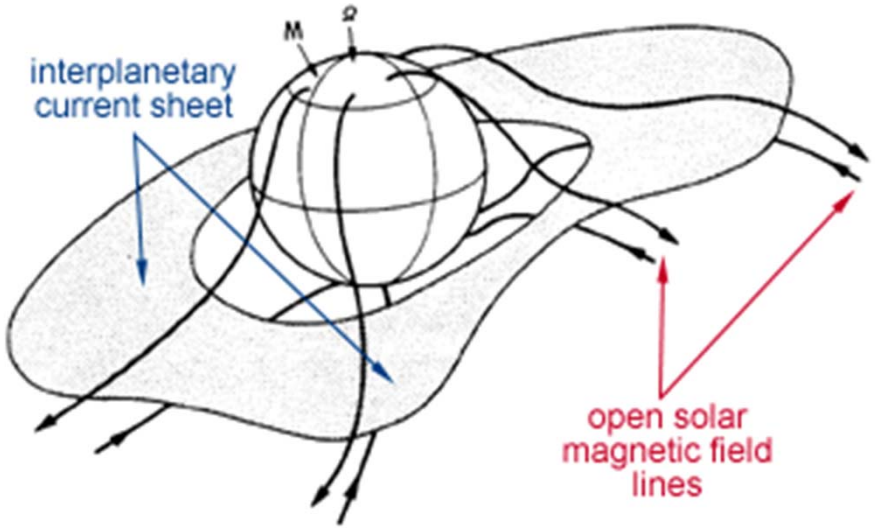
http://pwg.gsfc.nasa.gov/istp/outreach/images/Gusts/windsprl.jpg

Heliospheric Current Sheet



http://www.nmdb.eu/?q=node/135





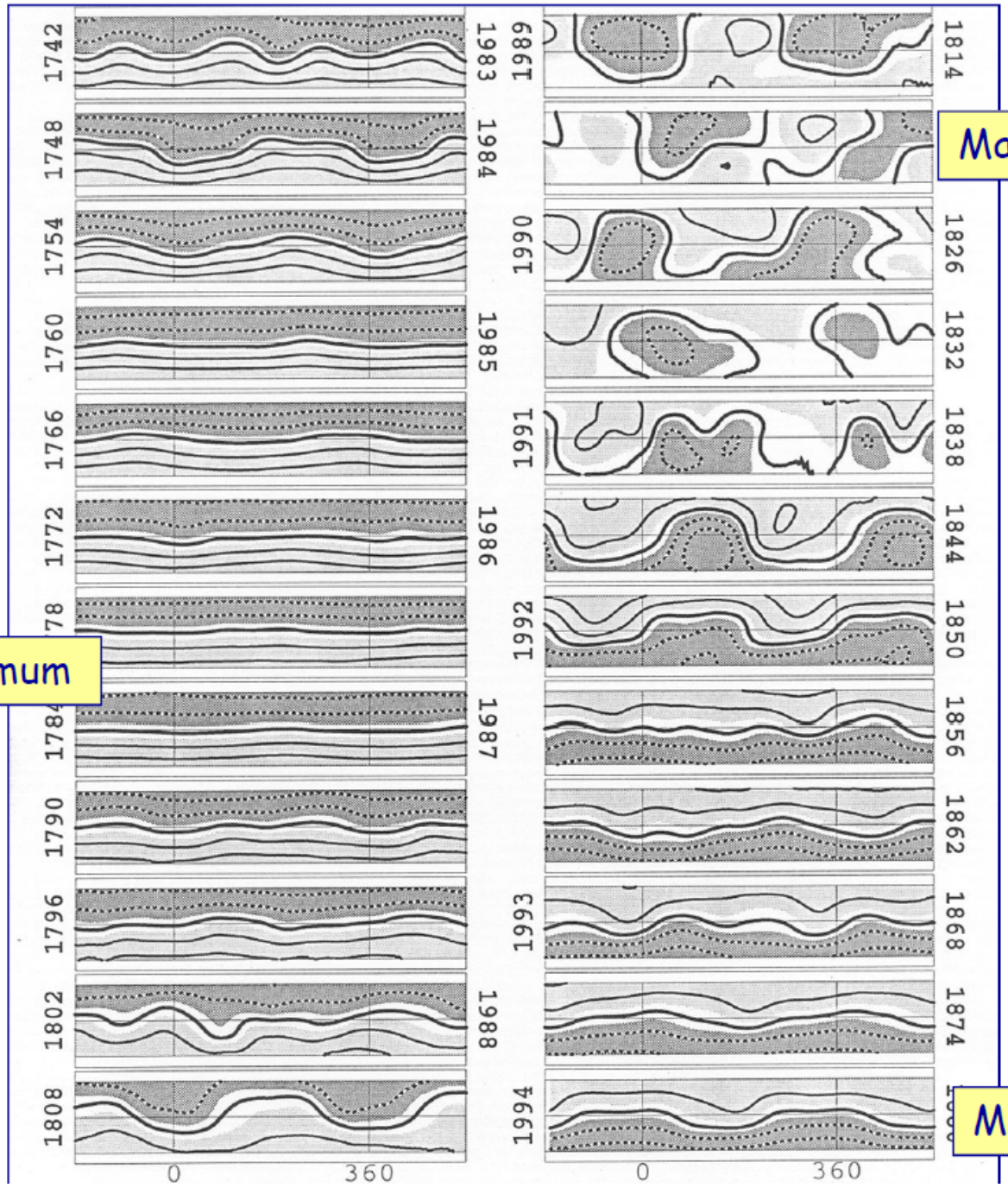
http://pluto.space.swri.edu/image/glossary/IMF.html

"ballerina skirt"

The Earth can be "toward" sector or in "away" sector

http://theory.physics.helsinki.fi~plasmainfo.html

The ballerina dancing through the solar cycle



Minimum

Maximum

Minimum

The magnetic topology of the large-scale heliosphere

At activity maximum, the ballerina skirt flips over, and the magnetic polarity is then reversed at next minimum. Thus, the magnetic cycle of the sun (the "Hale-cycle") takes 22 years!

Hoeksema, 1995

http://theory.physics.helsinki.fi~plasmainfo.html