Uncovering the Global Slow Solar Wind

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Motivation

The heliosphere consists of three types of solar wind:

Fast wind
(Solar wind from coronal holes)

Fast soalr wind originates from cool coronal holes.

CMEs
(Transient flows)

Interplanetary CMEs (or, ICMEs) are associated with their solar causes.

Slow solar wind
(associated with streamers)

?

There is no agreement origin of slow solar wind so far.

Motivation

Slow solar wind is very important in the heliosphere.

- Slow solar wind engulfs the Earth during a large fraction of time.
- Slow solar wind exhibits ionic and elemental compositions that clearly distinguish it from fast wind, seemingly excluding a single source for both wind-types.

- **Why the properties of slow solar wind are different from the other types of wind ?**
- **What is the contribution of slow solar wind ?**
- **What is the origin of slow solar wind ?**

……

Abstract

- We use ULYSSES & ACE about 10 years data to explore the properties of slow solar wind.
- We first develop a method to distinguish solar wind types.
- We identify the heliospheric current sheet (HCS) throughout the entire data-set. This allows us to analyze the relative importance of slow solar wind in our data.
- We estimate the total fraction of the heliosphere filled with steamer-associated slow wind.
- Our results provide important constraints on models for the slow solar wind, which are being discussed.

Data Description

Spacecraft	Instrument	Resolution	Data provided
ULYSSES (1997-2006)	SWICS *(Solar Wind Ion Composition Experiment)*	3.5 hours	Density ratios O^{7+}/O^{6+}, C^{6+}/C^{5+}, Fe/O and Fe average charge state.
	SWOOPS *(Solar Wind Ion Composition Experiment)*	1 hour	Proton velocity, density, temperature and Helium density
	VHM/FGM *(Vector Helium Magnetometer / Flux Gate Magnetometer)*	1 hour	Magnetic field in RTN coordinates
ACE (1998-2005)	SWICS *(Solar Wind Ion Mass Spectrometer)*	1 hour	Density ratios $O7^{+}/O6^{+}$, $C6^{+}/C5^{+}$, Fe/O and Fe average charge state.
	SWEPAM *(Solar Wind Electron, Proton, and Alpha monitor)*	1 hour	Proton velocity, density, temperature and Helium density
	MAG *(Magnetic Field Experiment)*	1 hour	Magnetic field in RTN coordinates

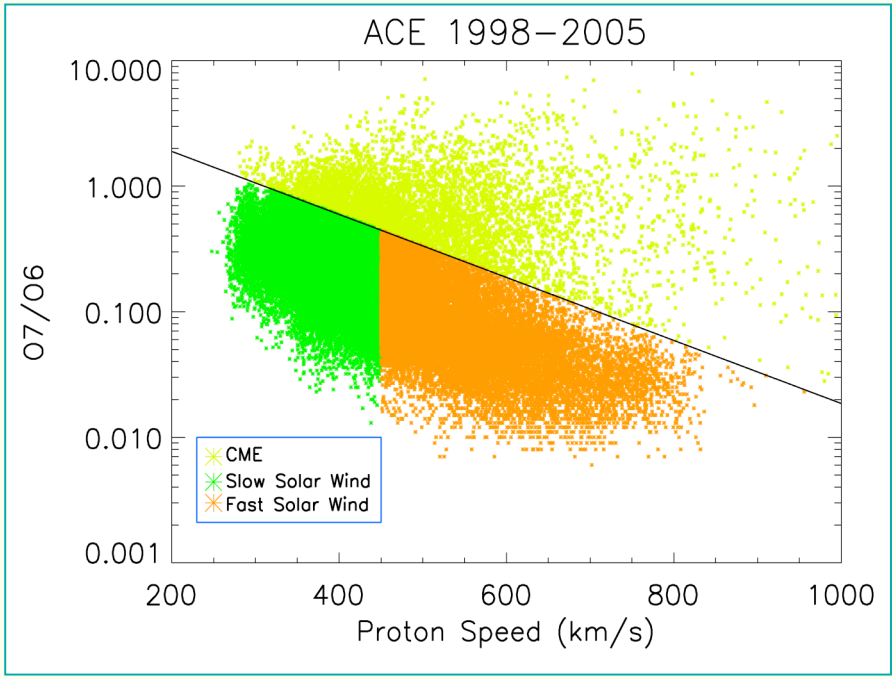
Identifying solar wind typs

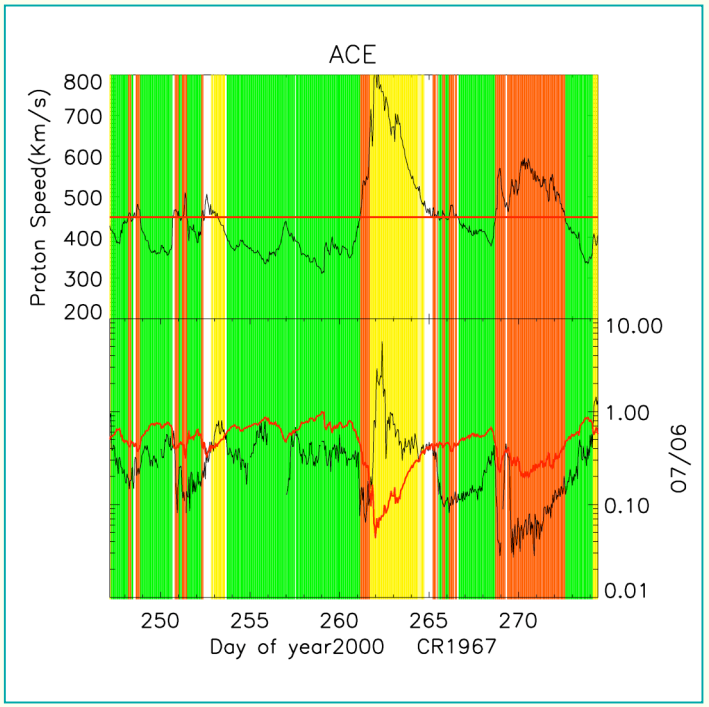
- Criterions:

  - CME: O^{7+}/O^{6+} larger than the limiting critical value described below (Richardson and Cane ,2004):

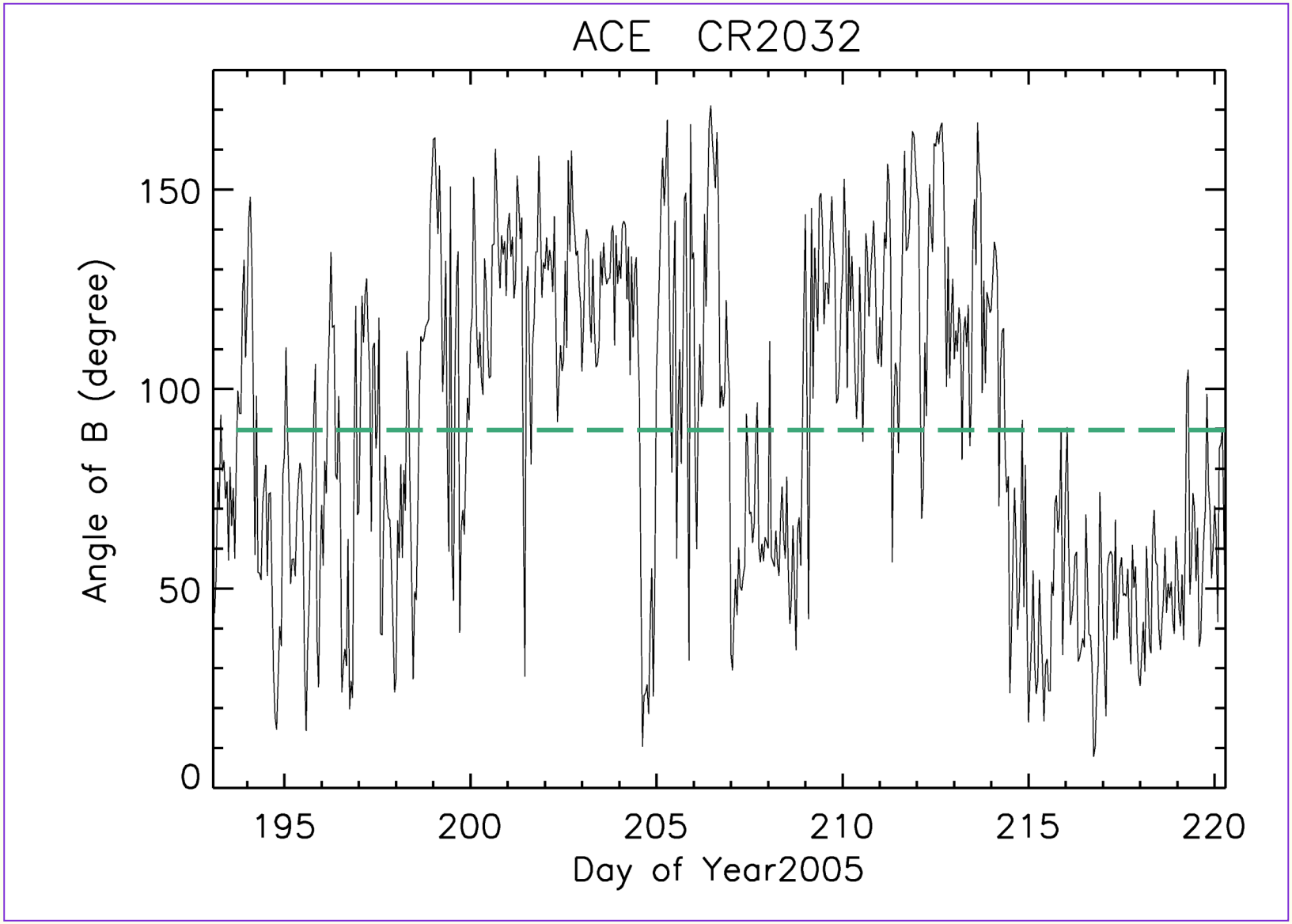
$$(O^{7+}/O^{6+})_{CME} = 2 \times 3.004 \exp(-0.00578 V_{SW})$$

  - Slow Solar Wind: Vsw<450 Km/s
  - Fast Solar Wind (from coronal holes) : Vsw>450Km/s

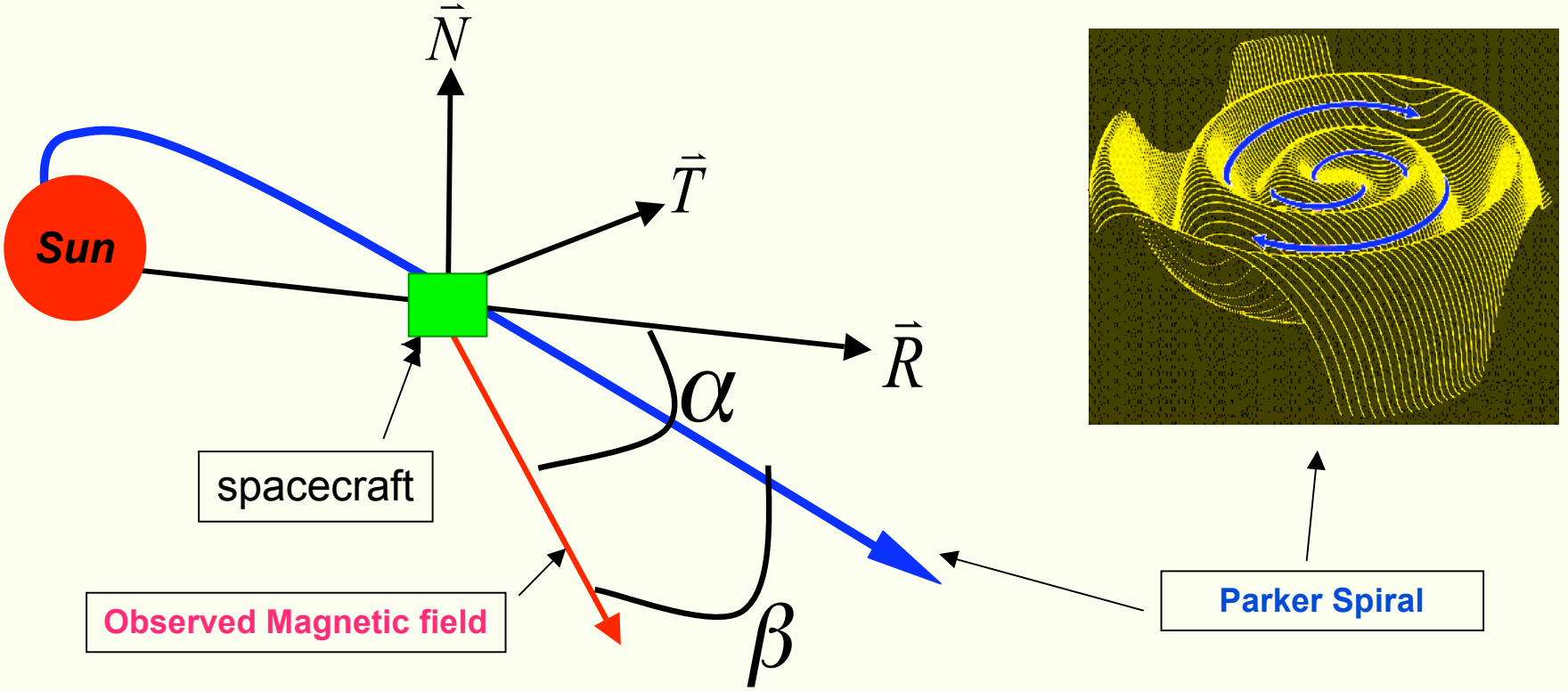




Identifying the heliospheric current sheet based on abservation data



Identifying the heliospheric current sheet based on abservation data



Angelα: the angel between observed magnetic field and R direction.

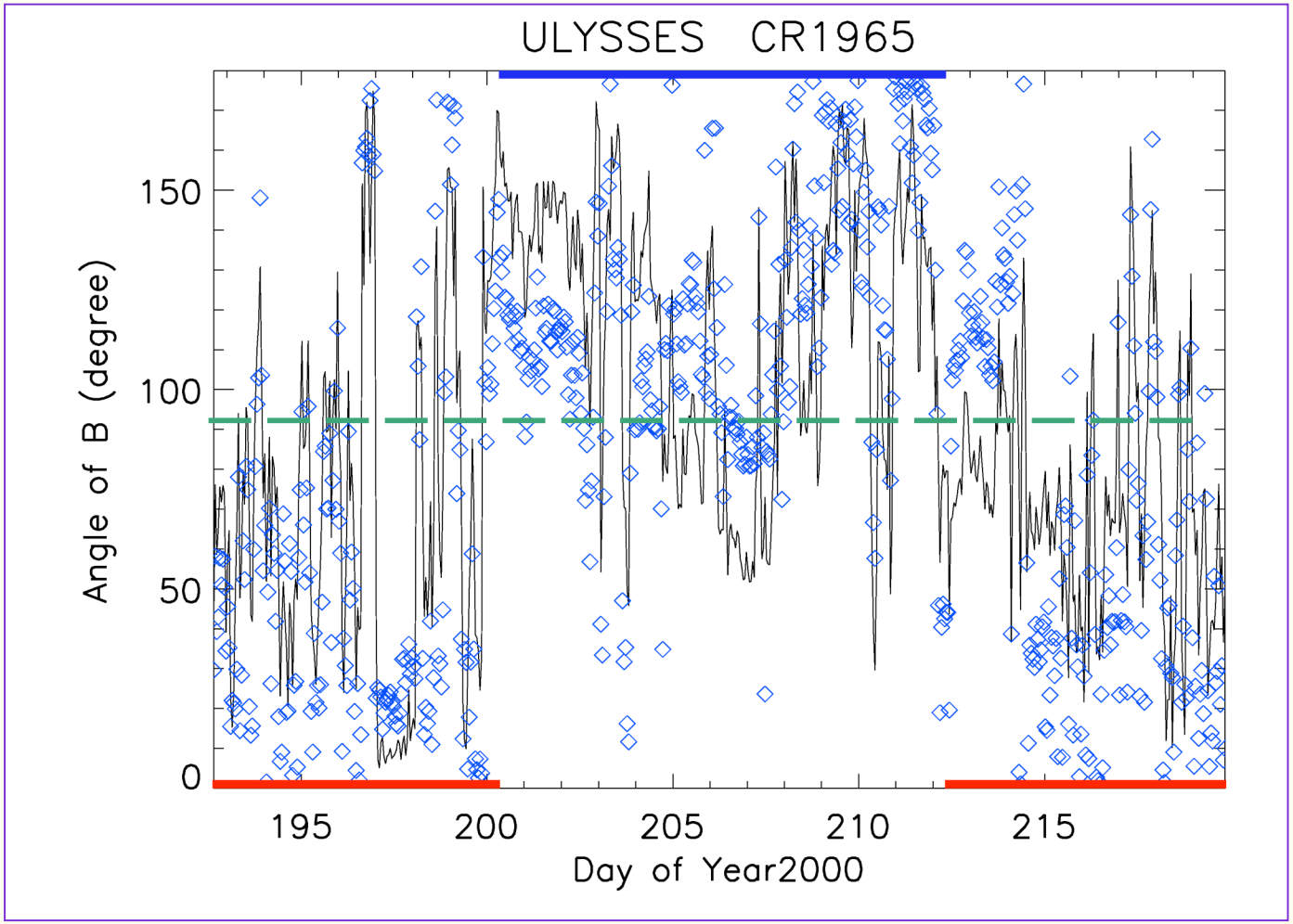
Angelβ: the angel between observed magnetic field and Parker spiral.

Identifying the heliospheric current sheet based on abservation data

- During 4 days interval:

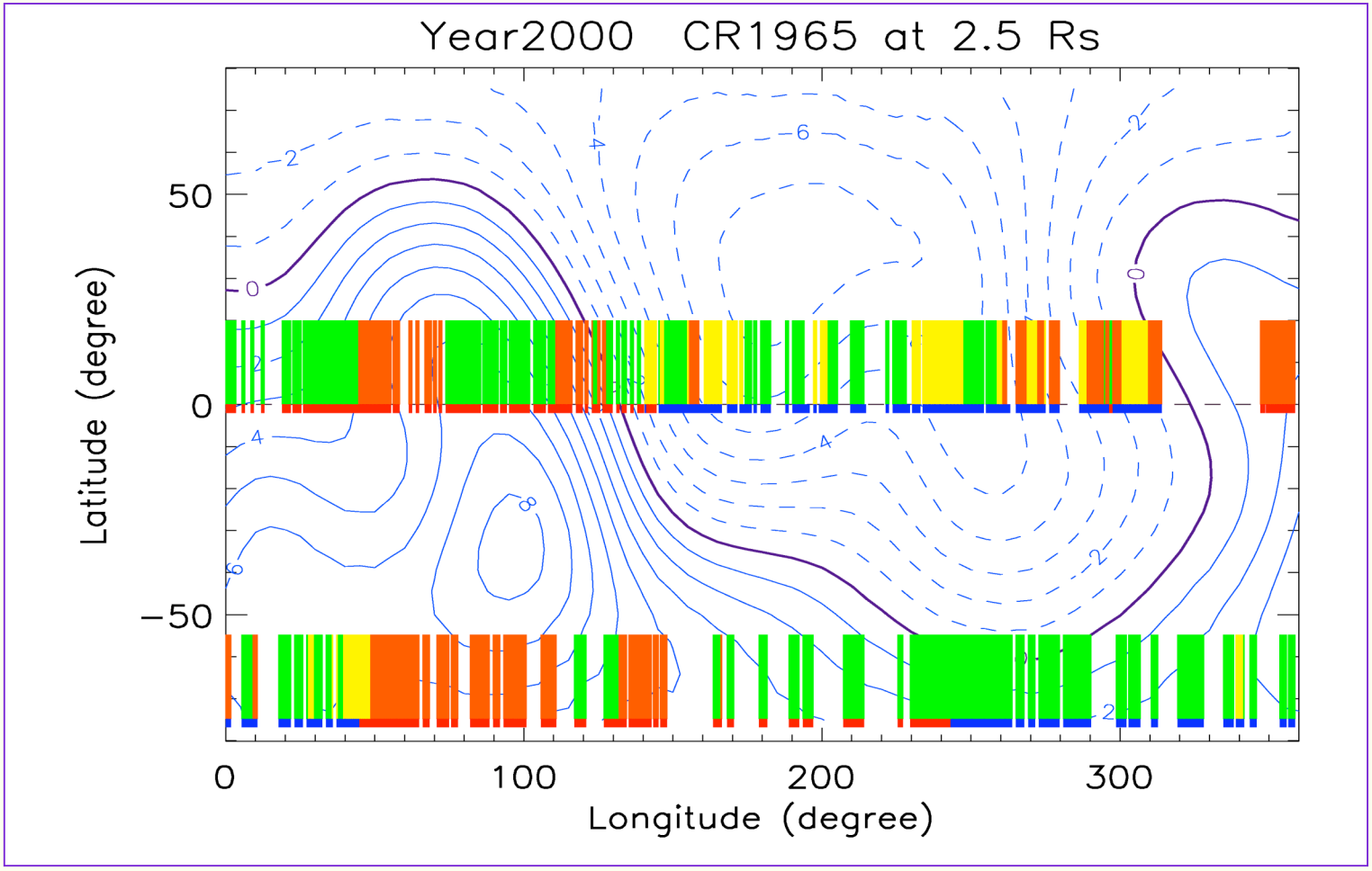
Occurrence rate of β> 90 degree lager than the occurrence rate of β< 90 degree ⇒ **Inward**

Occurrence rate of β> 90 degree less than the occurrence rate of β< 90 degree ⇒ **outward**



Results 1 (Mapping back to the solar surface 2.5 Rs)

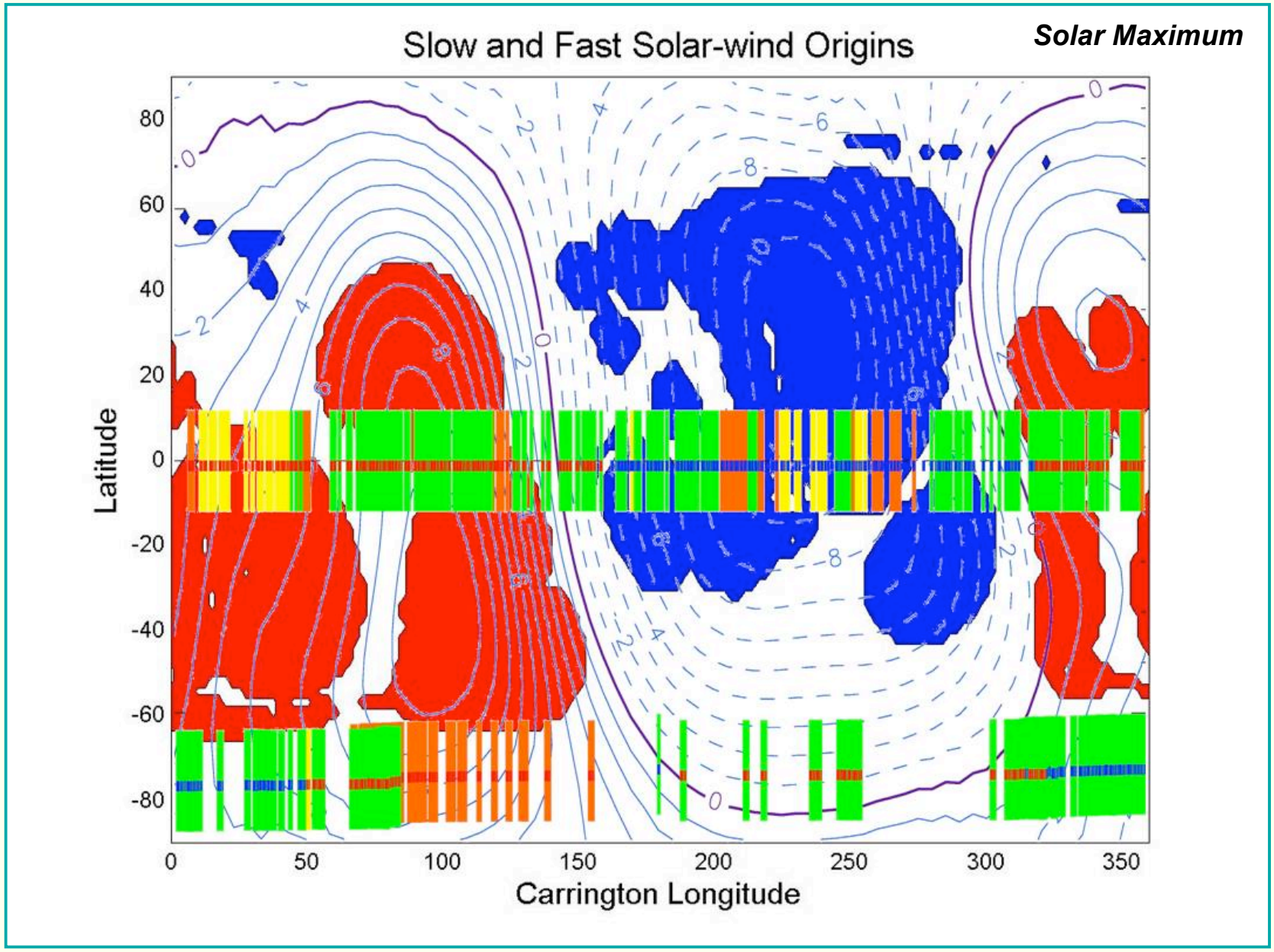
Solar Maximum



Fast wind **Slow wind** **CMEs**

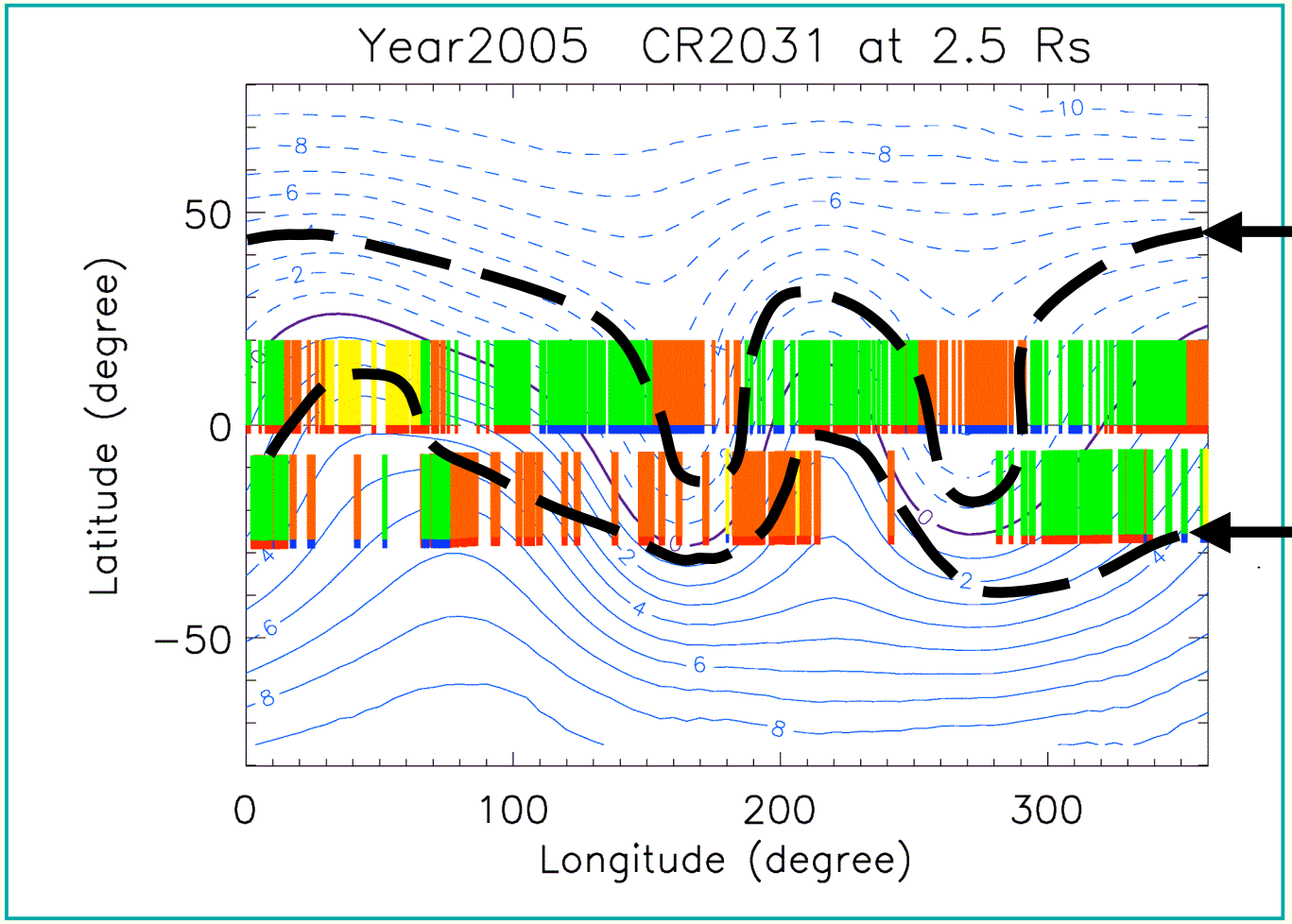
outward B **inward B**

Results 1 (comparing with PFSS model result, Gilbert)



Results 2

Estimate the solid angle (Ω) of the band around the HCS covered by slow solar wind at solar minimum

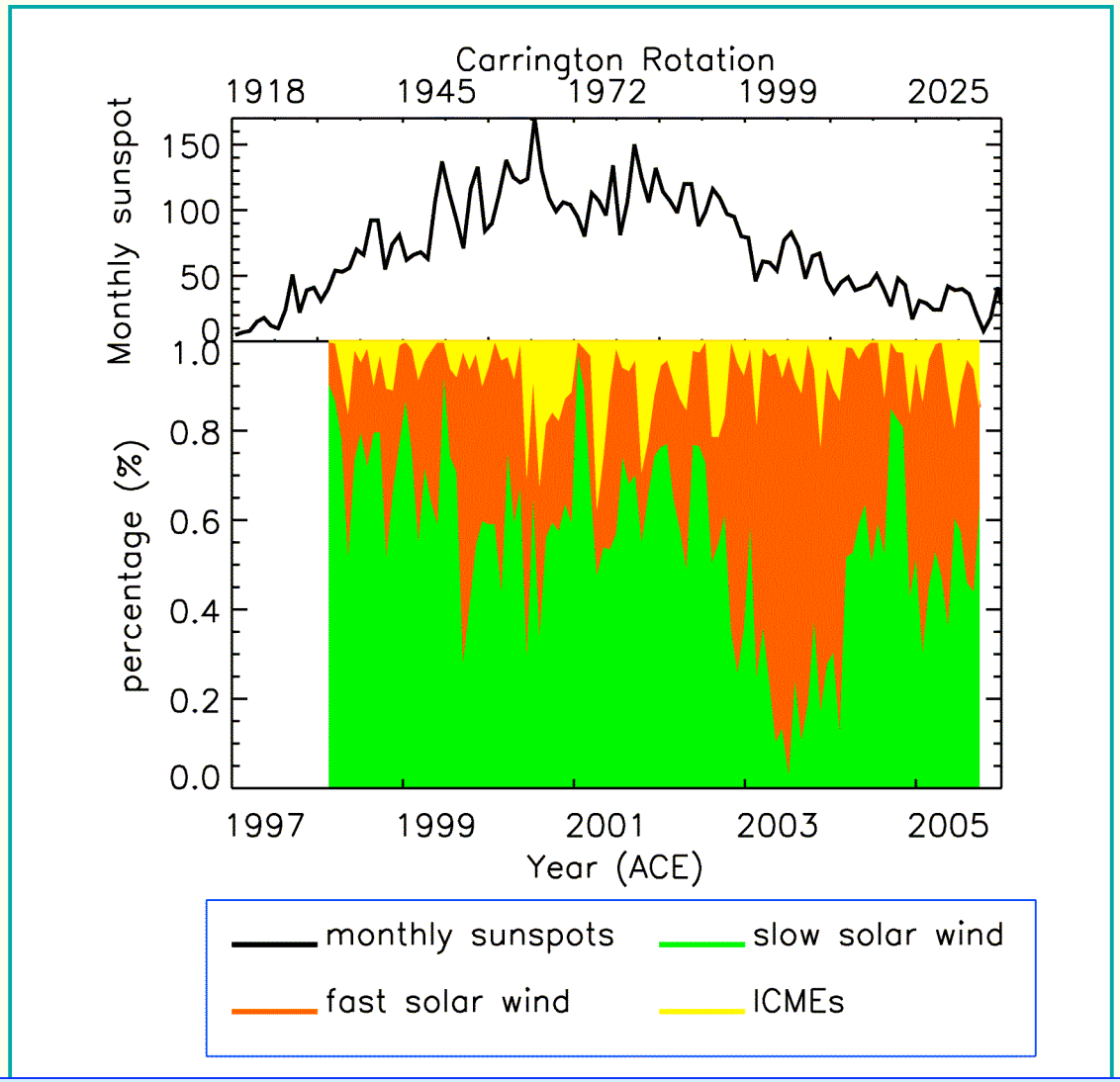


From the result of PFSS model given by Gilbert, at solar maximum, Ω~65%

Ω is highly solar cycle dependent !

Results:

Occurrence rate of solar wind types during one solar cycle.



Slow solar wind is an important contribution of the heliosphere during the entire solar cycle.

Major Conclusions:

- Slow solar wind is a crucial and important part of the heliosphere during the entire solar cycle.
- We find a strong solar cycle dependence of the relative slow solar wind occurrence: At solar minimum, we find the relative contribution to be around 25%, growing to 65% at solar maximum.
- This analysis was performed independent of model predictions and should therefore provide test-cases for any model that seeks to explain the heliospheric origin on the slow wind.

Thank you !

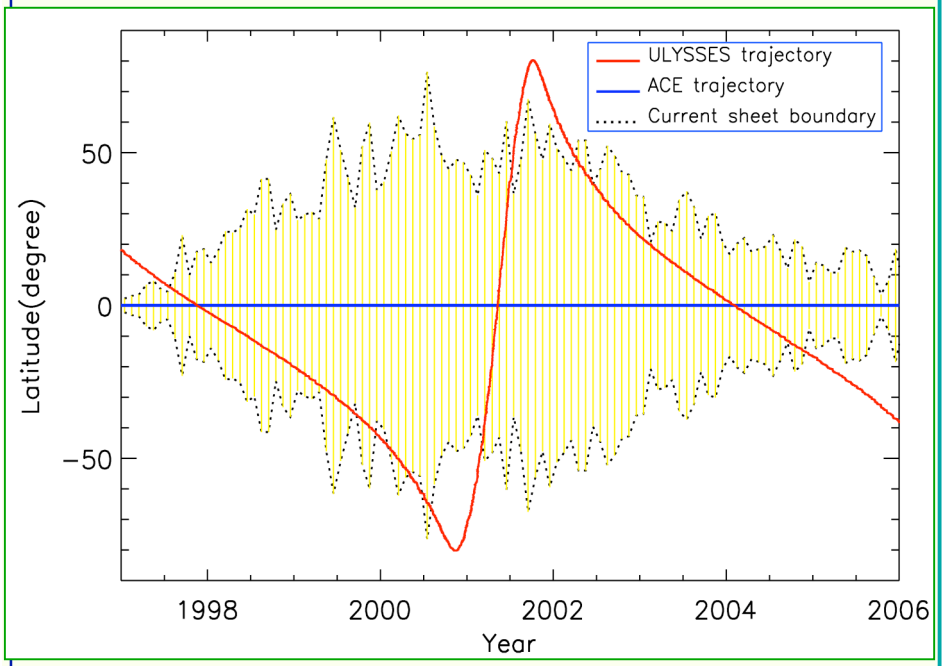
Discussion

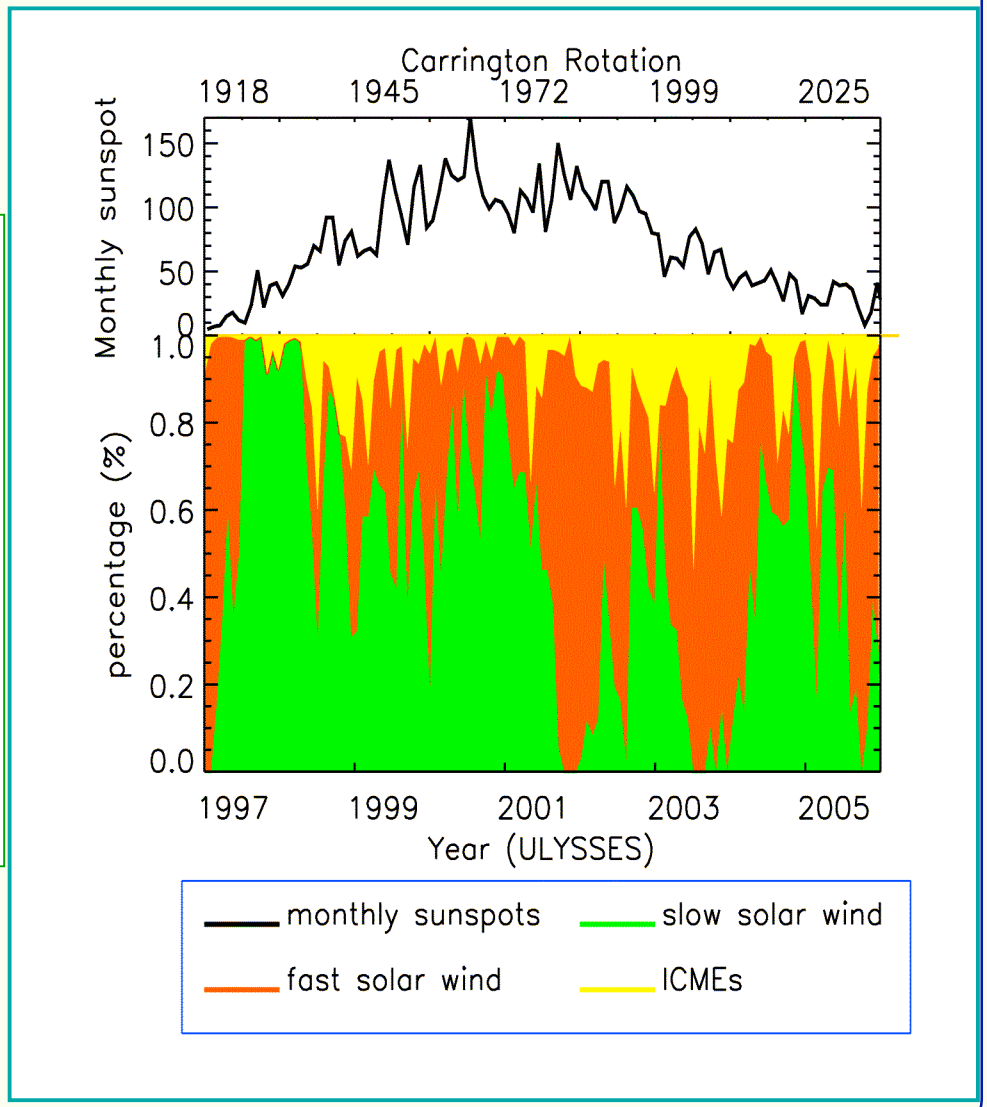
- Slow solar wind cannot be considered to be a boundary-effect of coronal holes, as suggested by Bravo et al.1997, or Wang et al., 2000. Instead, it clearly dominates the fast solar wind flows during a large fraction of the solar cycle.

- Neugebauer et al. have introduced the concept of Active Region Coronal Holes (ARCH) as source regions of these slow flows. However, it is not clear why their elemental and ionic compositions should be different from fast flows associated with other coronal holes.

- We therefore conclude that there is solar wind from regions with closed large-scale topology, as suggested by Fisk et al, 1998 and Zurbuchen et al., 2000 (*See poster by Gilbert et al.)*.

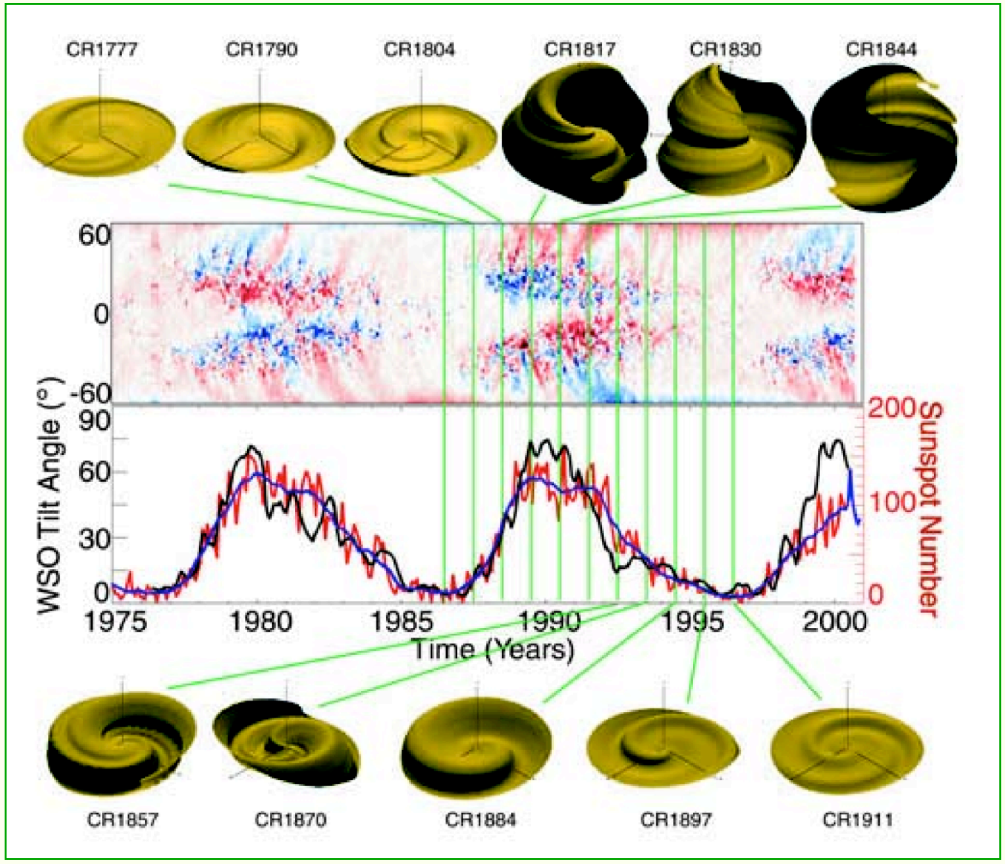
Discussion:


ULYSSES trajectory
ACE trajectory
Current sheet boundary
Latitude(degree)
50
0
−50
1998
2000
2002
2004
2006
Year


Carrington Rotation
1918
1945
1972
1999
2025
Monthly sunspot
150
100
50
0
1.0
0.8
0.6
0.4
0.2
0.0
percentage (%)
1997
1999
2001
2003
2005
Year (ULYSSES)
monthly sunspots
slow solar wind
fast solar wind
ICMEs

Trajectory overview

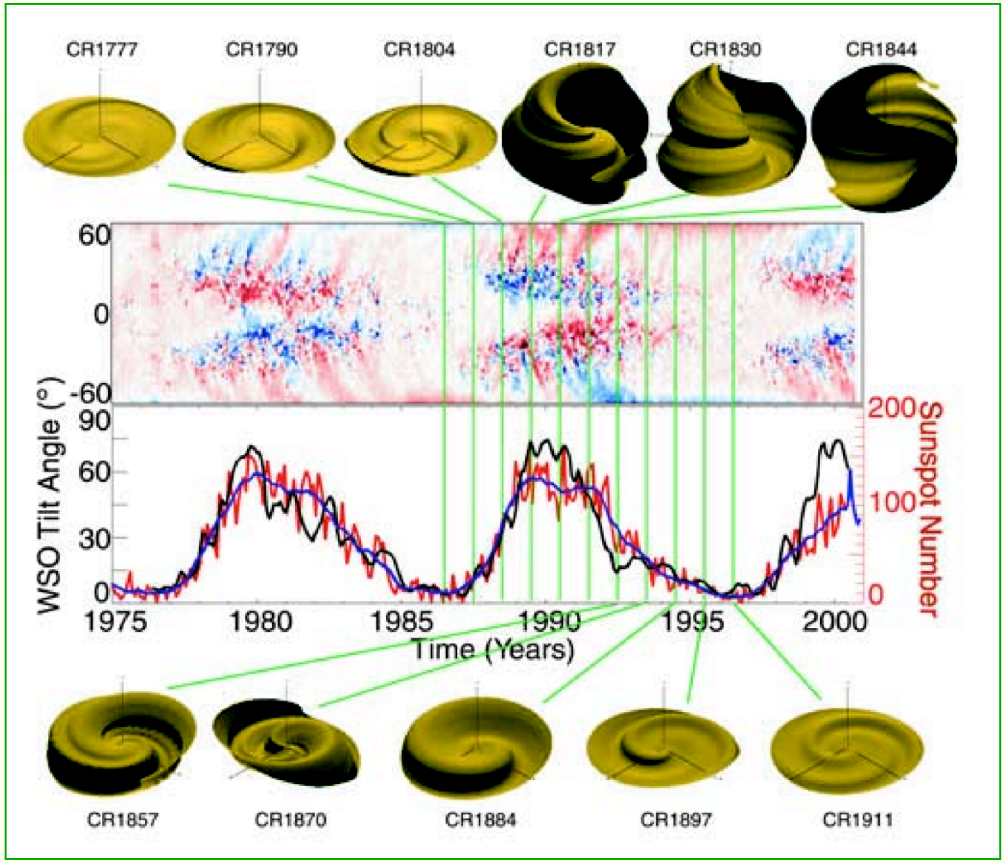
Monthly Sunspot number → **Tilted angle** → **Current sheet angle**



Riley and Linker *et al* (2002)

Trajectory overview

Monthly Sunspot number → **Tilted angle** → **Current sheet angle**



Riley and Linker *et al* (2002)

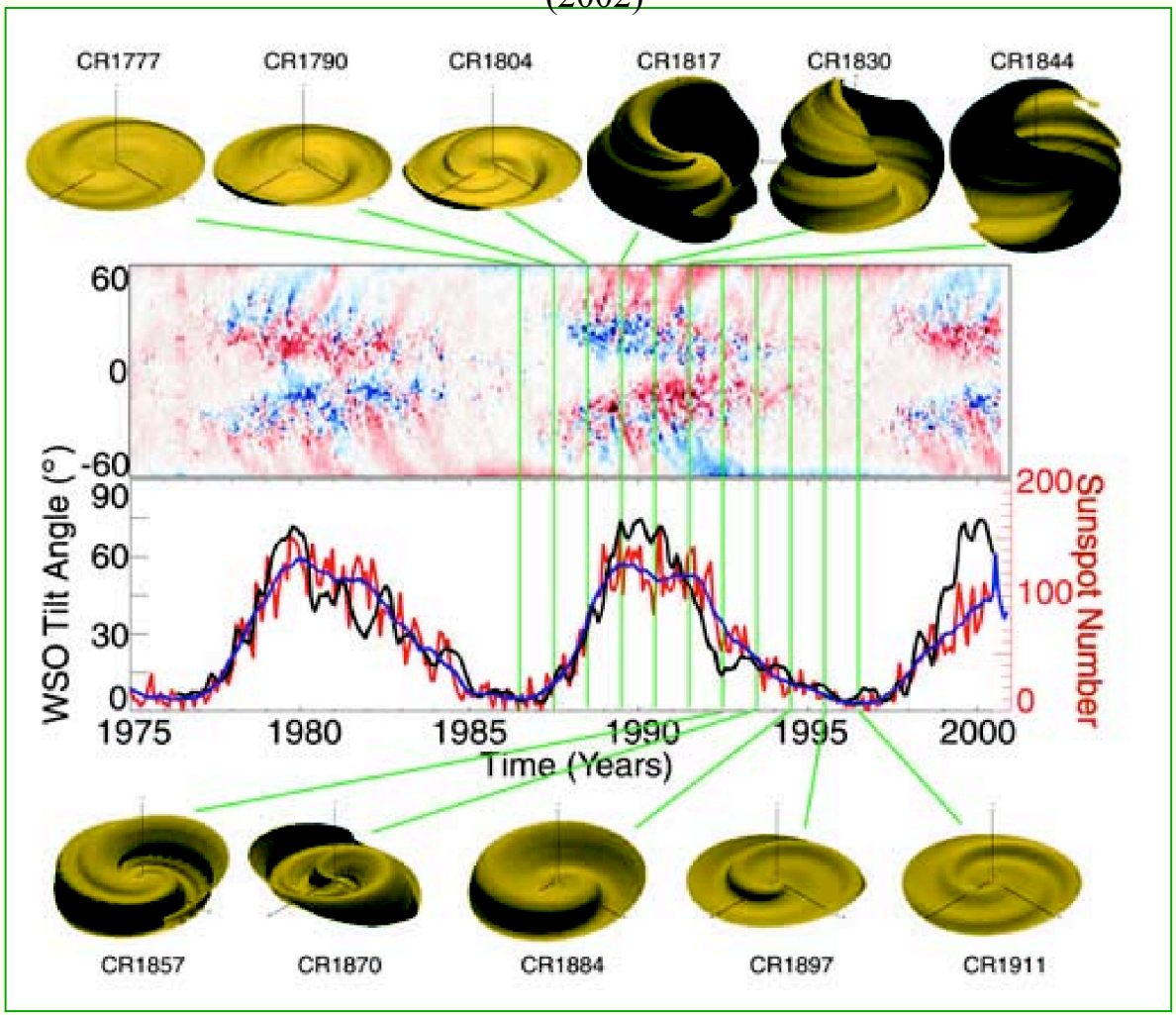
Trajectory overview

Monthly Sunspot number

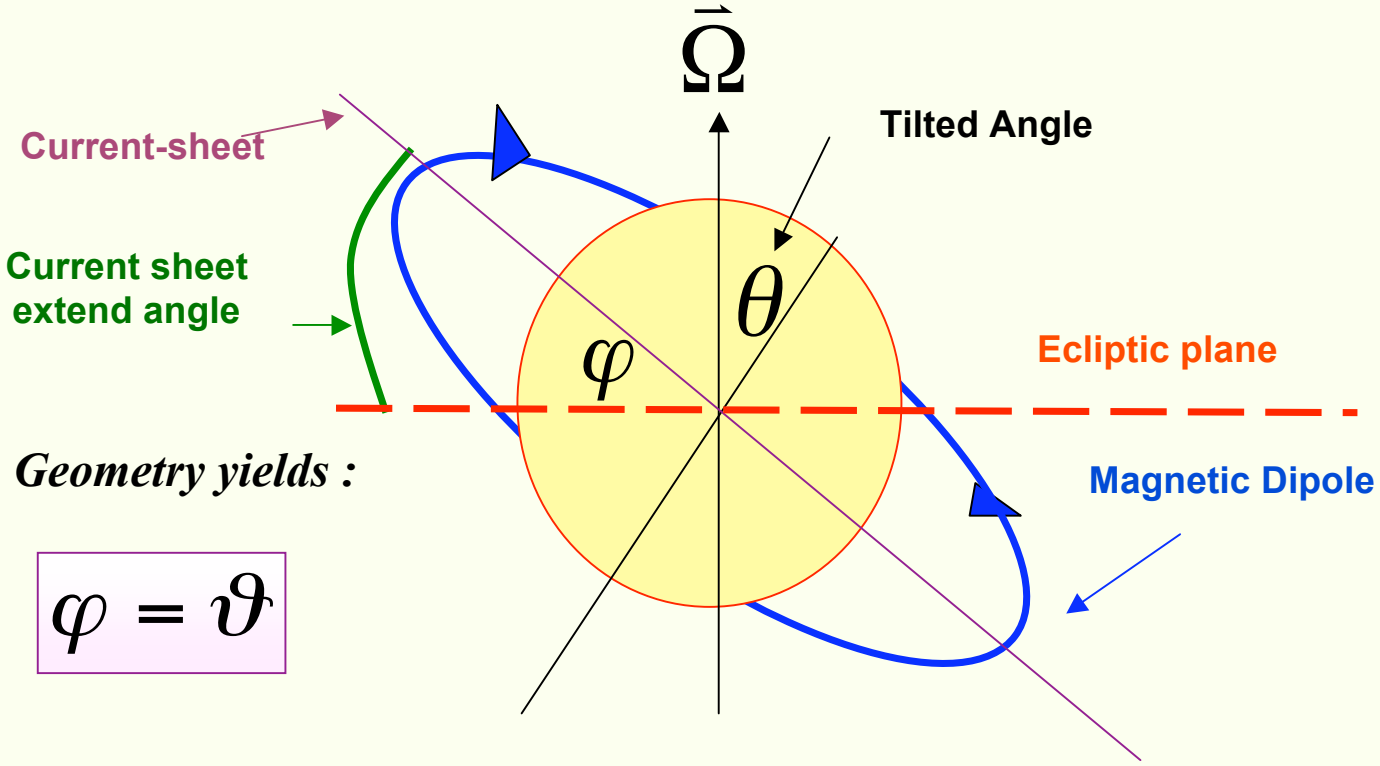
Tilted angle

Current sheet angle

Riley and Linker *et al* (2002)



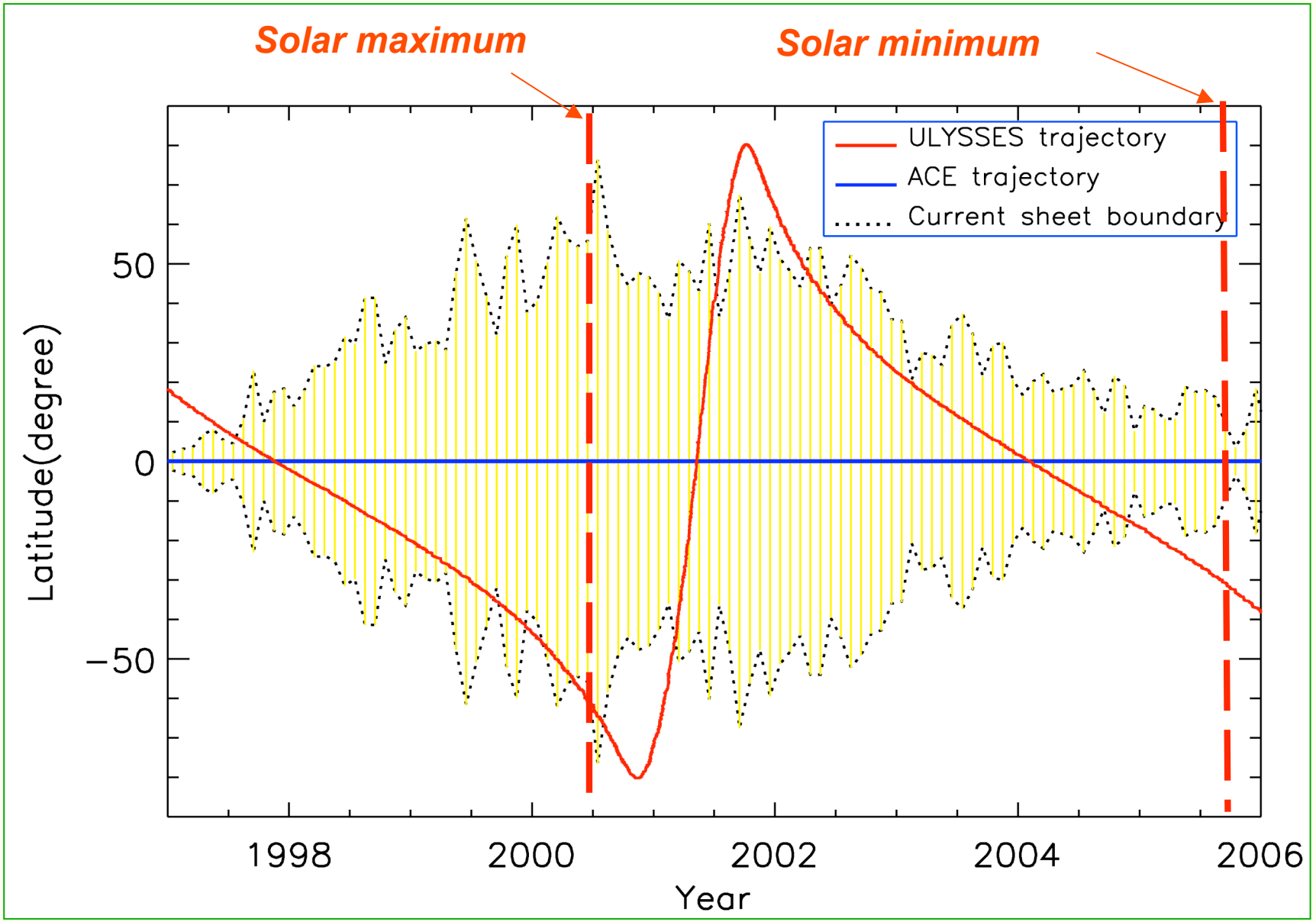
Trajectory overview

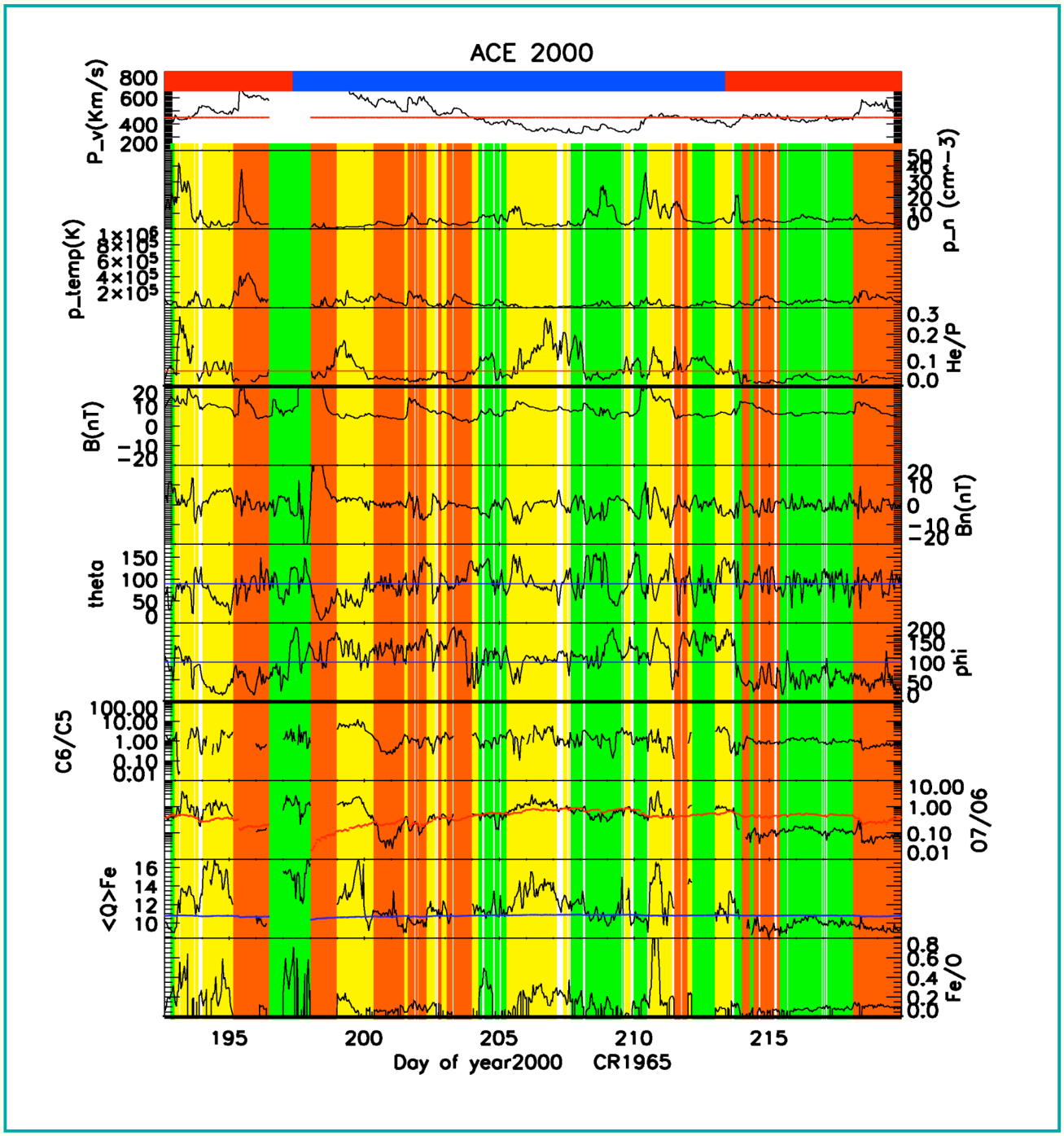


Geometry yields :

$$\varphi = \vartheta$$

Trajectory overview




ACE 2000
P_v(Km/s)
800
600
400
200
p_temp(K)
1×10^6
8×10^5
6×10^5
4×10^5
2×10^5
p_n (cm^-3)
50
40
30
20
10
0
He/P
0.3
0.2
0.1
0.0
B(nT)
20
10
0
−10
−20
Bn(nT)
theta
150
100
50
0
phi
200
150
100
50
0
C6/C5
100.00
10.00
1.00
0.10
0.01
07/06
<Q>Fe
16
14
12
10
Fe/O
0.8
0.6
0.4
0.2
0.0
195
200
205
210
215
Day of year2000
CR1965