Plasma and Magnetic Field Observations of Stream Interaction Regions near 1 AU

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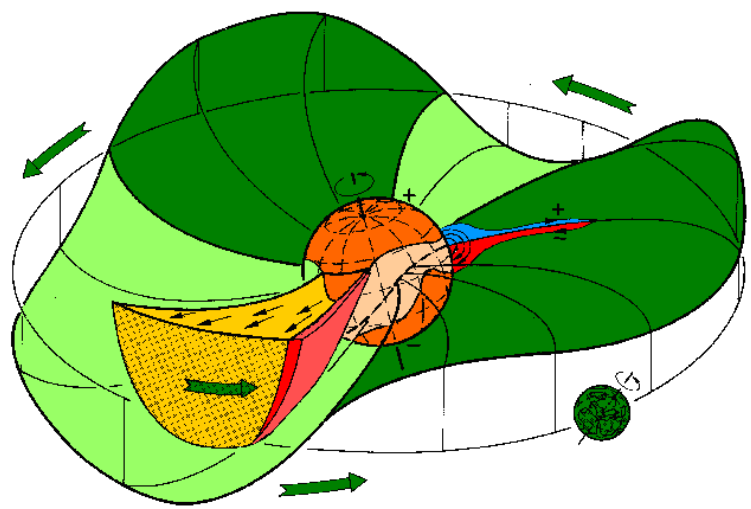
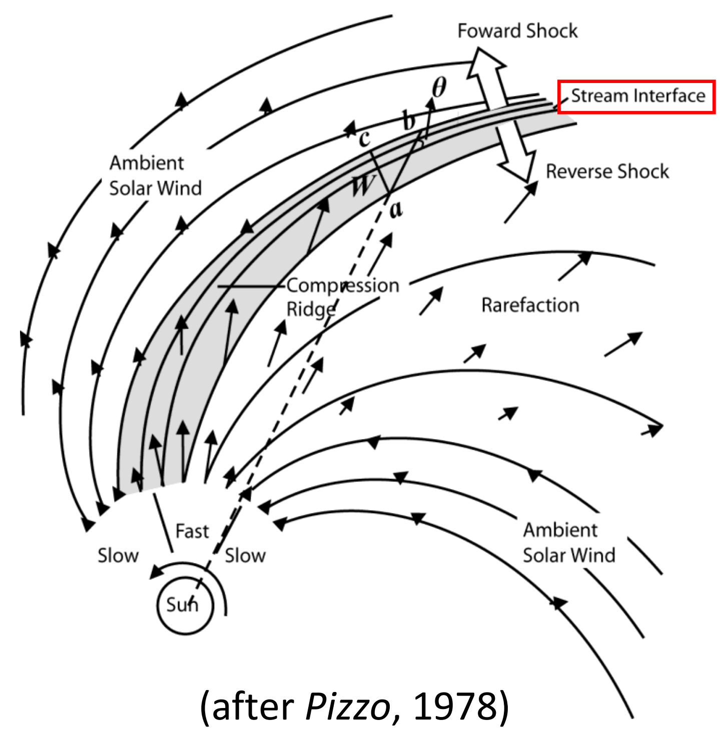
Stream Interaction Region (SIR)

- Fast and slow streams originate from different regions on the Sun at different times. They are threaded by different magnetic field lines and prevented from interpenetrating
- As the Sun rotates, fast wind can overtake preceding slow wind and form SIRs with a pressure ridge at the stream interface
- If the flow pattern is roughly time-stationary, these compression regions form spirals in the solar equatorial plane that corotate with the Sun → Corotating Interaction Regions (CIRs)
- SIRs = CIRs (recur at least once) + transient & localized stream interactions
- The pressure waves associated with the collision steepen with radial distance, eventually forming **shocks**, sometimes a pair of forward-reverse shocks

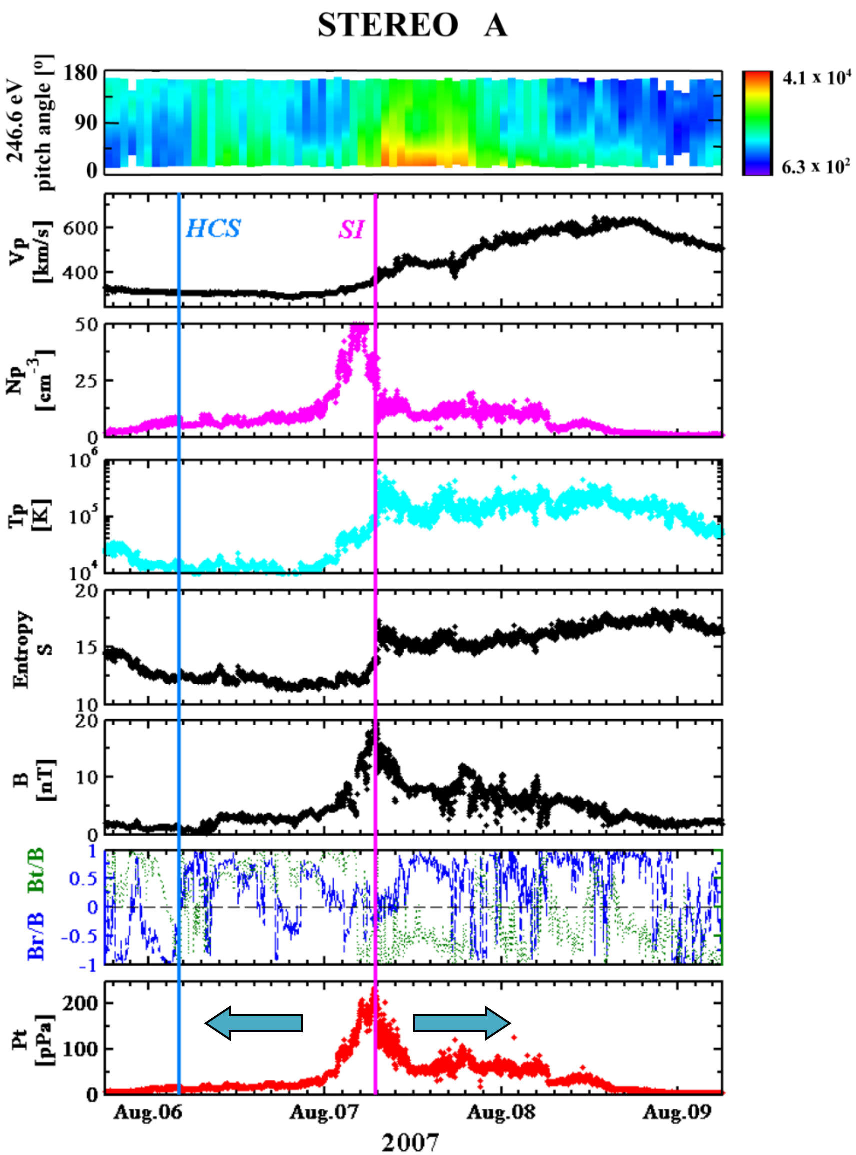


(according to *Alfvén*, 1977)



(after *Pizzo*, 1978)

SIR Identification



(*Jian et al*, 2009)

* **Criteria (by visual inspection)**
  - ① Increase of V_p
  - ② Deflection of V_p
  - ③ A pile-up of P_t (*sum of magnetic pressure and perpendicular plasma thermal pressure*) with gradual declines at two sides
  - ④ Increase and then decrease of N_p
  - ⑤ Increase of T_p
  - ⑥ Compression of **B**, usually associated with **B** shear
  - ⑦ Change of entropy $\ln(T_p^{1.5}/N_p)$

* **Stream Interface (SI)**

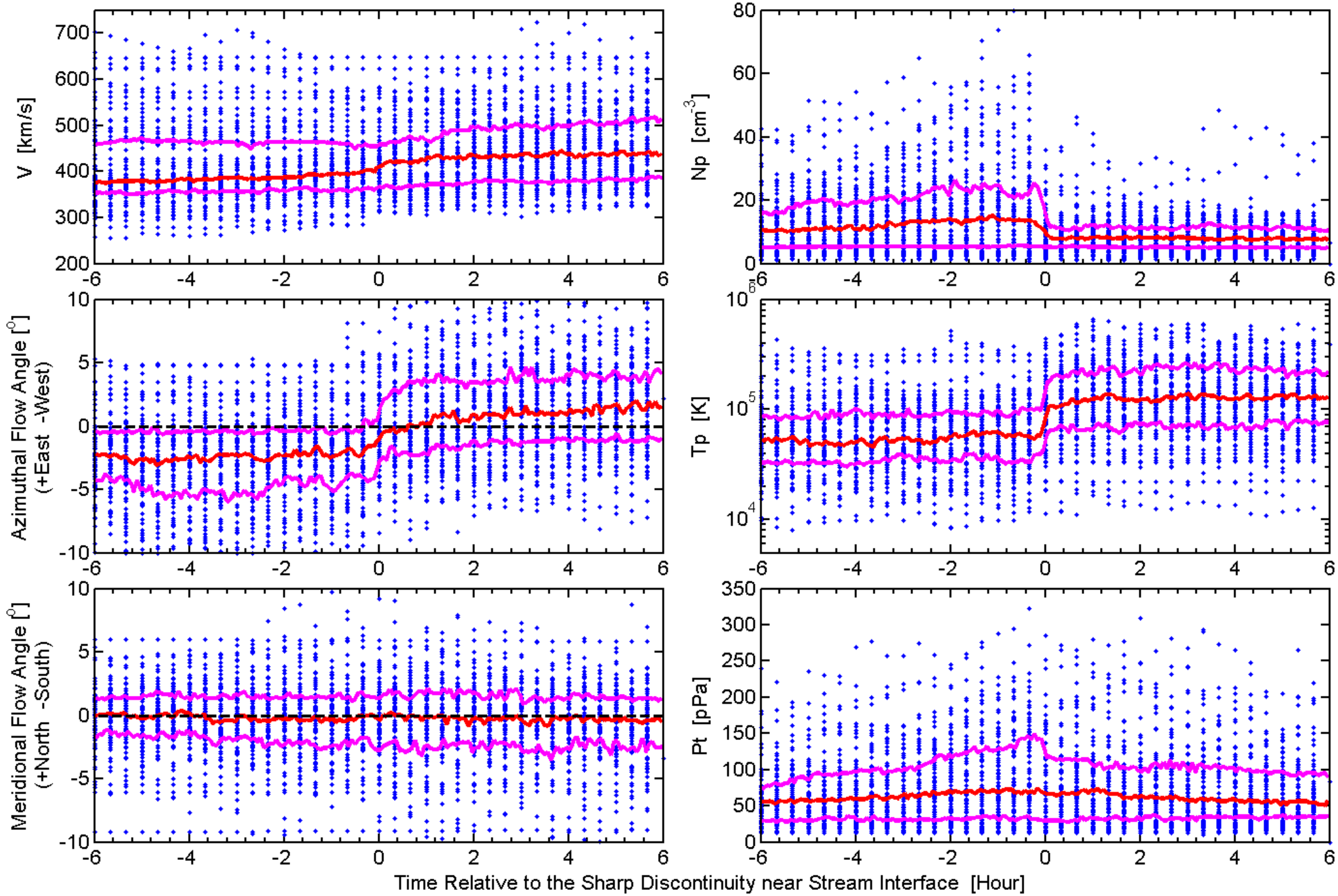
  Because only 20% of SIRs have sharp boundary between fast and slow streams, we define SI to be at the peak of P_t

* **Heliospheric Current Sheet (HCS)**

  Identified by the changes of the IMF polarity and the suprathermal electron pitch angle

Stream Interface

About **20%** of SIRs have a sharp discontinuity near the stream interface defined by P_{tmax}



Survey of SIRs

- Wind/ACE from 1995 to 2009
  - As Level 3 and contributed data of ACE science center
  - http://www-ssc.igpp.ucla.edu/~jlan/ACE/Level3/SIR_List_from_Lan_Jian.pdf
- STEREO from 2007 to 2009
  - As Level 3 data of STEREO
  - http://www-ssc.igpp.ucla.edu/forms/stereo/stereo_level_3.html
  - Separate list of interplanetary shocks

Snapshot of the SIR List for Wind/ACE

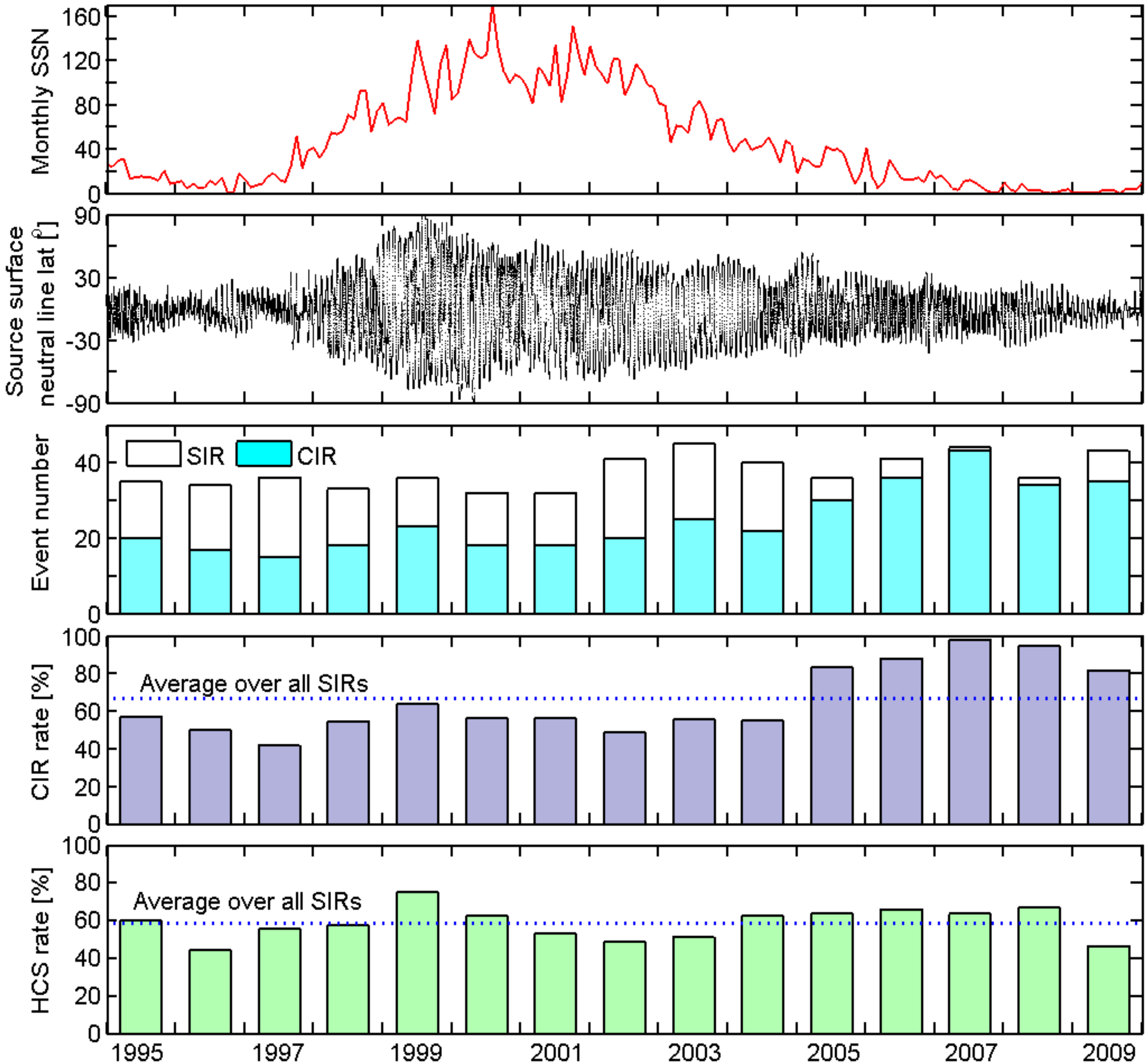
SIR #	CIR #	Start UT [mm/dd hhmm]	End UT [mm/dd hhmm]	Discontinuity UT [mm/dd hhmm]	F/R[1] Shock	Stream Interface (SI) UT [mm/dd hhmm]	P_{tmax} [pPa]	V_{max} [km/s]	V_{min} [km/s]	ΔV[2] [km/s]	B_{max} [nT]	Comments
1995												
1	1	01/01 1937	01/03 2000	01/01 1937	F	01/02 0556	173	720	320	400	16.3	Pt plateau-like and irregular
2	2	01/17 0200	01/18 2000	01/17 1918	/	01/17 2323	240	536	330	206	19	
3		01/22 0400	01/23 0200			01/22 1300	110	435	335	100	11	
4	3	01/28 1800	01/30 1100	01/30 1000	/	01/29 1520	290	747	290	457	20.5	Pt zigzag
5	4	02/10 2200	02/13 1400			02/11 0600	170	710	330	380	14	Pt irregular
6	5	02/25 2000	02/28 2000	02/26 0256	F	02/26 0325	180	640	262	378	14.6	long-time plateau after Pt peak
				02/26 0718	/							
7 *	6	03/25 2200	03/27 2100			03/26 1013	207	520	290	230	18.5	after an ICME[3]

Solar Cycle Variation of SIR Properties: 1995 – 2009

564 events over 15 years

(after *Jian et al*, 2006)

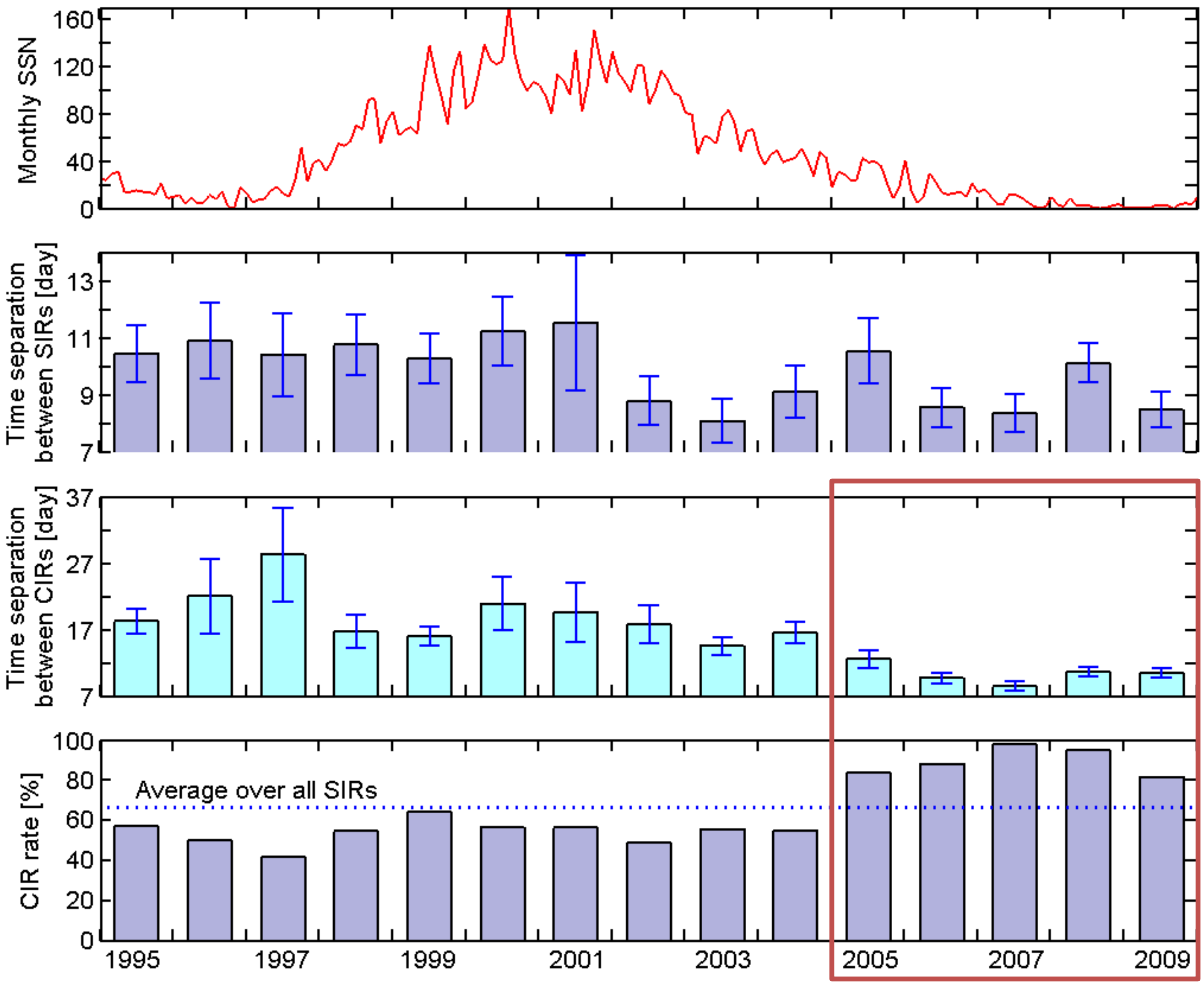
Occurrence Rate and HCS Association Rate



More SIRs and CIRs, a higher fraction of CIRs in the declining phase and the solar min 23/24

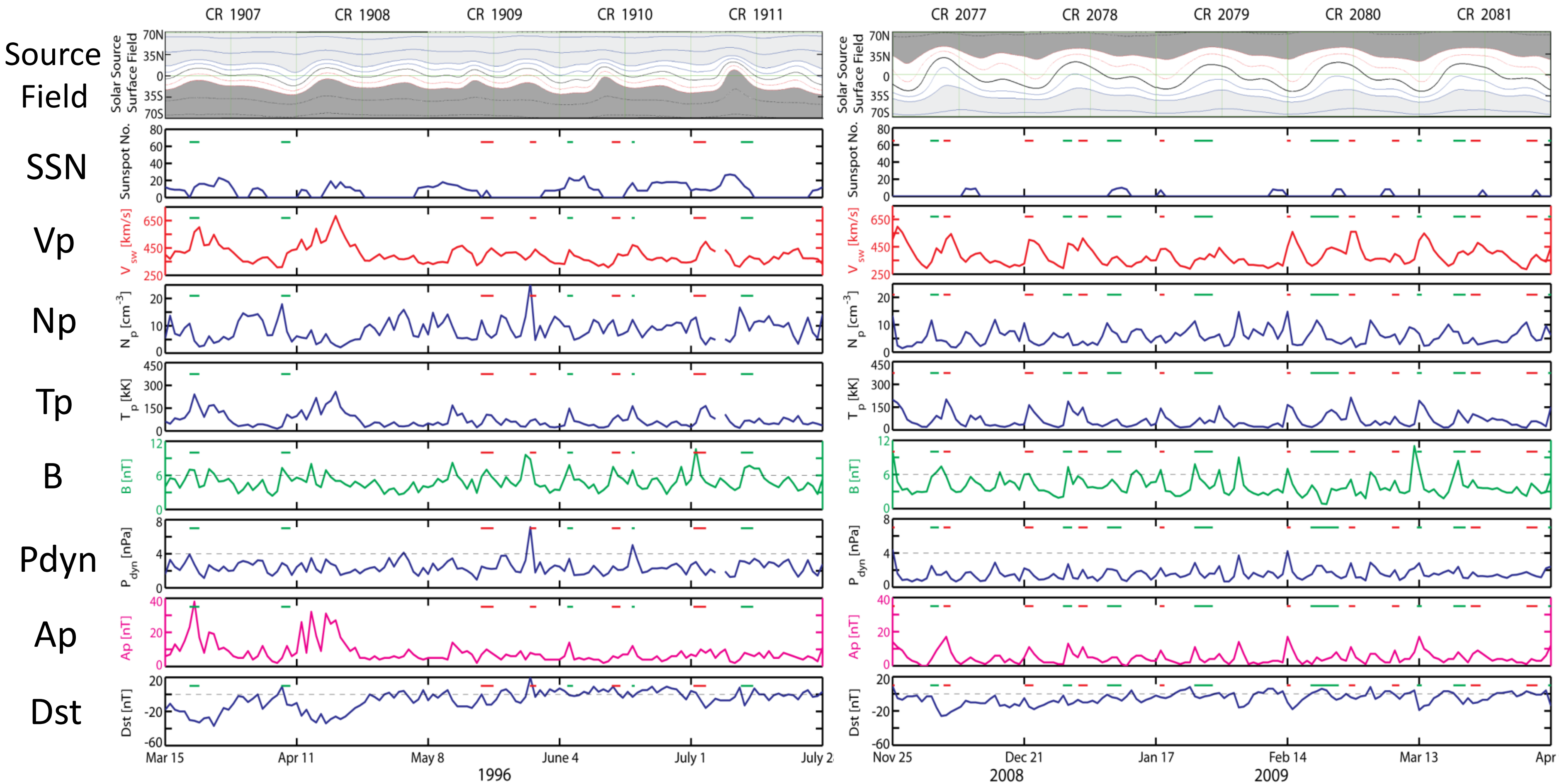
HCS association rate is lower at solar min and solar max

Time Separation between SIRs

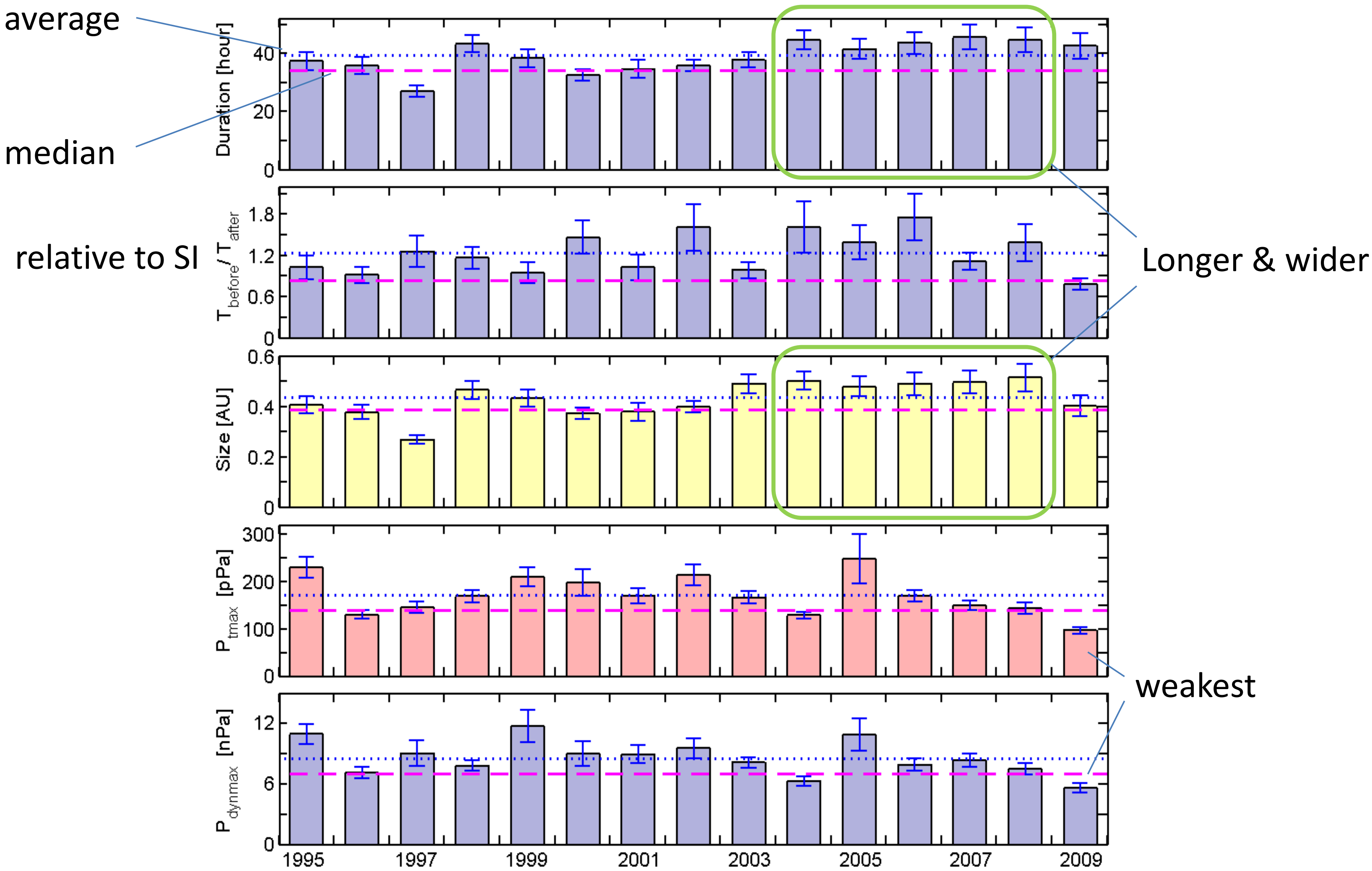


Comparison between Solar Min 22/23 and 23/24

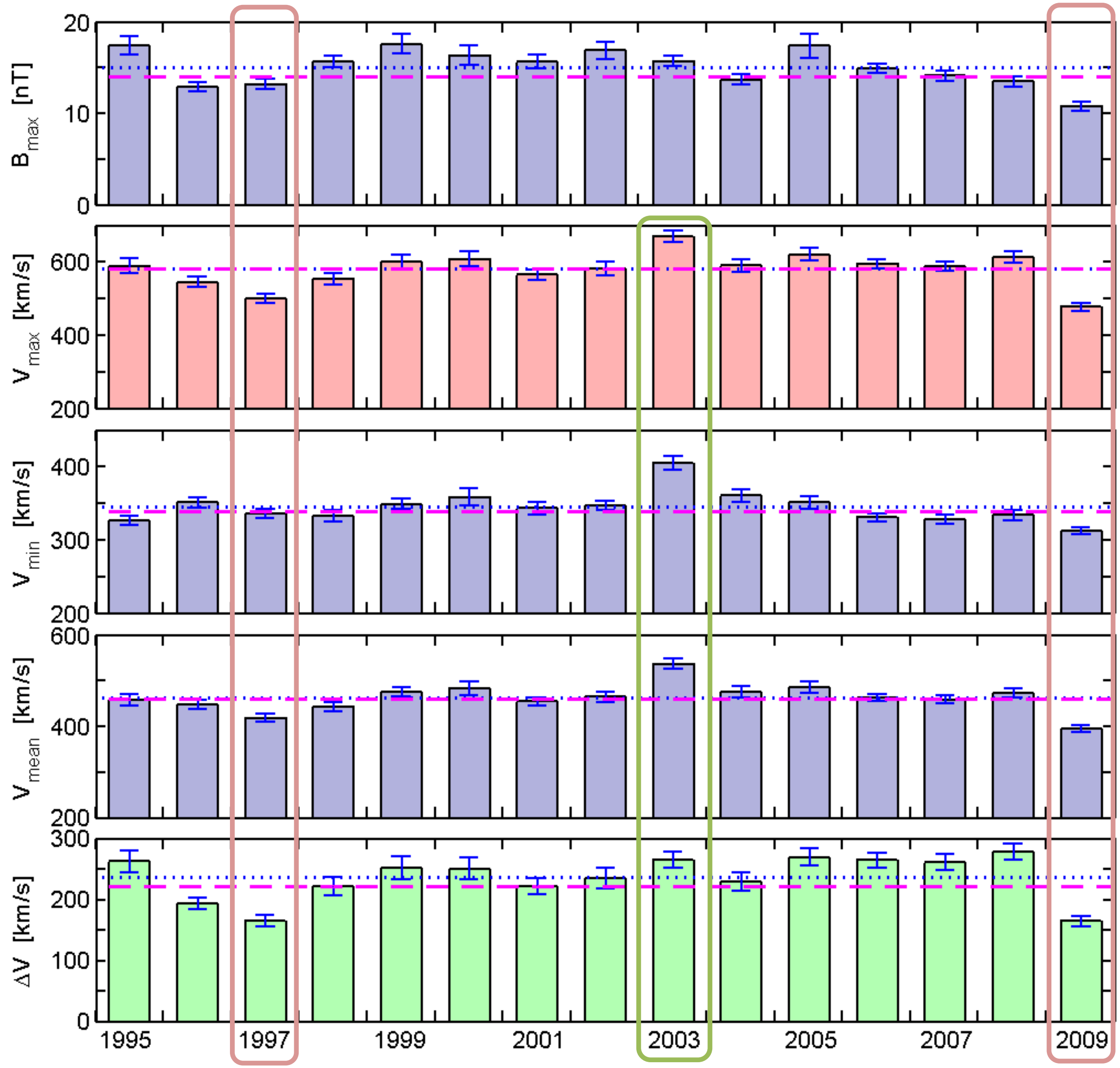
Solar Min 22/23 | Solar Min 23/24 (more SIRs)



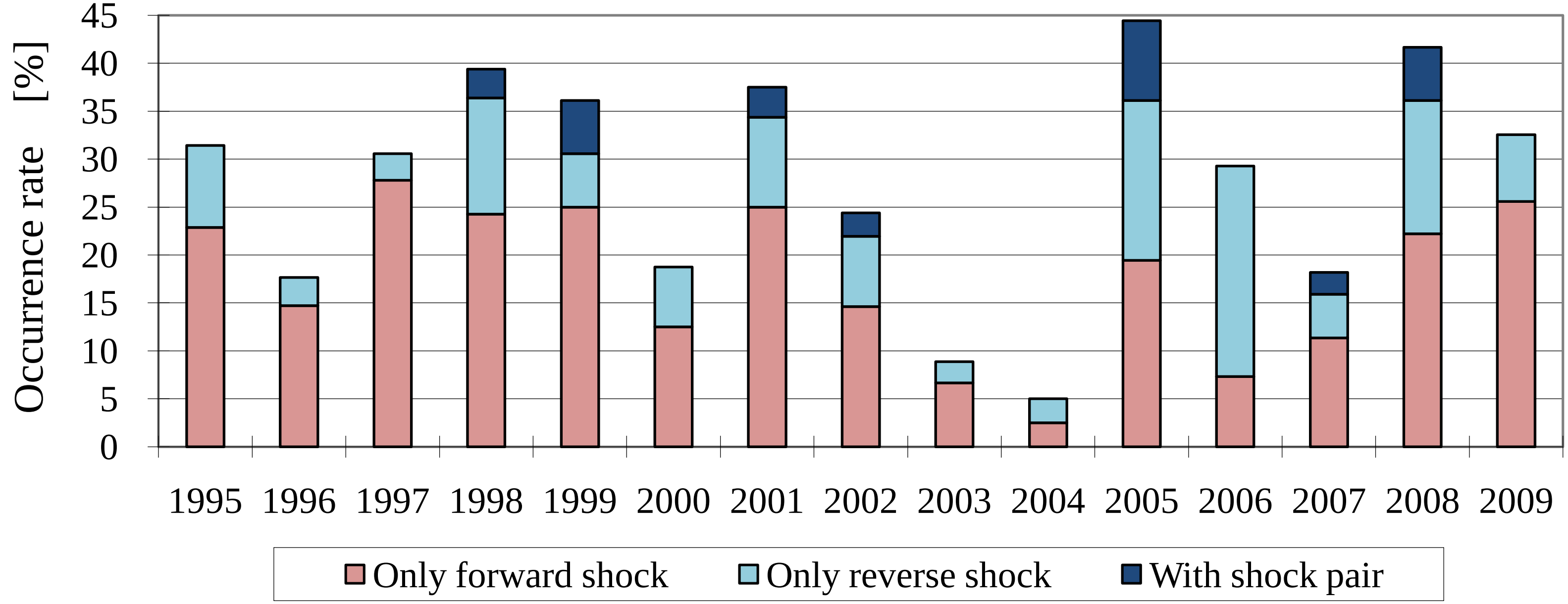
Duration, Size, Maxima of Total Pressure and Dynamic Pressure

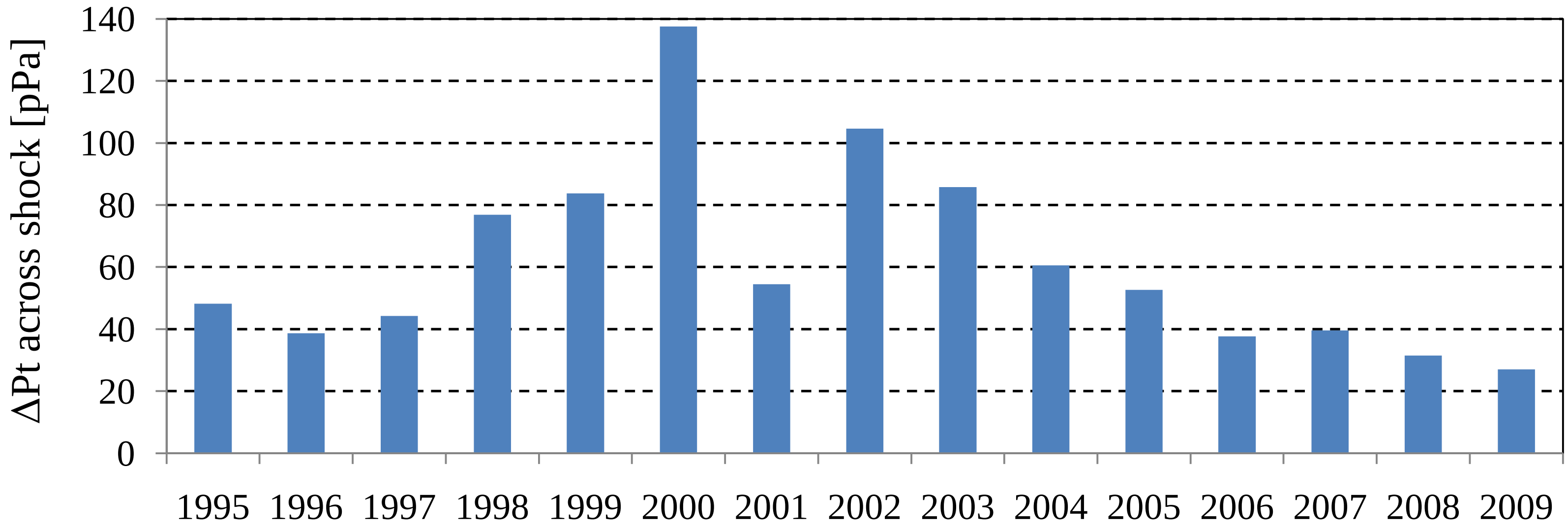


Magnetic Field and Solar Wind Speed



Shock Occurrence Rate & Pressure Change at Shocks





Why More Forward Shocks

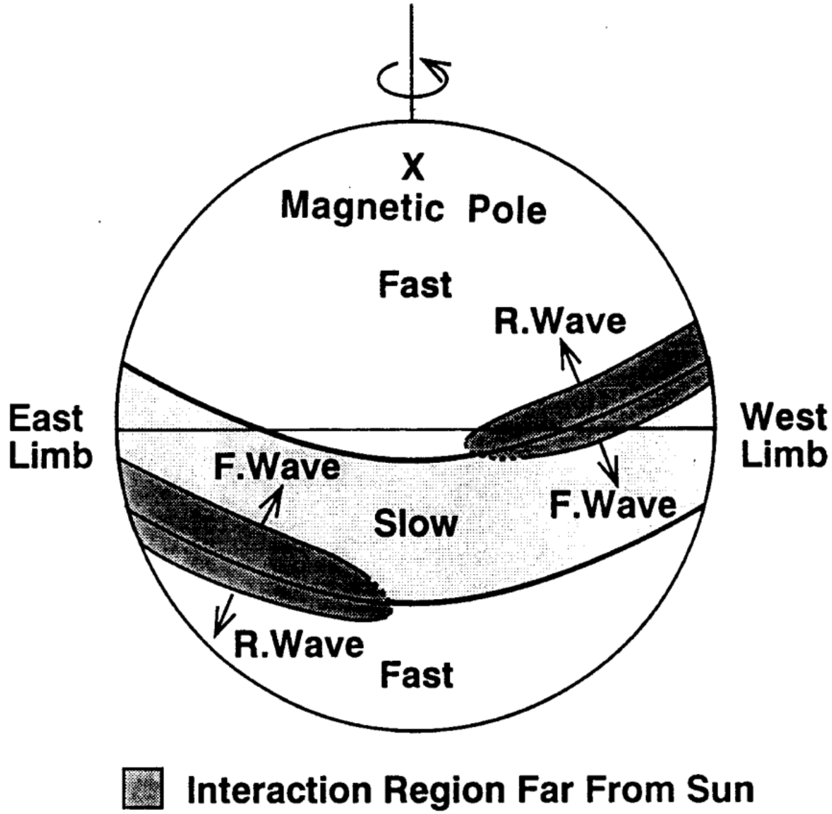
- Assuming the wave propagates perpendicular to ***B***, the fast magnetosonic wave speed V_{MA} is $\mathbf{(V_A^2 + C_s^2)^{1/2}}$.

- Acceleration region of a slow stream (1), deceleration region of a fast stream (2):

  $N_{P1} > N_{P2}$, & $T_1 < T_2$

  → $\mathbf{V_{MA1} < V_{MA2}}$.

- For a same velocity change along the interface normal, the Mach number in the acceleration region of a slow stream would be larger than in the deceleration region of a fast stream, *i.e.*, the forward shock is easier to form.



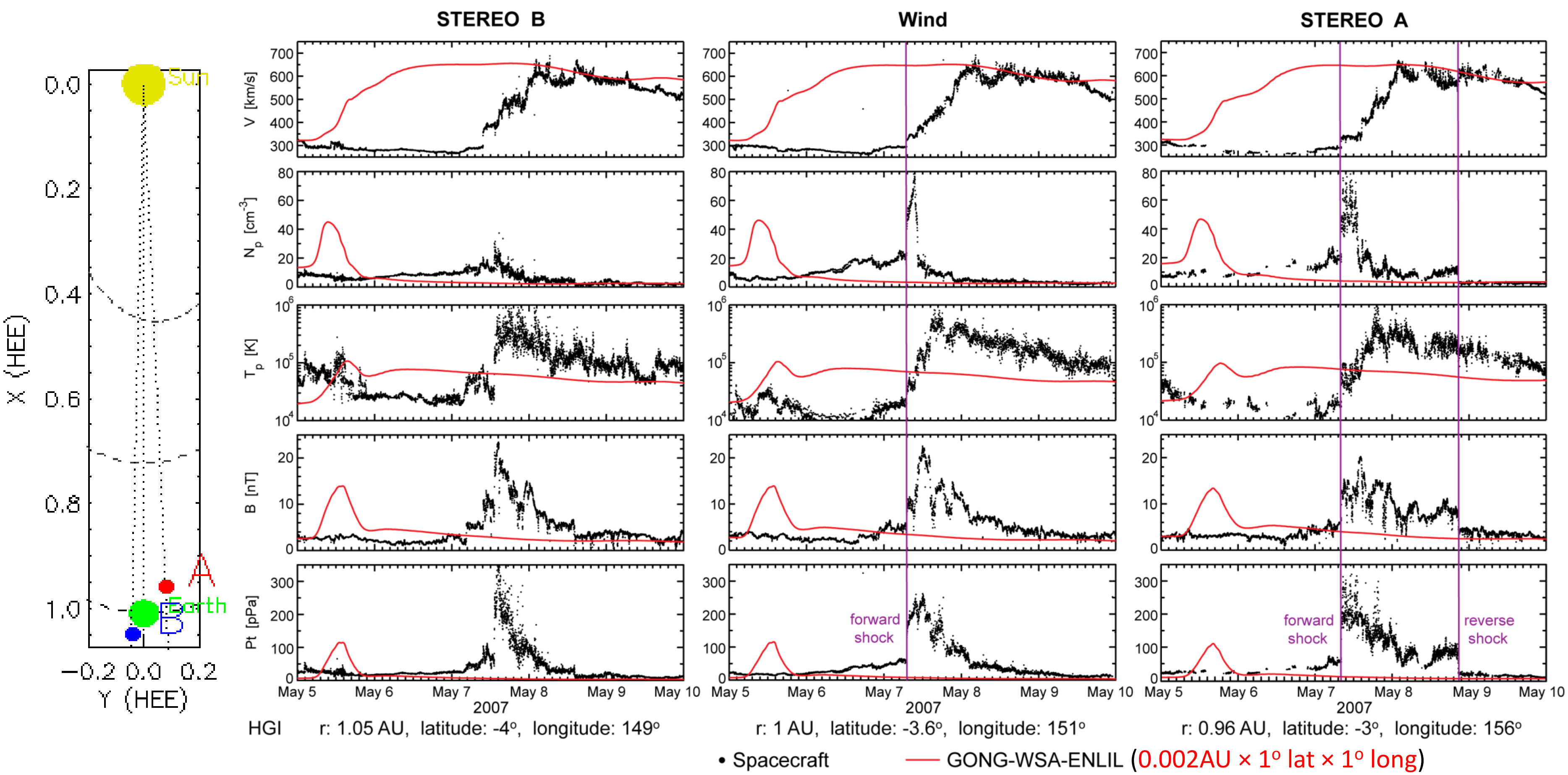
(*Gosling*, 1996)

Multi-Spacecraft Observations of SIRs & the Comparison with ENLIL Modeling Results

(after *Jian et al.*, 2009)

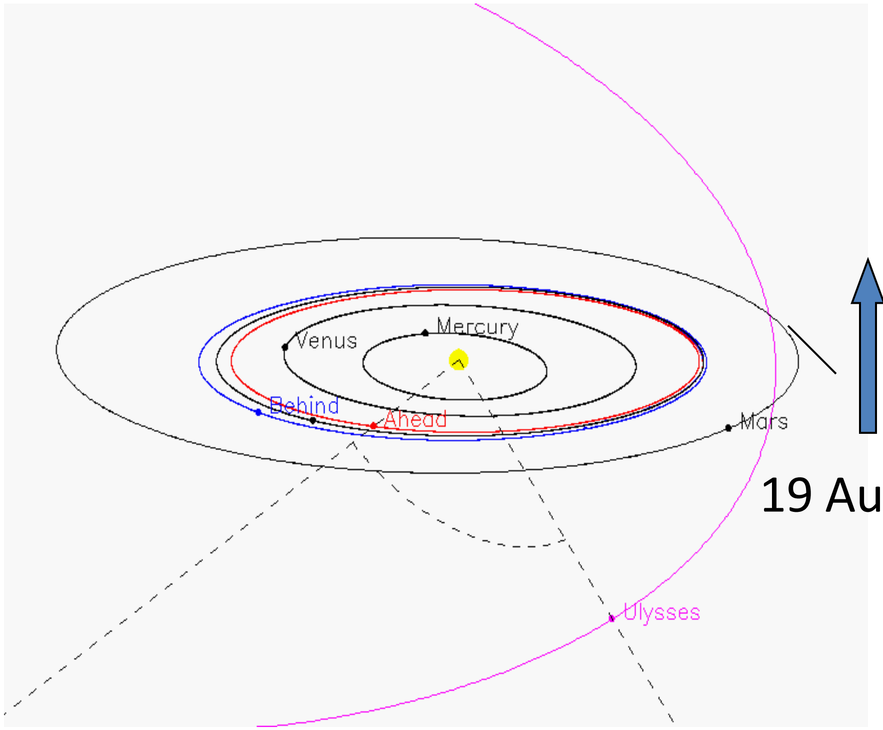
Acknowledge staff at CCMC for running the models

7-8 May 2007 SIR

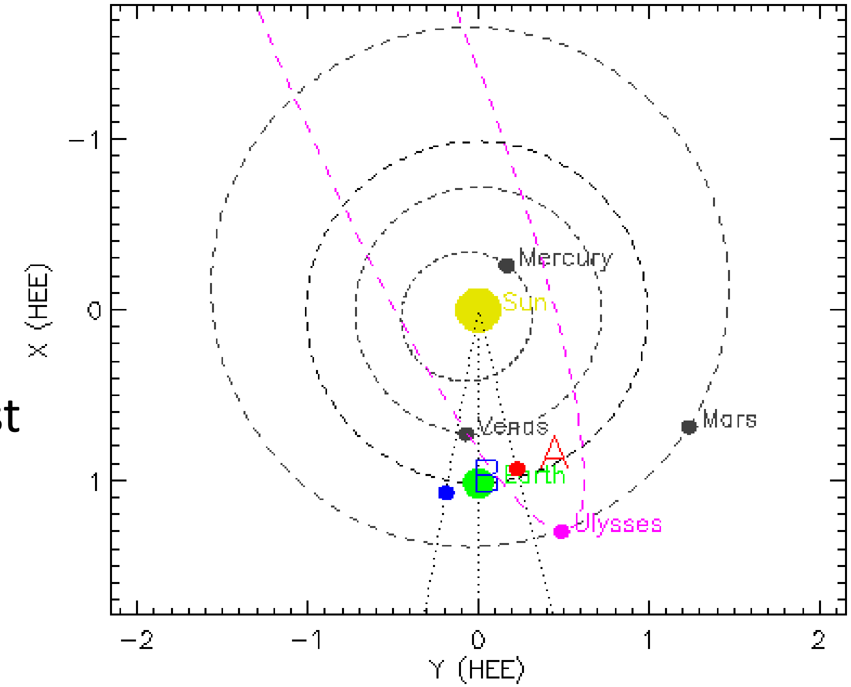


- With small spatial offset between STA and STB (0.09 AU in R, 1° in lat, 7° in long), the Np, B, and Pt observed at the two spacecraft are very different
- Wind: an intermediate stage between STB and STA
- Different observations of shocks: SIR shocks at 1 AU are transient and small structures and they are still under development at 1 AU

5-11 August 2007 SIR: Spacecraft Position



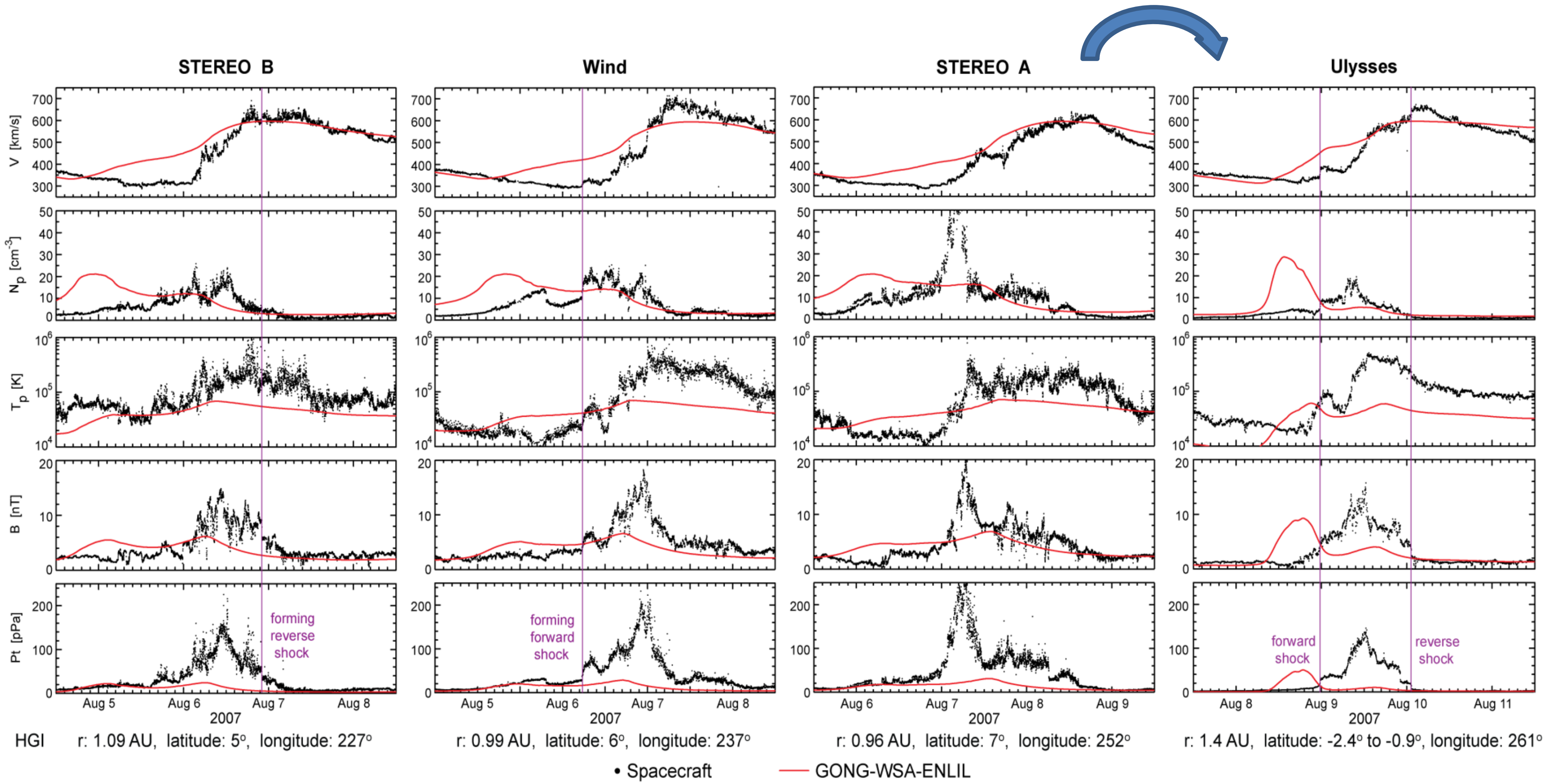
9 August



Ulysses orbits the Sun from south to north hemisphere

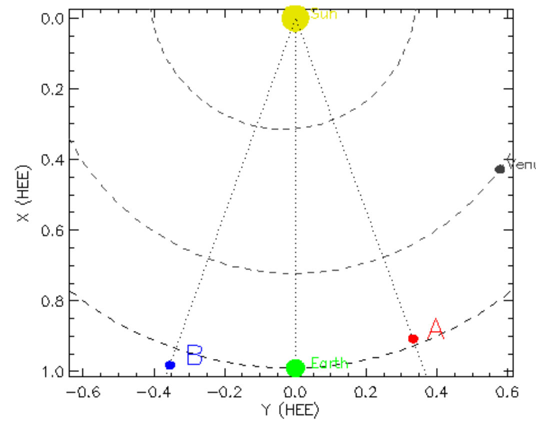
- ecliptic plane passage: 19 August 2007
- solar equatorial plane passage: 11 August 2007

5-11 August 2007 SIR: S/C Observations

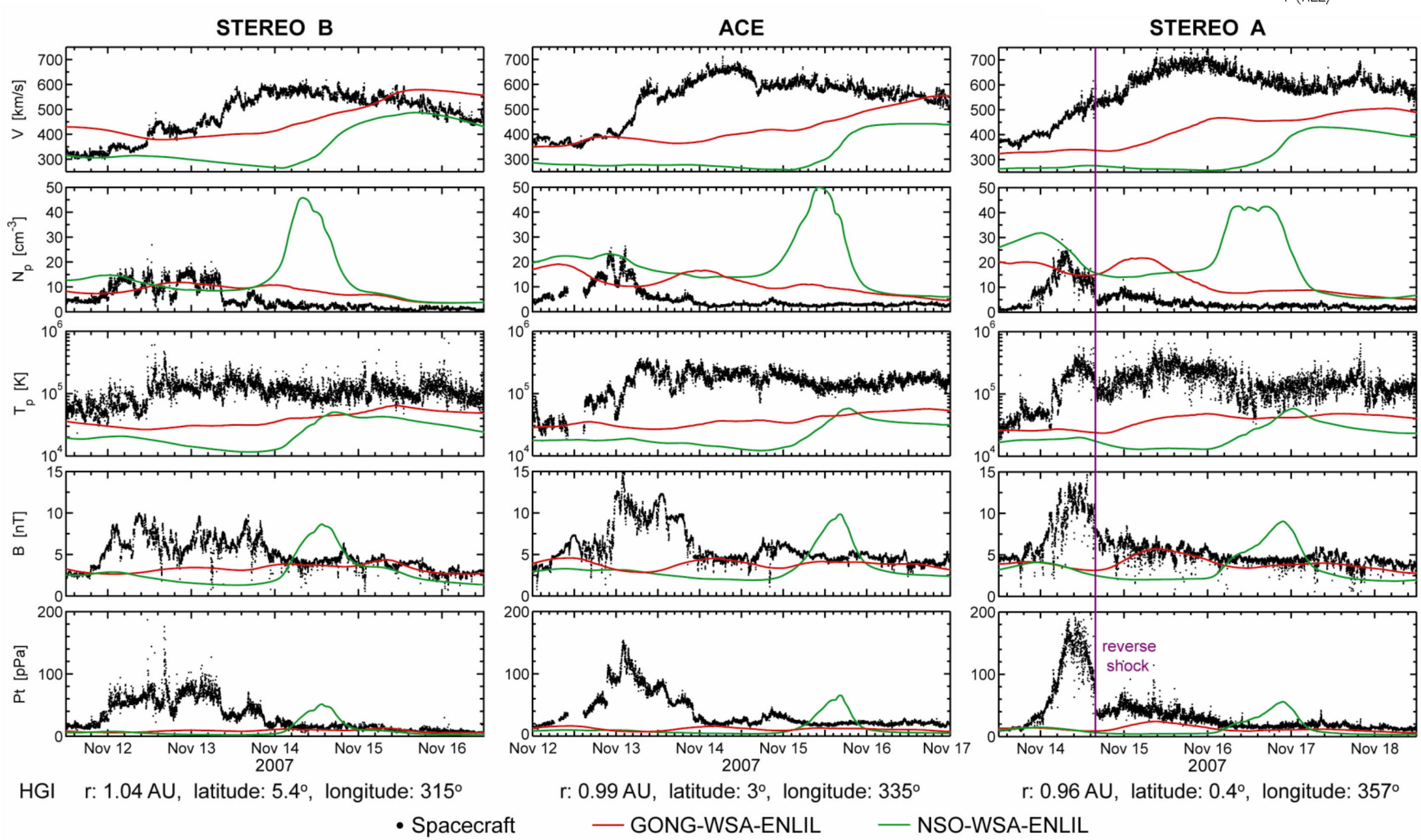


- SIR shocks at 1 AU are still growing
- From STA to Ulysses, the SIR became smaller, probably because the compression effect was stronger than the expansion effect. Meanwhile, the shock pair formed
- GONG-WSA-ENLIL model cannot reproduce variations between 1-AU s/c and the parameter variation trend at 1.4 AU. The Pt is under-estimated significantly at both 1 and 1.4 AU

12-16 November 2007



- SIR arrival time from the models is 1-2 days later than observed
- Different solar synoptic maps ➔ very different model results
- Neither of the models can reproduce variations between s/c although they are separated widely



Summary and Conclusions

- **Properties of SIRs at 1 AU (564 events over 15 years)**
  - 27% of SIRs drive shocks, 63% of these shocks are forward shocks
  - 66% of SIRs recur in one solar rotation period
  - 58% of SIRs occur near HCS crossing
- **Solar Cycle Variation**
  - More SIRs and CIRs, higher CIR fraction in declining phase and solar min 23/24
  - Lower HCS association rate at solar min & solar max
  - Longer and wider in the declining phase
  - 2009: weakest compression of field and total pressure, slowest speed
- **Multi-Spacecraft Observations**
  - Spacecraft separated by small offset can observe SIRs as differently as s/c separated widely
  - SIR-driven shocks at 1 AU are small, transient, and still developing
- **Comparison with WSA-ENLIL Modeling Results**
  - The model does not always predict a right arrival time for SIR
  - It often under-estimates the temperature increase, the field and pressure compression
  - The model cannot capture the difference between multi-s/c observations