The Radial Variation of Interplanetary Shocks

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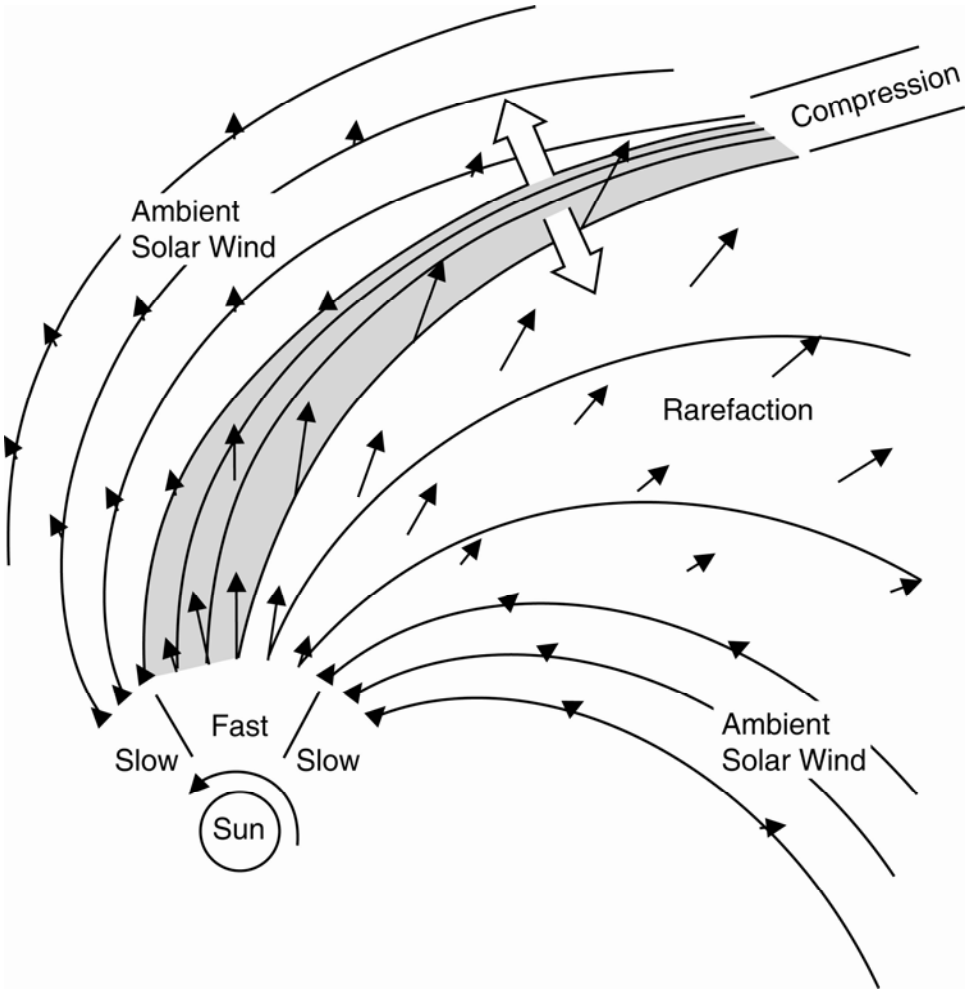
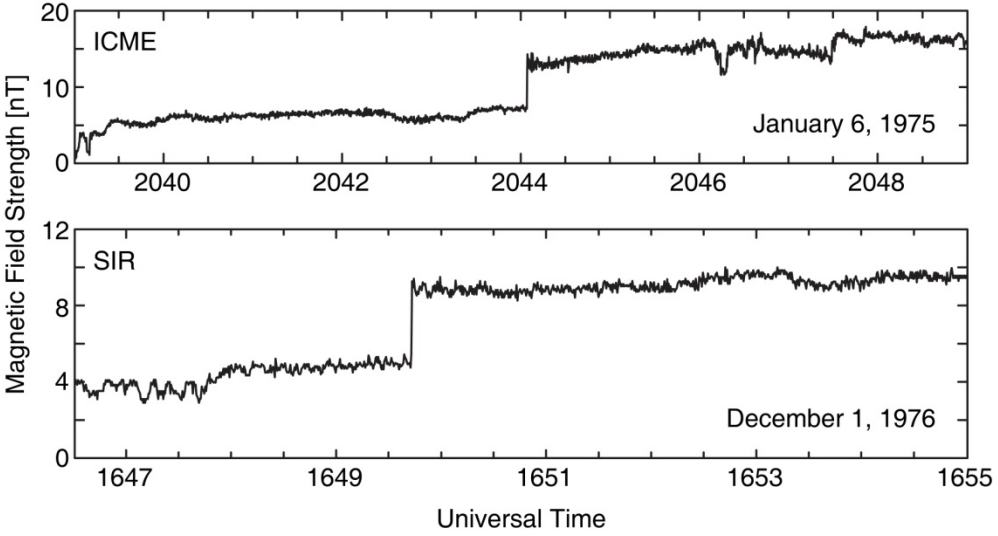
Interplanetary Shocks

- Two sources of interplanetary shocks are stream interactions and ICMEs.
- Stream interactions strengthen with distance from the Sun and are present at low and high solar activity.
- ICMEs weaken with distance from the Sun and are much more prevalent at solar maximum.
- Interplanetary shocks accelerate Solar Energetic Particles and produce radio waves, both phenomena of interest to the STEREO community.
- So how do interplanetary shocks evolve with heliocentric distance?



Shock Identification

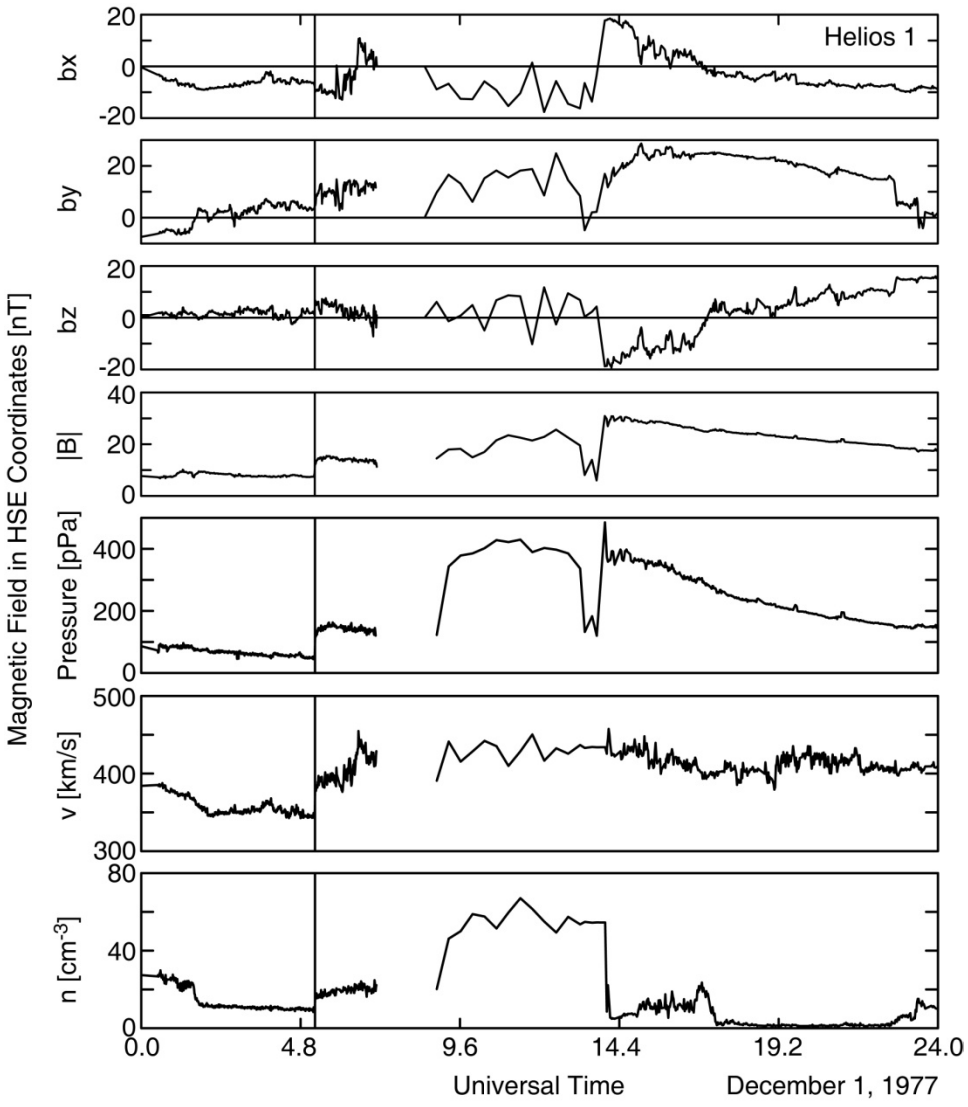
- Helios obtained data from 0.29 to 1.0 AU in the period 1975 to 1984. There were 2 Helios spacecraft launched separately in successive years.
- Magnetometer data were sometimes obtained with 4 Hz resolution. The plasma data was available with 40s cadence at best. The data had many gaps.
- It is possible to identify shocks unambiguously with the high-resolution magnetometer data and to normalize their occurrence rate to account for the gaps.
- It is less easy to attribute them as ICME or stream interaction driven.



Helios Shocks

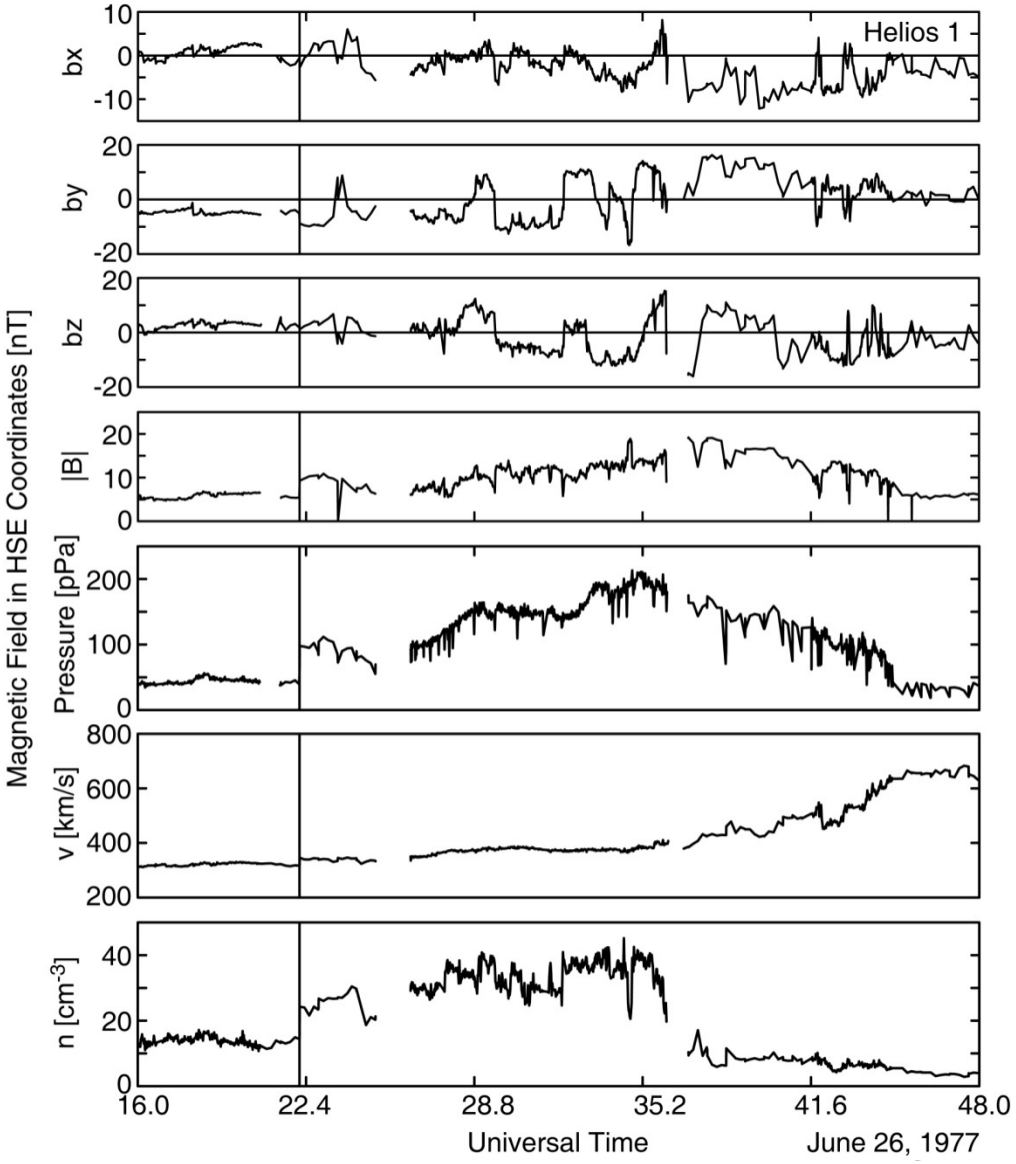
ICME-Driven Shocks

- If we have relatively gap-free data, we can identify ICMEs by their magnetic twist and increased field strength and their pressure profile.
- We expect ICMEs to expand and weaken as they move outward.
- Studies show that they may continue to expand until past 5 AU.
- Their shocks do not weaken as they do because the magnetic field decreases much faster than the square root of density or the temperature so that the magnetosonic Mach number declines with increasing heliocentric distance.



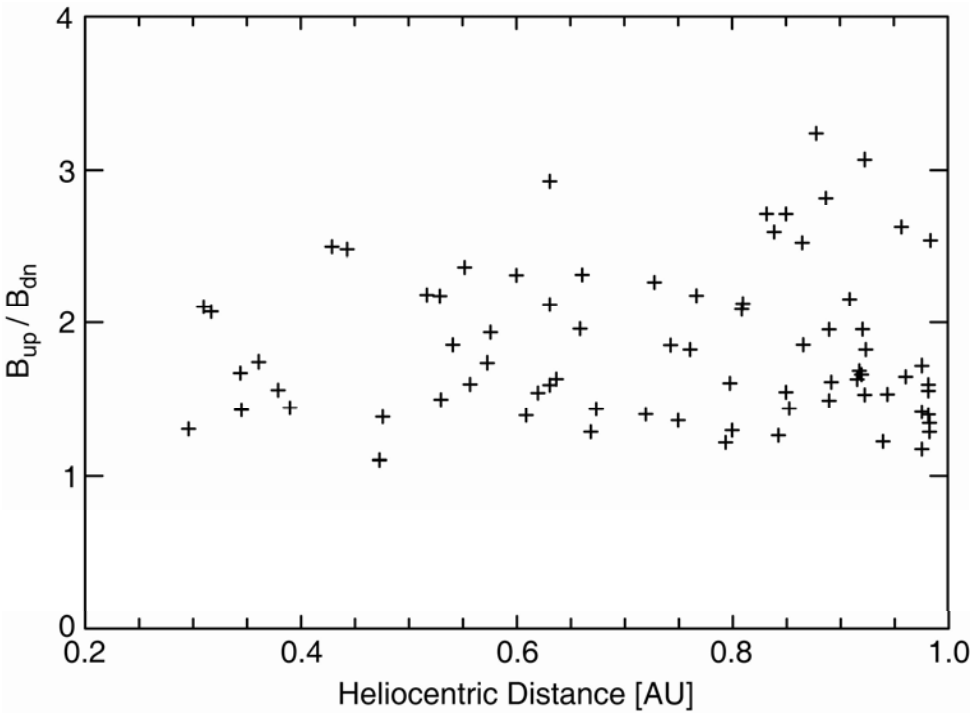
SIR-Driven Shocks

- If we have relatively gap-free data, we can identify SIR-driven shocks by the velocity profile of the solar wind plasma. Also, the total pressure helps to identify the SIR.
- We expect SIRs to be weak near the Sun and to strengthen as they move outwards and the streams collide.
- The shocks do not form until the velocity change across the SIR exceeds the fast magnetosonic speed. This speed declines with increasing heliocentric radius.



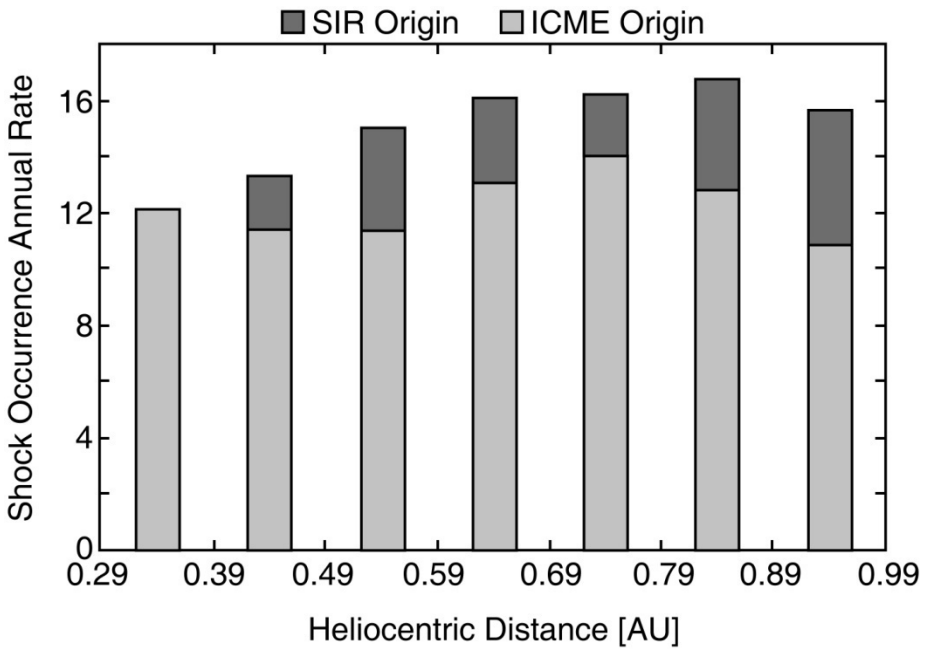
Shock Strength versus Heliocentric Distance

- The jump in field strength across interplanetary shocks depends on the change in plasma velocity across the shock compared to the magnetosonic speed and the direction of the upstream magnetic field to the shock normal as well as to a weaker extend on the plasma beta, the ratio of plasma to magnetic pressure.
- A simple measure, albeit approximate, of the shock strength is the change in field strength across the shock.
- The radial variation of shock strength at Helios indicates that weak shocks occur at all distances but stronger shocks occur just at greater distances.
- This plot gives the impression that shock number increases rapidly with heliocentric distance but that is because the occurrence rate is unnormalized.



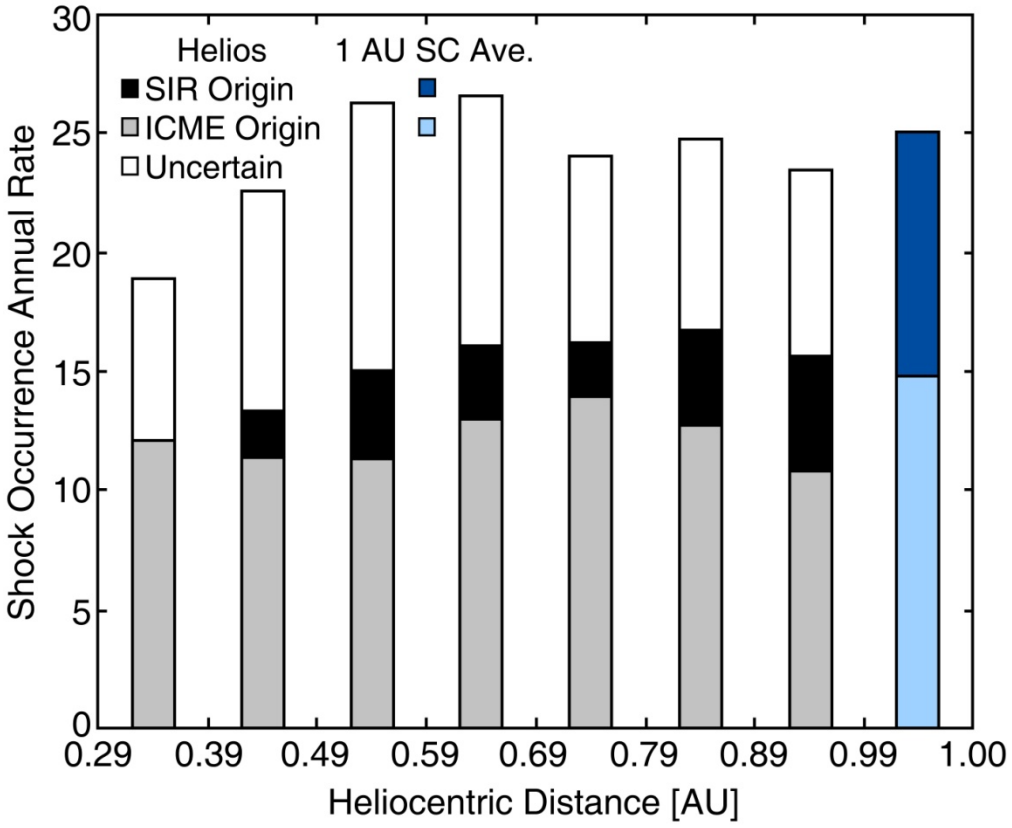
Shock Occurrence Rate versus Distance

- If we normalize for the availability of data at each distance, we see a slight increase in shock occurrence with radial distance.
- Since we are trying to determine the cause of the shock as well as their radial variation, we only count shocks here whose source we know. The total rate is somewhat higher.
- SIR-driven shocks are seen over a range of distances, but we seldom see them close to the Sun. They occur in greater numbers further from the Sun.
- Since SIR shocks are forming in this region, they are generally the weakest shocks and ICME shocks are the strongest shocks.



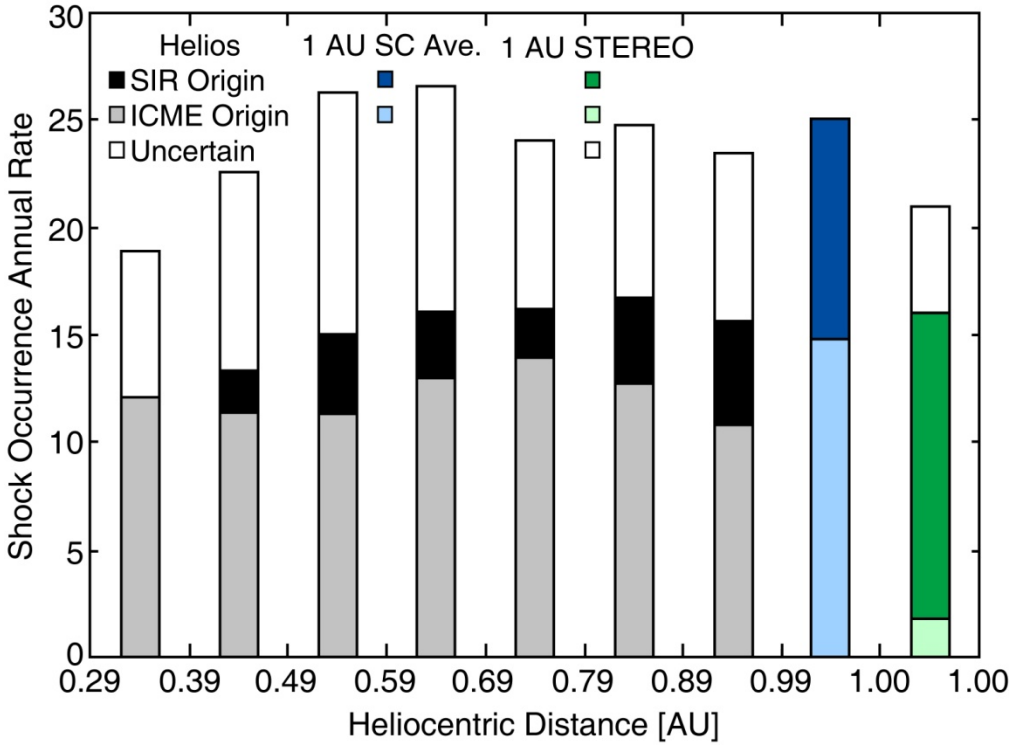
How Do the Helios Statistics Match Up with Wind and ACE at 1 AU?

- We have much better statistics at 1 AU. We can compare with the occurrences of many hundreds of shocks over an entire solar cycle.
- Here we compare with the Wind and ACE statistics of Jian et al. (2006a, b).
- The number of shocks seen by Wind and ACE is consistent with the Helios shocks at 1 AU when the number of uncertain identity shocks is included.



How Do the Helios Statistics Match up with STEREO at 1 AU?

- STEREO was launched at the beginning of the deepest solar minimum of the space age, perhaps the deepest in over 200 years.
- The occurrence of ICME-driven shocks is much less frequent than expected from the average conditions studied by Helios, Wind, and ACE.
- However, the number of shocks is not unusually small. Fewer ICME-driven shocks have been replaced by more SIR-driven shocks.



Summary and Conclusions

- Shocks on average grow stronger as they propagate from the Sun to the Earth.
- Near the Sun, the shocks appear to be all ICME-driven.
- SIR-driven shocks begin about 0.4 AU.
- SIRs produce weak shocks initially so there is a population of weak shocks within the inner solar system.
- The Helios shock data are similar at 1 AU to those obtained by Wind and ACE averaged over typical solar wind conditions.
- The Helios, Wind and ACE data are very different at 1 AU than the STEREO data in 2007, 2008 and 2009.
- There are now many mainly weak shocks - most SIR-driven, not ICME-driven.