Evolution of Interplanetary shocks through the inner heliosphere

C.A. Pérez-Alanis[1], M. Janvier[2], T. Nieves-Chinchilla[3], E. Aguilar-Rodriguez[4], P. Démoulin[5], P. Corona-Romero[6]

[1]Posgrado en Ciencias de la Tierra/IGF/UNAM. [2]Institut d'Astrophysique Spatiale. [3]GSFC-NASA [4]IGF/Unidad Michoacán/UNAM. [5]Paris Observatory Meudon, [6]CONACyT/UNAM.

SHINE 2022
June 27th – July 1th

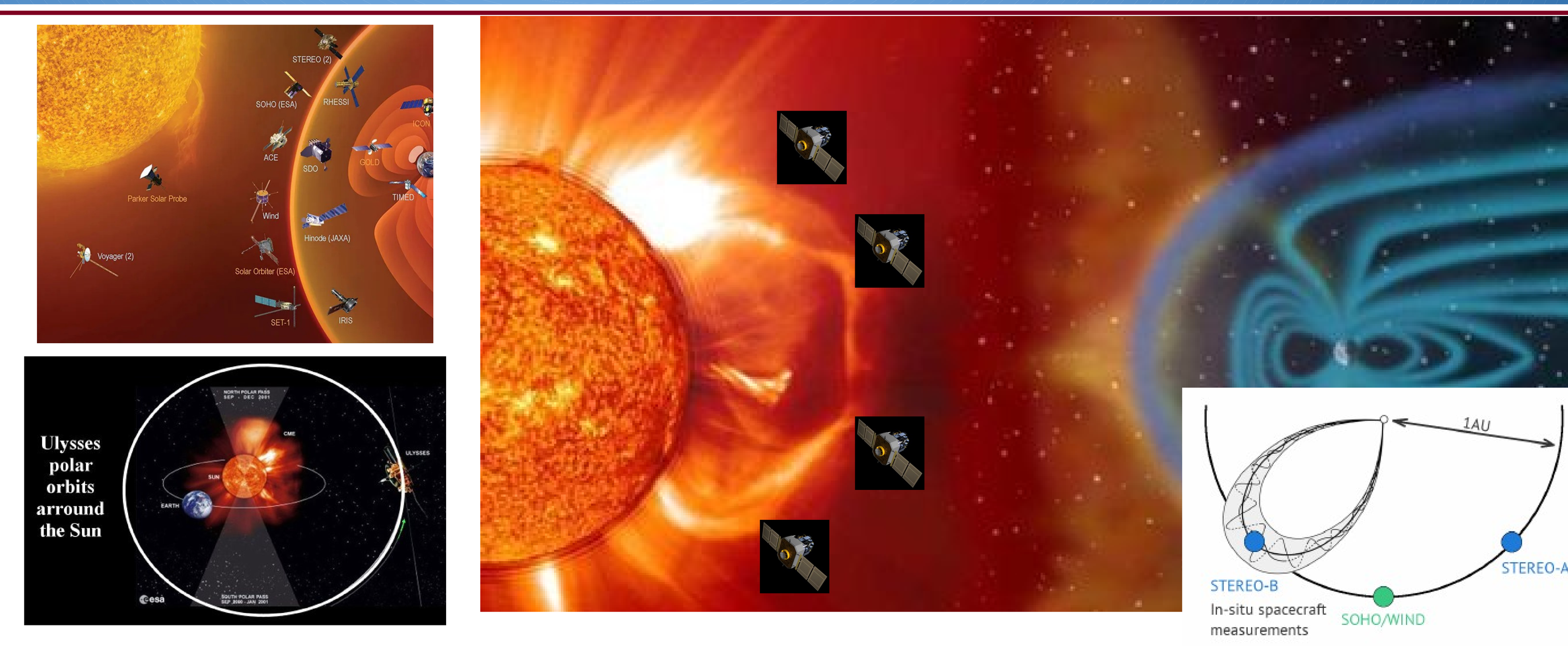
#141 WG2: Interplanetary

ABSTRACT

Hundreds of IP shocks and ICMEs have been detected at different times and heliocentric distances through several space missions.

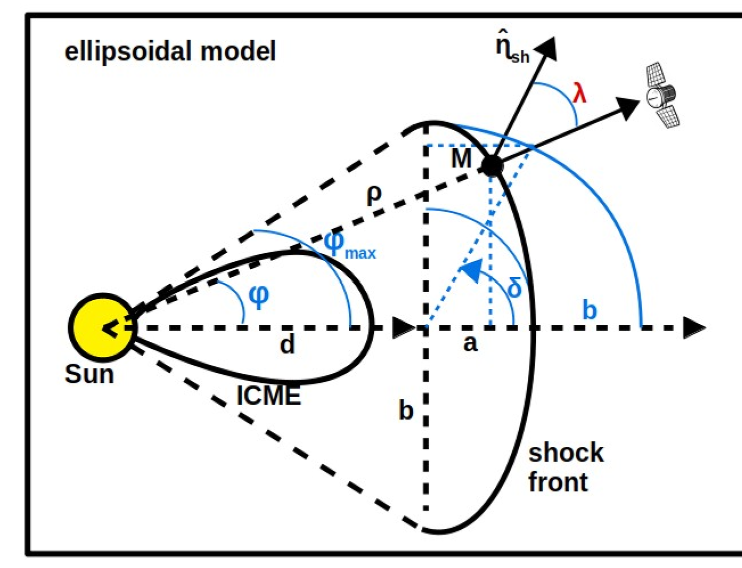
With in-situ observations from several solar missions, we are able to study the propagation of large-scale structures.

The main aim of this study is to present a statistical study of a large shocks events in order to understand the evolution of shock properties with the heliospheric distances. As well explore, through a statistical analysis of the shock orientations, if there are a preferential orientation of the shock normal vector around the Sun apex line.

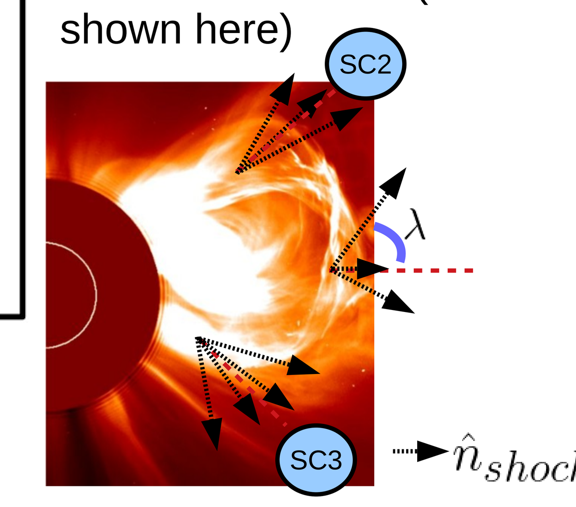


Measurements of the magnetic field and plasma are only available along the trajectory of the spacecraft, so its necessary to obtain a general view of the ICME structure. Through a statistical study of different points of view of the structure, we can determine the properties of the shock evolution in the inner heliosphere.

According with Janvier et al., (2014, 2015) we use the inclination angle ***i*** on the ecliptic, introduced to quantify the inclination between the projected vector $\hat{n}_{shock,yz}$ and the direction $\hat{y}$. (The angle ***i*** depend on the orientation of the shock normal vector and the coordinate system of the spacecraft). As well the location angle **λ** definied as the angle between the shock normal vector $\hat{n}_{shock}$ and the radial direction $-\hat{x}_{gse}$. **λ** informs the relative location of the spacecraft crossing the shock structure from the apex, if **λ**=0, it means that the spacecraft crosses the shock right along its apex.



The angle **λ** is useful to estimate the global shape of the shock front through a stadistical study of the shock orientations (not shown here)



Events selection

Total number of IP shocks

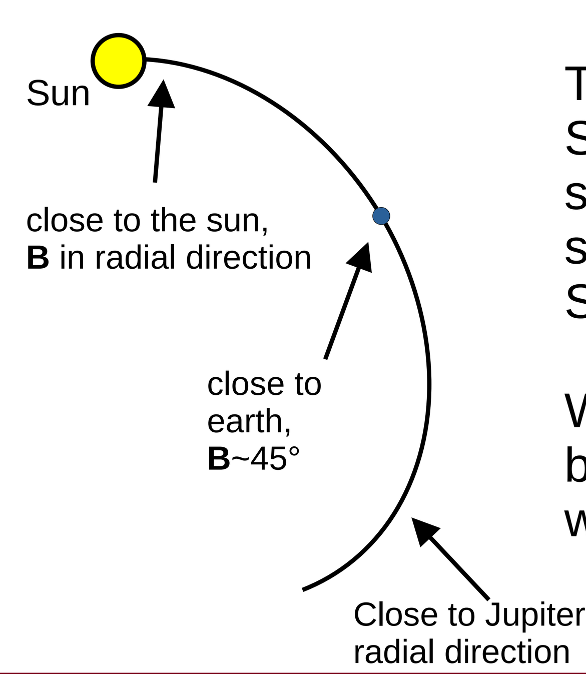
Spacecraft	Time coverage	R [au]	Source	No. events
Helios-A/B	1975-1981	0.29-0.99	a	103
Wind	1994-2017	1	a	469
ACE	1998-2013	1	a	255
STEREO-A/B	2007-2014	0.95/1.05	a	204
Ulysses	1990-2009	1.3-5.4	a	238
Number of shocks with an associated ICME				
Helios-A/B	1975-1981	0.29-0.99	e	30
Wind	1994-2017	1	b	185
ACE	1998-2013	1	c	125
STEREO-A/B	2007-2014	1	d	98
Ulysses	1990-2009	1.3-5.4	f	38

[a]https://ipshocks.fi/
[b]Nieves-Chinchilla *et al.* (2018)
[c]Regnault *et al.* (2020)
[d]Jian *et al.* (2006, 2013)
[f]Richardson (2014)

Table 2. Number of FF shocks observed by Ulysses, during 1990 to 2009, organized by different radial and latitude intervals.

Radial distance [au]	Heliographic latitude [θ] < |30°|	|30°| < θ < |60°|	| > 60°|	
[1, 2.5]	36	3	4	
[2.5, 4]	33	10	0	
[4, 5.5]	151	1	0	
Total	220	14	4	238

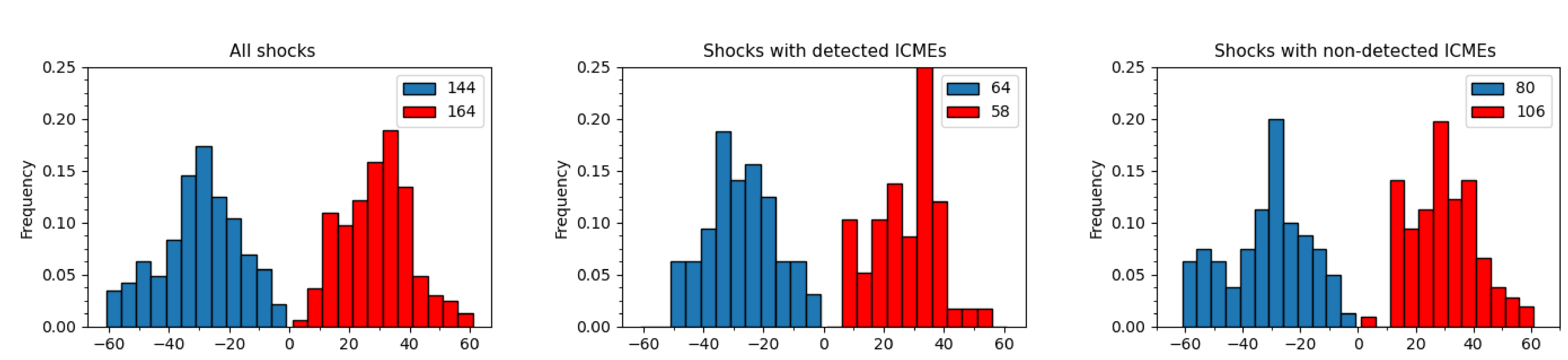
Is there an asymmetry in the east/west direction?



The majority of shocks observed at 1 au are generated by ICME launched from the Sun. For several years, the Sun launched CMEs from a large number of unrelated source regions with diverse orientations. If there is no preferential orientation in the sources, a spacecraft is expected to cross the shocks associated with the ICMEs (or SIRs) with an approximative uniform probability of λ.

We separate the shock events in two groups: those shocks where the angle ***i*** it is between [320°, 40°], corresponding to the east direction (± 40°), and for those shocks with ***i*** between [140, 220], corresponding to the west direction (± 40°).

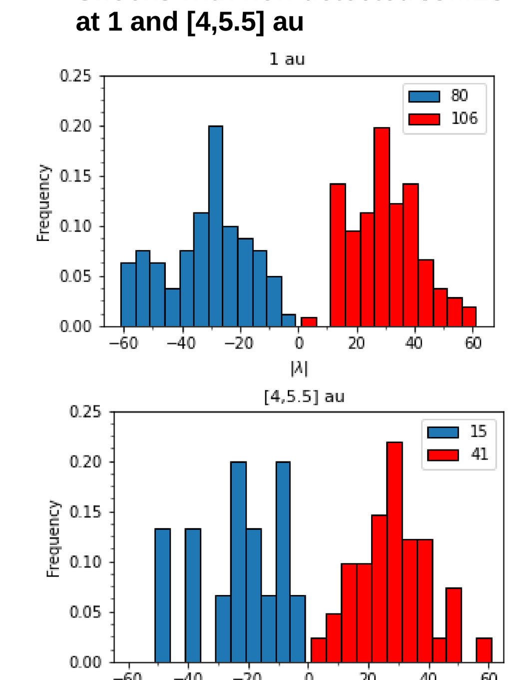
Distribution of the location angle λ



- The low number of ICME shock detected for small values of **λ** can be explained by the small extension of the shock surface near the apex. So that, there is less chance of crossing the shock near its apex that at other parts of the structure.

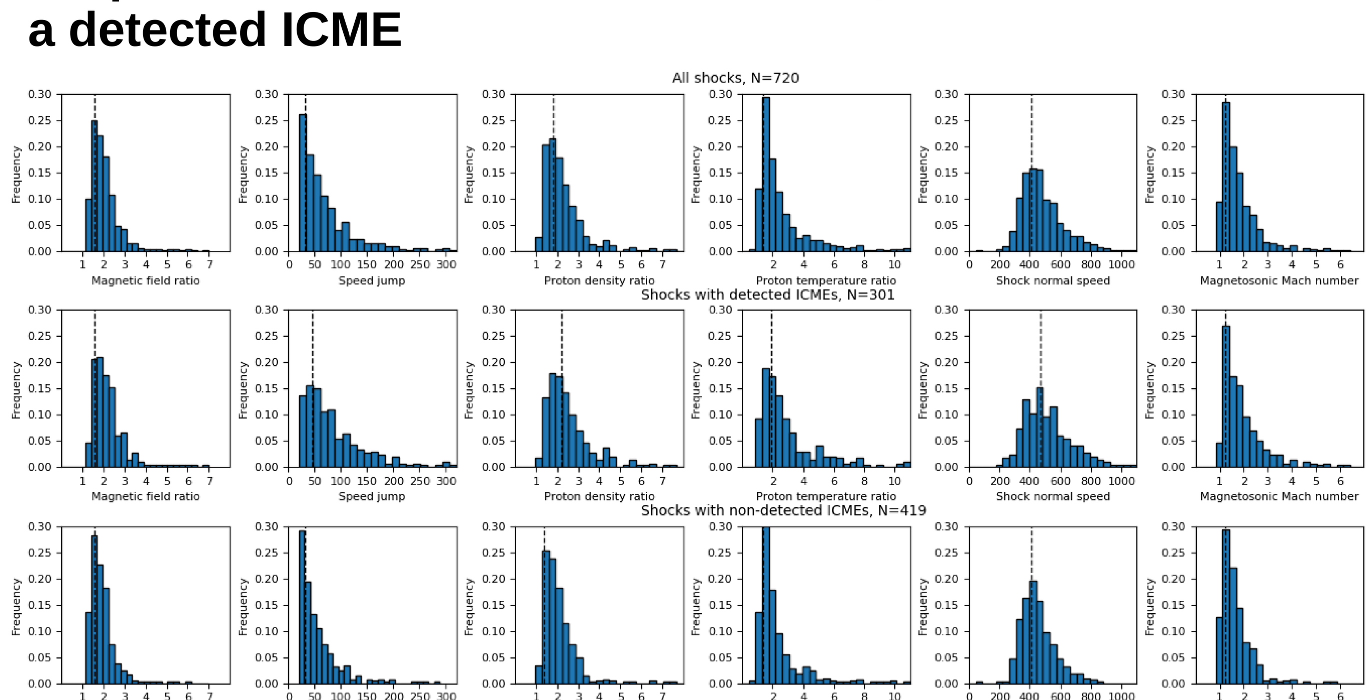
- For large values of λ, between 50° and 60°, there are more shocks without than with ICME behind. This is probably due that when a spacecraft cross the structures farther from the apex, the encounter with the following ICME is too near its boundary to detect the ICME, or even the crossing can be outside the ICME.

Shocks with non-detected ICMEs at 1 and [4,5.5] au



- We do not find a clear evidence that there is a variation of **λ** angle as a function of the heliocentric distance.

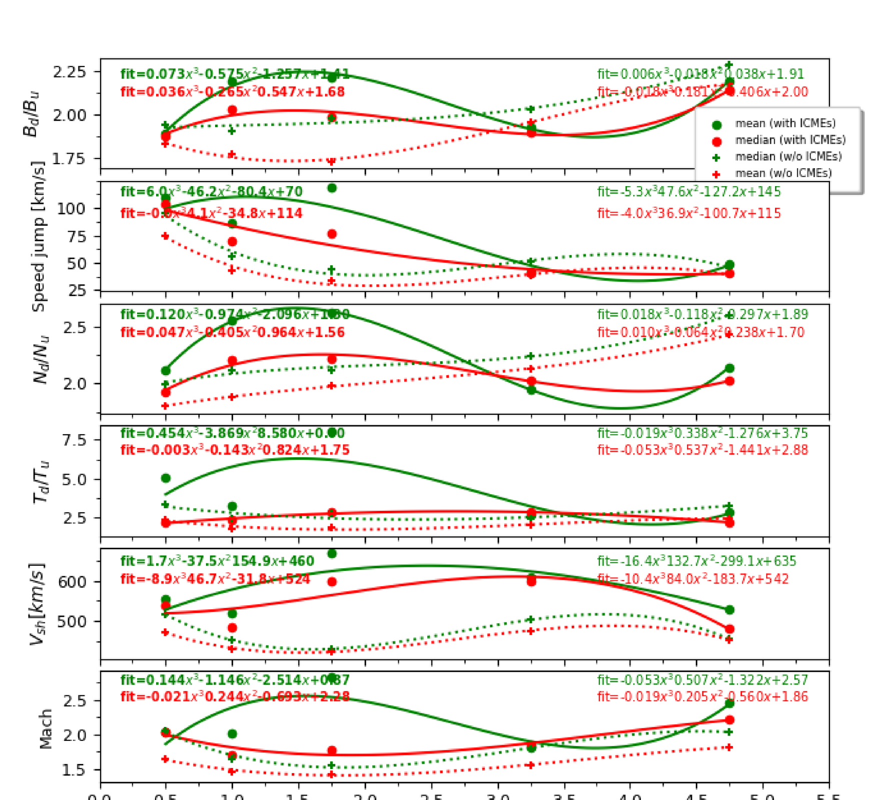
Properties distributions of IP shocks, with and without a detected ICME



- The fact that stronger and faster shocks are associated with a detection of an ICME is not surprising: indeed, faster and stronger shocks build up a more compressed sheath, and are also associated with a more intense magnetic field within the magnetic ejecta.

- The similarity of the distribution shapes, as well as the proximity in the values of the maximum values for all the parameters indicate that the most typical shocks with and without a detected ICME are similar.

Variation of mean (green line) and median (red line) values of the shock ratio properties from 0.3 to 5 au, for shocks with ICMEs (solid line) and shocks without ICMEs (dotted line) detected.



- The speed jump is decreasing with distance for both categories.

- The shock velocity do not show significant evolution with distance.

- The magnetosonic Mach number of both categories increases slightly with distance indicating stronger shocks with increasing distance.

- The shock properties have a weak evolution with heliocentric distances.

With observations of PSP or SO it is possible to complement this type of study to better understand the propagation of these structures.

- When a spacecraft cross the structures farther from the apex, the encounter with the following ICME is likely too near its boundary to detect the ICME, or even the crossing can be outside the ICME. Then, shocks with large |λ| values are expected to be more associated with no detected ICMEs.

- The results derived from the angle **i** indicate that there is no a indications of a bias induced by the Parker spiral.

- From Ulysses data, most shocks have no detected ICME behind while it is the reverse at and below 1 au. A possible interpretation is that shocks detected by Ulysses are most likely to be CIR/SIR, as the interaction between fast and slow winds needs time, so distance, to build up in a strong shock.

- The shock properties have a weak evolution with heliocentric distances.