Geoffective twisted flux ropes in the solar wind near Earth

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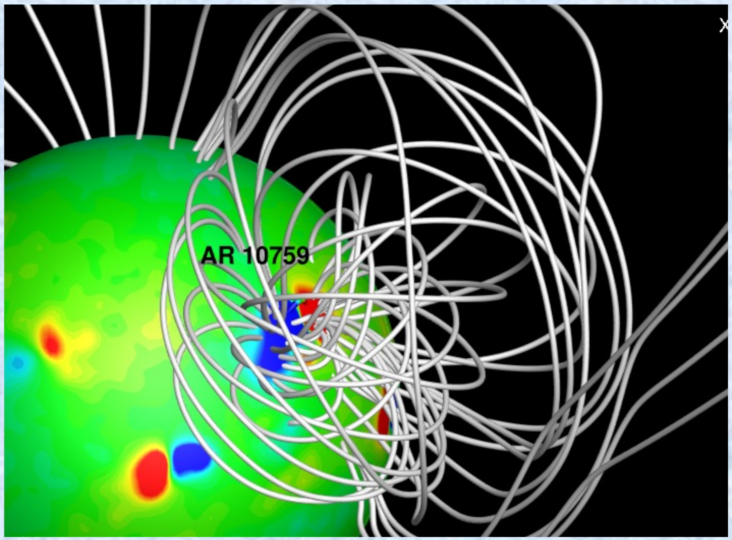
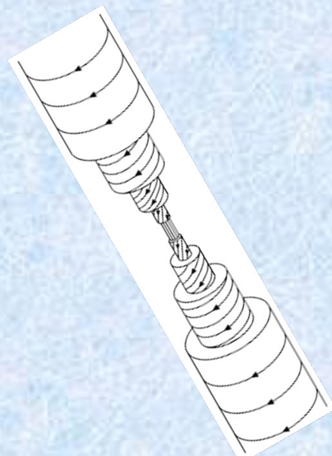
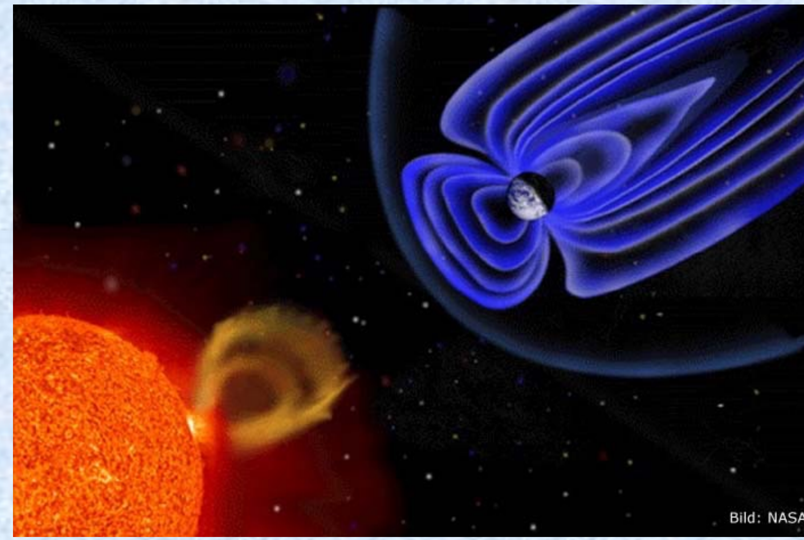
[in collaboration with Vanina Lanabere, Pascal Demoulin, Miho Janvier & Luciano Rodriguez]







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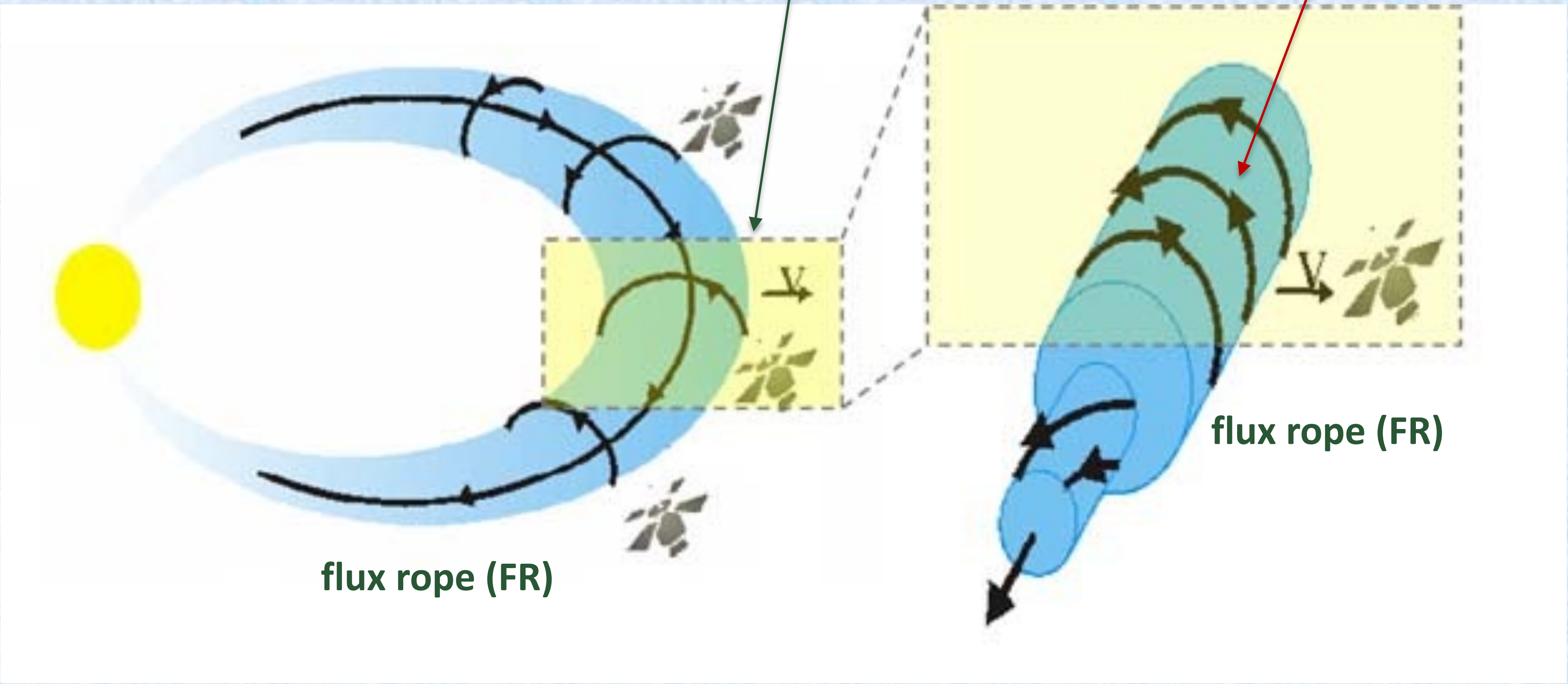
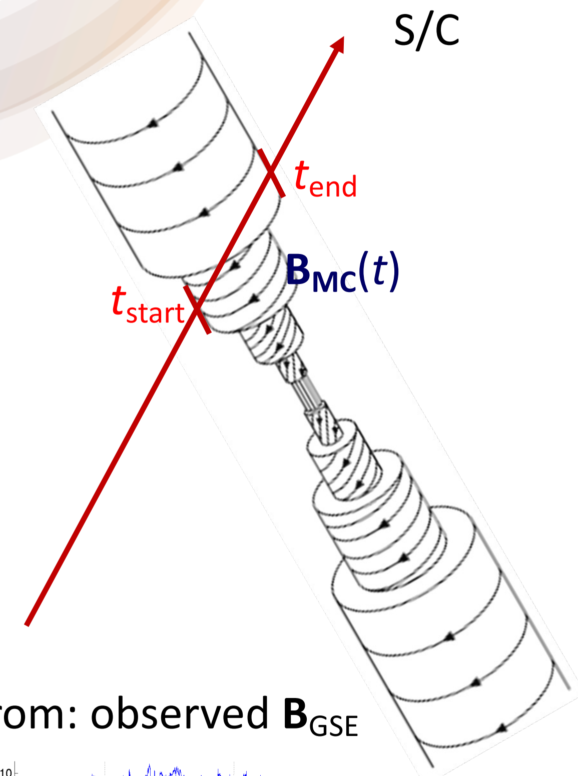
Some properties do not depend on the flux rope orientation, others yes

Scalars (more robust): density, Pressure, |**B**|, |**V**|, T, **β**, …

Vectors: e.g., axis direction, **B** in FR frame, twist, **B** fluxes, helicity, …



How to properly identify the Flux rope (FR) [proper analysis of in-situ observations]

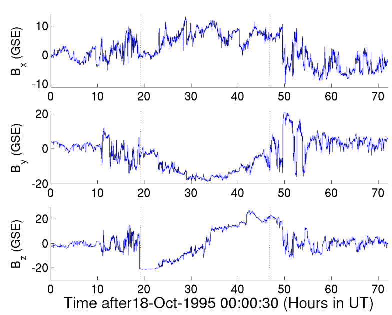


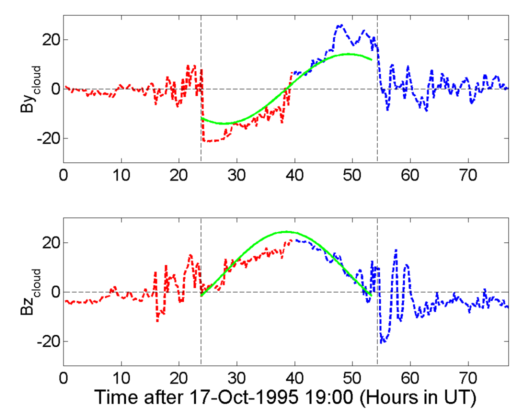
- Crucial to find the correct FR boundaries & orientation

- Different techniques-authors find significant differences

- vector components of $\mathbf{B}_{MC}(t)$ time series (local FR frame) to get major physical quantities: **magnetic fluxes, the magnetic helicity, and the distribution of magnetic twist.**

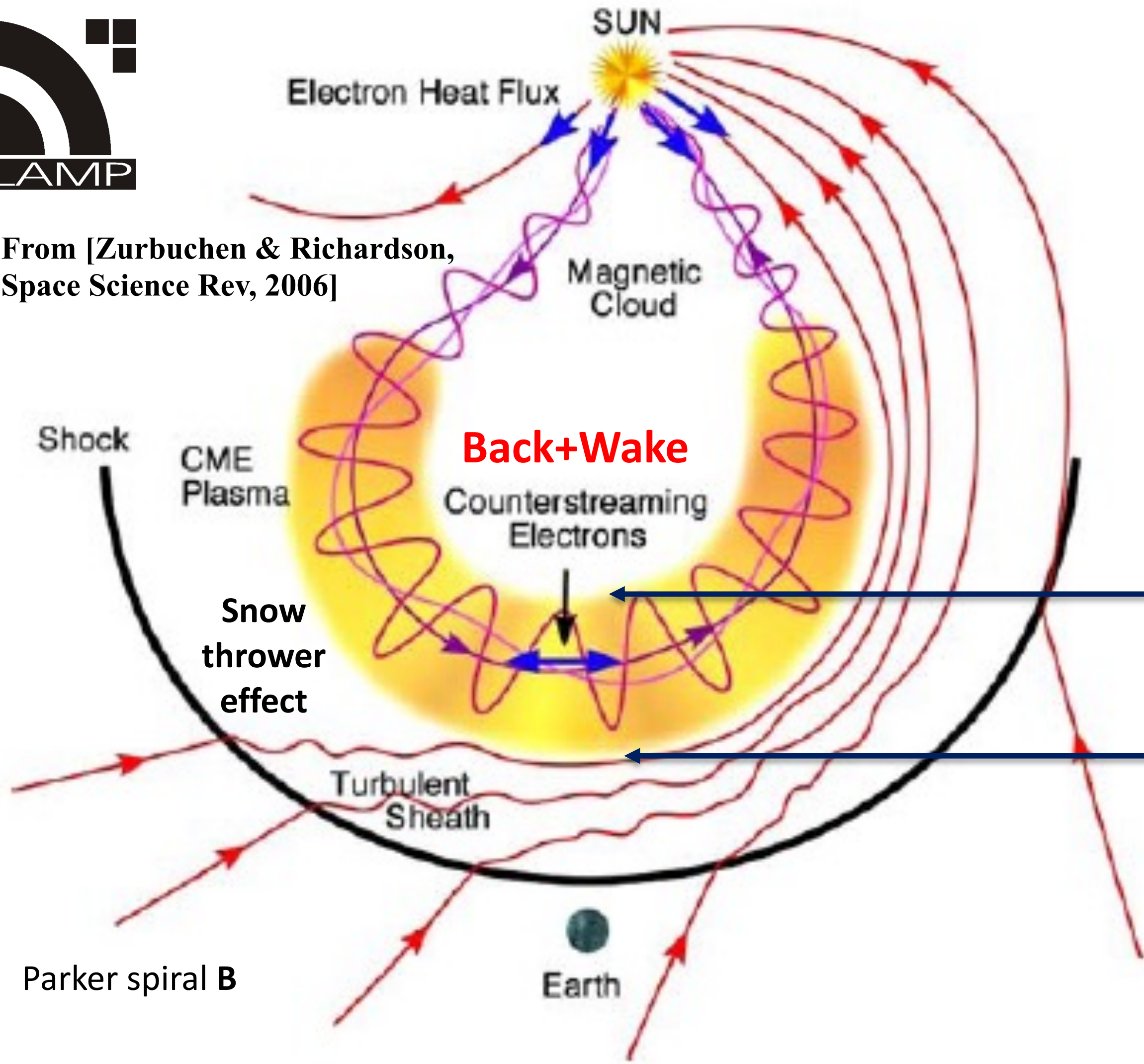
From: observed $\mathbf{B}_{GSE}$

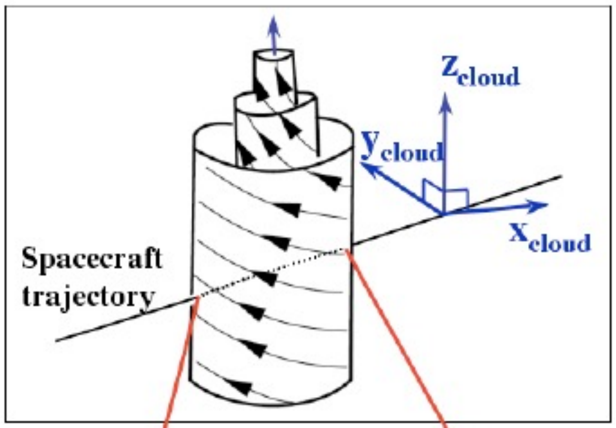




To: $\mathbf{B}_{FR}$ in local FR frame components

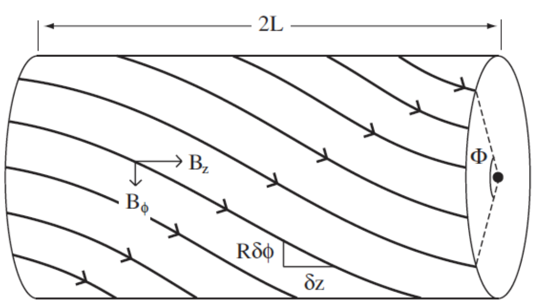
From [Zurbuchen & Richardson, Space Science Rev, 2006]





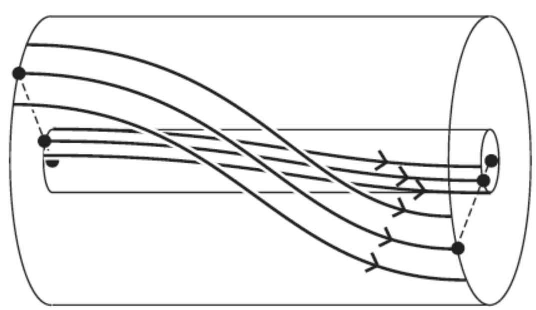
Critical to determine flux rope **boundaries**

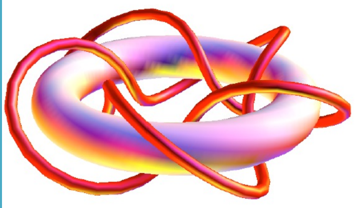
Critical to determine the flux rope **orientation**



$$\tau = d\theta/dz$$

$$\tau = B_\theta/(rB_z)$$





Implications of FR orientation (bad quality for assym B and large impact parameter) biases on Twist

- **Even in case of simple <u>cylindrical</u> FR cross section, transforming B_{GSE} to B_{FR} (local orientation) needs additional conditions to be properly done.**

- **Major quantities depend on the local B components: magnetic fluxes, magnetic helicity, twist distribution, etc.**

- For a cylindrical FR: $\mathbf{B}=B_z(r)\mathbf{z} + B_\phi(r)\boldsymbol{\phi}$, the amount of the magnetic field twist around the FR axis, $\tau(r)=d\varphi/dz=B_\varphi(r)/rB_z(r)$, has an avoidable singularity at the origin due to that $B_\varphi(r)\rightarrow 0$ when $r\rightarrow 0$, being $\tau_0=\tau(r\sim 0)$ a finite number.

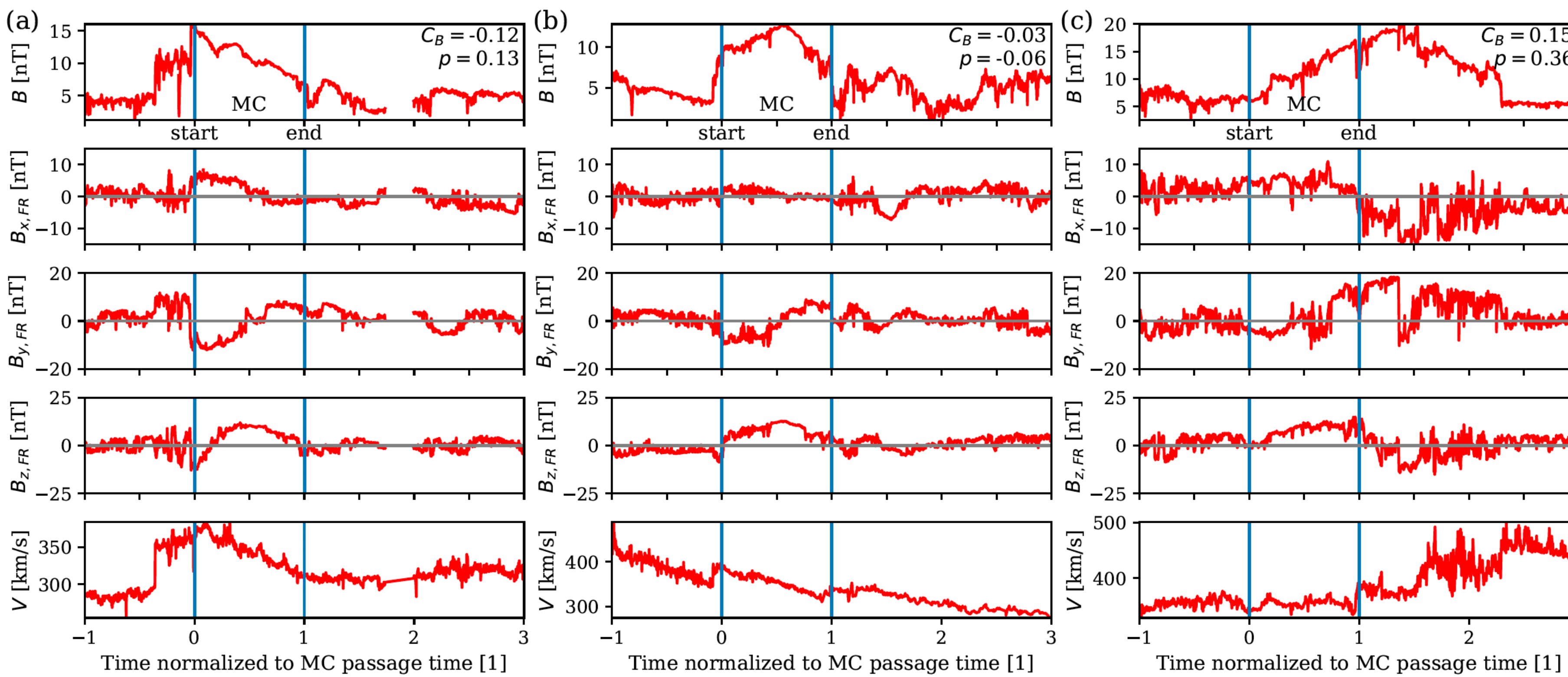
- **Thus, a small error in the orientation of the FR axis could strongly impact on the correct determination of the twist.**

Quantifying the assymmetry of the B(t) profile

Parameter to quantify the assymetry of the time profile of B(t)

$$C_B = \frac{\int_{t_{\rm start}}^{t_{\rm end}} \frac{t-t_c}{t_{\rm end}-t_{\rm start}}\, B(t)\,{\rm d}t}{\int_{t_{\rm start}}^{t_{\rm end}} B(t)\,{\rm d}t} = \frac{\int_0^1 (t'-0.5)\, B(t')\,{\rm d}t'}{\langle B\rangle}$$

$C_B < 0$ | $C_B \sim 0$ | $C_B > 0$

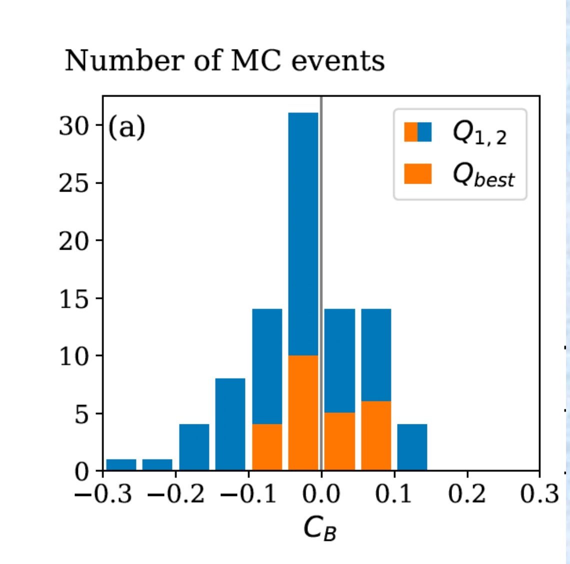


[From Lanabere+2020]

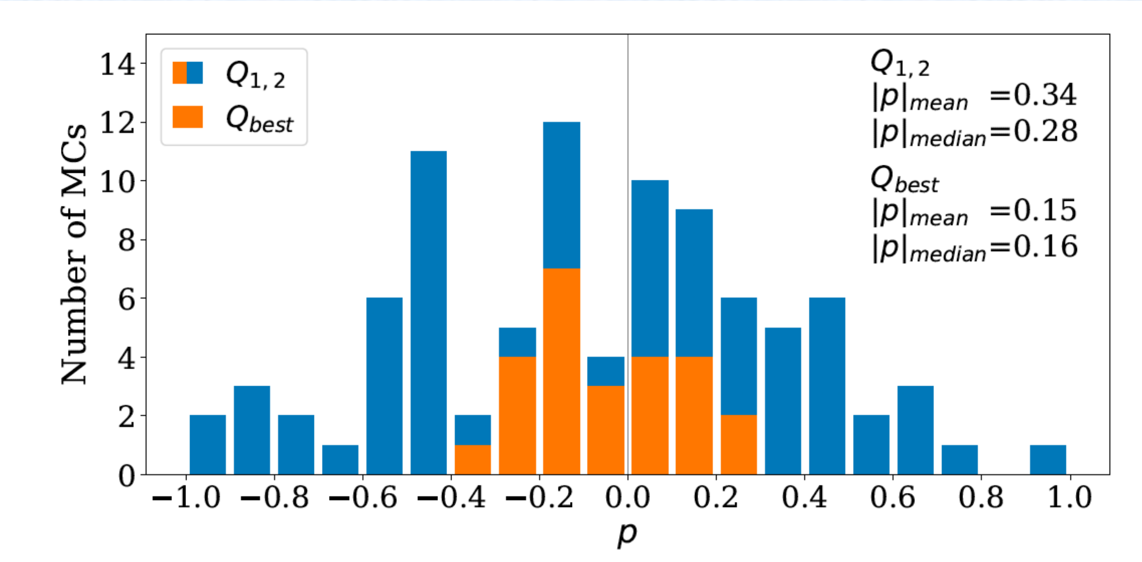
Data and sample used for the MCs analysis

- Analysis of MCs observed by Wind (MFI/SWE)
- Time range: 1995-2012
- Catalog of Lepping [Lepping+06]: Q1 & Q2

  - Almost 80% of cases presents $|C_B|<0.1$



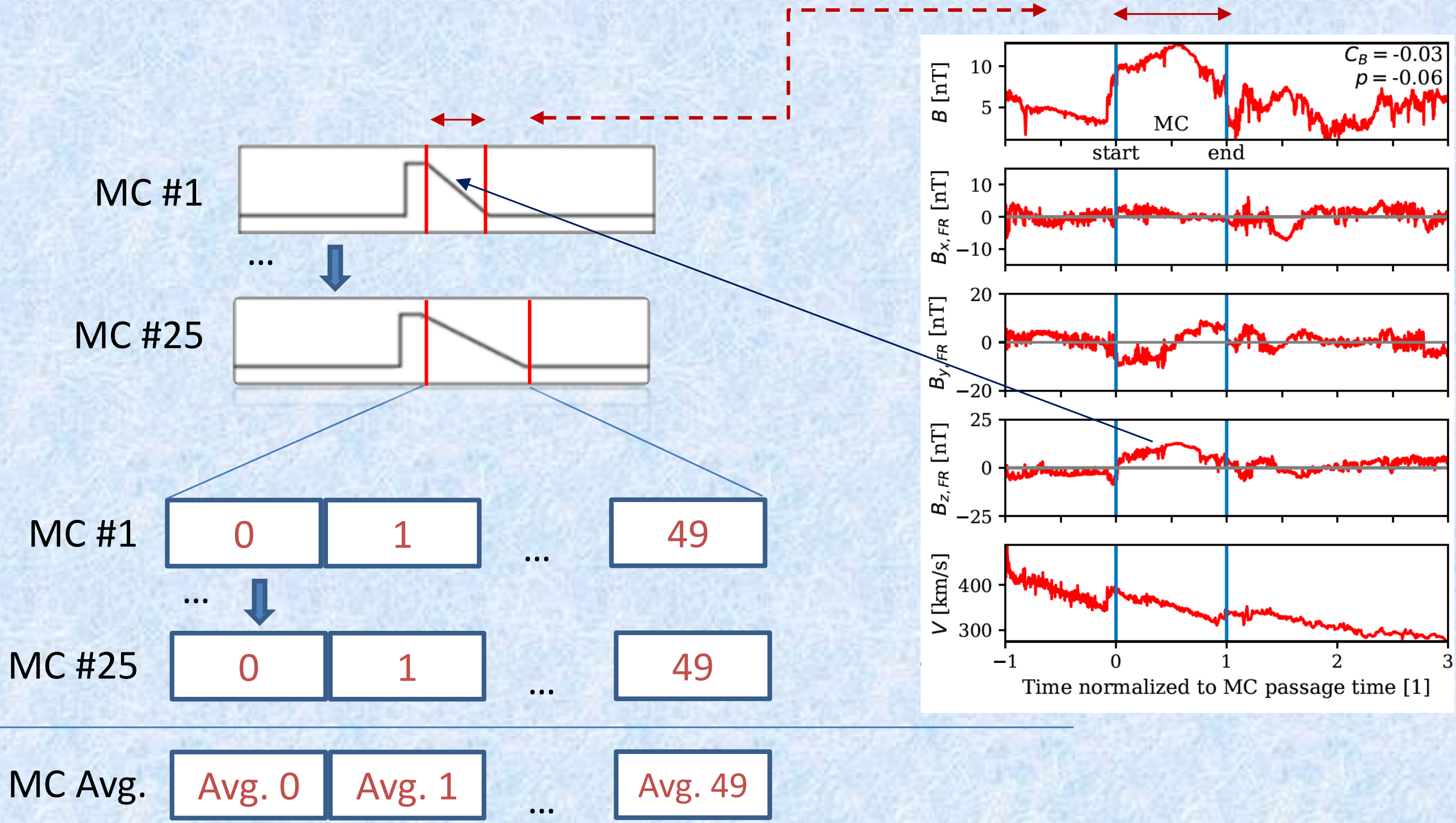
[From Lanabere+2020]



Selection of 25 MC (Q_{best}):

- Q1 and Q2 (Lepping's quality)
  - $|p| \leq 0.3$
  - $|C_B| \leq 0.1$

Superposed epoch method
(common features)

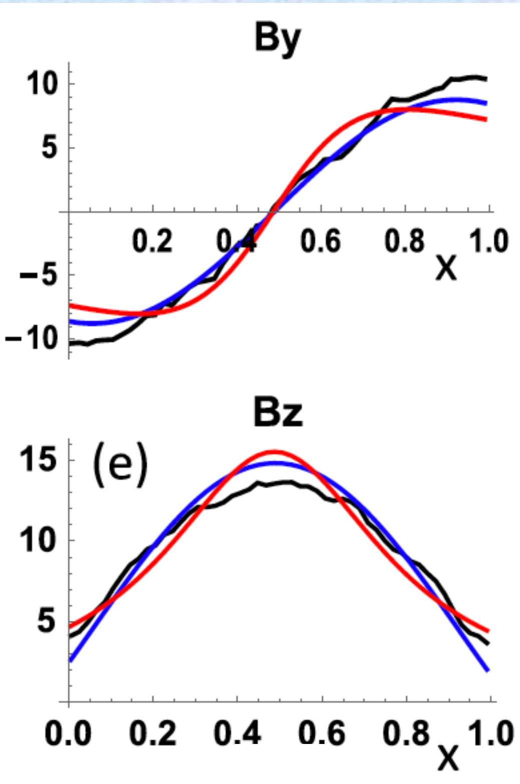


Superposed epoch for components of B in flux rope frame

[From Lanabere+2020]

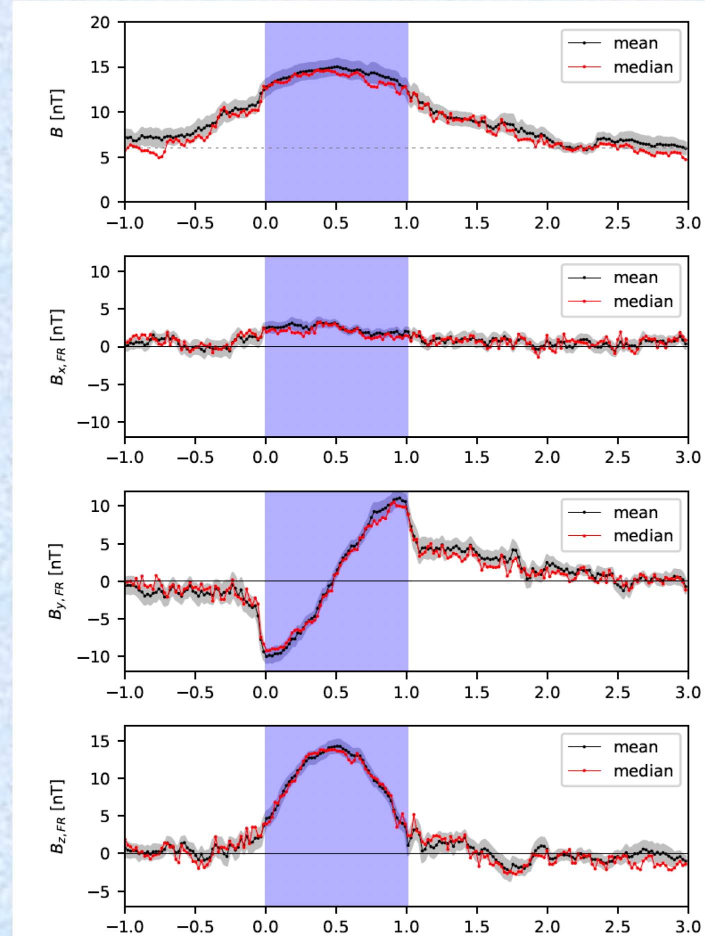
Time normalization [$t_{start,FR} = 0$ & $t_{end,FR} = 1$]

Helicity and impact parameter sign are considered to get the same pattern for $B_{x,FR}$ and $B_{y,FR}$



Lundquist (blue) and Gold-Hoyle (red) fitting to the observed superposed profile (black)

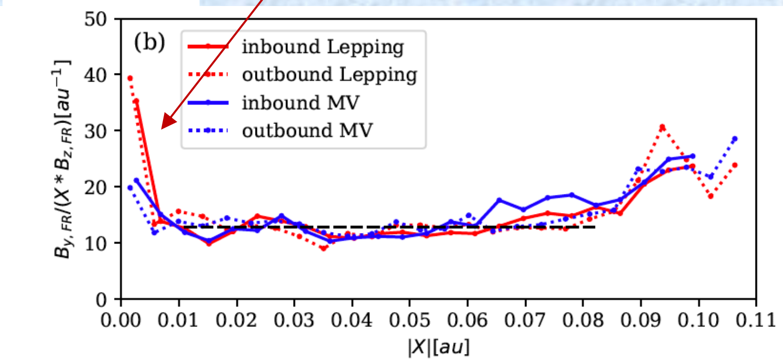
Very good agreement of both models



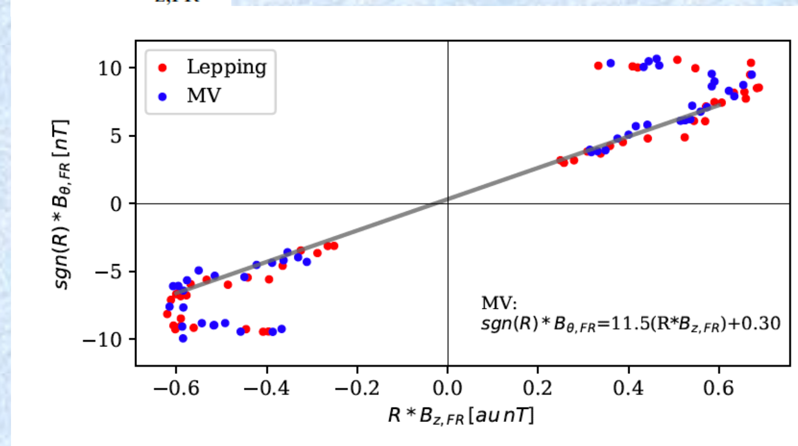
Twist profile inside the FR from Superposed epoch

Increasing at the axis due to the singularity at X=0

$$\tau(X) = \frac{B_{y,FR}}{X B_{z,FR}}$$



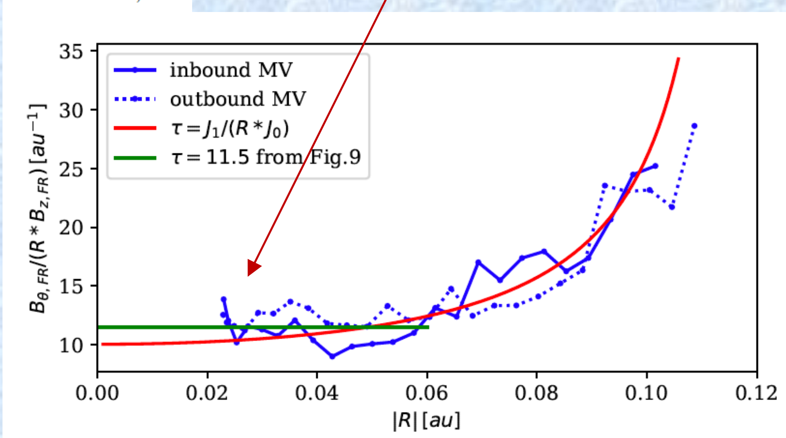
$$\tau(R) = \frac{B_{\theta,FR}}{R B_{z,FR}} .$$



[From Lanabere+2020]

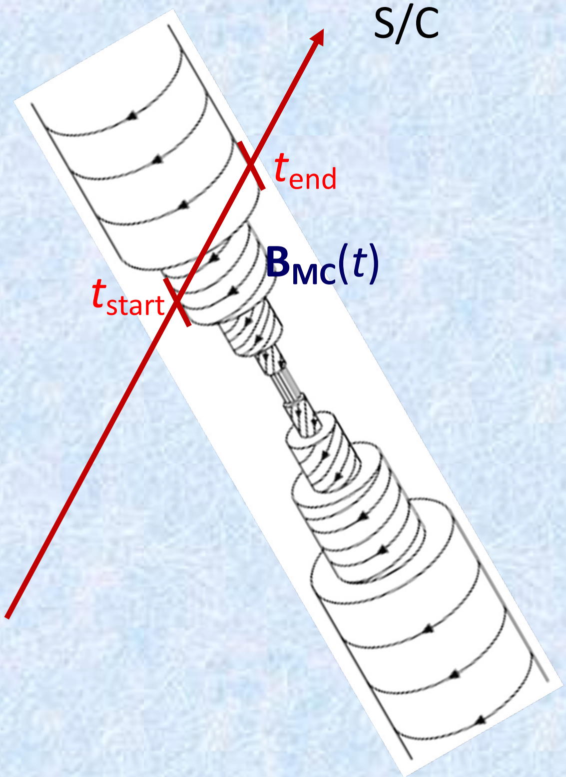
The singularity is avoided when $B_{\theta,FR}$ is used, instead $B_{y,FR}$

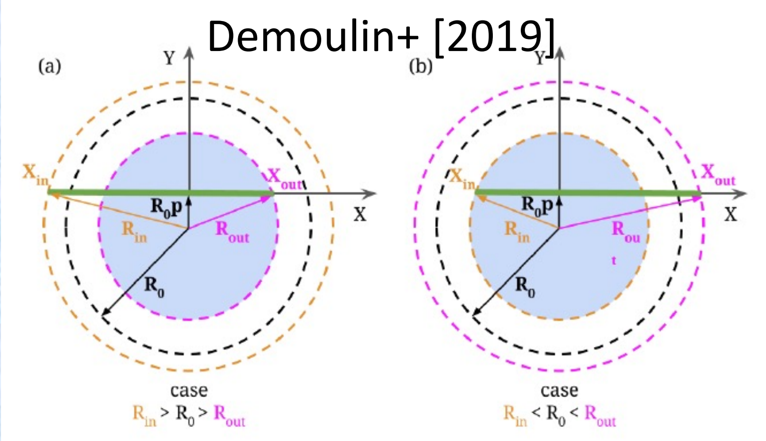
$$\tau(R) = \frac{B_{\theta,FR}}{R B_{z,FR}} .$$

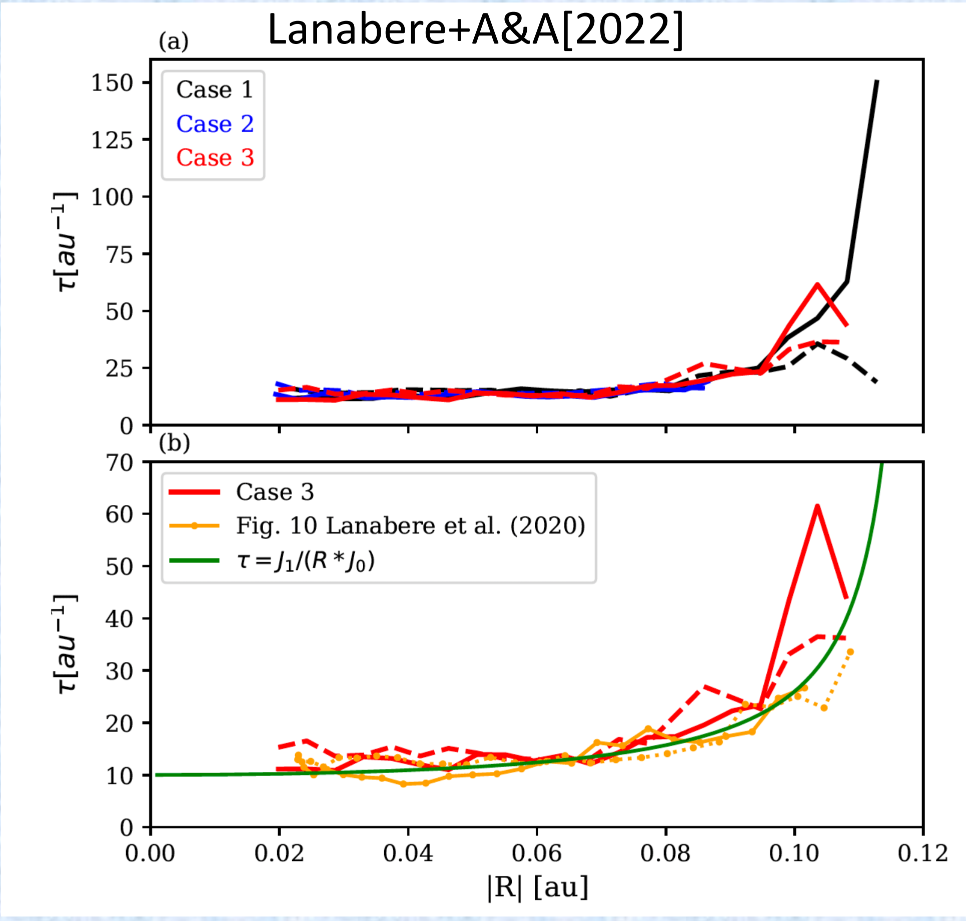


We found a twist profile: $\boldsymbol{\tau} \sim$ constant (11.5 au^{-1}) near the FR axis up to the half of the radius, and increasing toward the border, reaching $\boldsymbol{\tau} \sim$ 25 au^{-1}.

Refinement of crossed FR shells, according with the Catalogue of Lepping







We confirmed a (free biased) twist profile: $\tau \sim$ constant (~ 2 turns au^{-1}) near the FR axis up to more than the half of the radius, and increasing toward the border, typically reaching $\tau \sim 5$ turns au^{-1}.

Summary and Conclusions

- Physical and geometrical properties of interplanetary FRs are crucial to link them with their potential solar sources, to better understand physical mechanisms in the solar wind, and to improve SW forecasts.
- The twist (τ) around the FR axis is one key to link MCs with their solar origin [e.g., for computing H, comparing number of turns, etc].
- The computation of τ needs to carefully consider different elements, such as methods/assumptions for obtain the axis orientation, methods/hypothesis for avoid the singularity at the FR axis, among others.
- We found a nearly constant τ (~ 2-3 turns per au) in the FR core, increasing τ toward the boundaries by a factor ~ two.
- The typical magnetic structure obtained from SEA is more consistent with a Lundquist profile, than with a Gold-Hoyle configuration (τ=τ_0), except when FR is significantly eroded (i.e., only the core is present).

Thank you very much for your attention !