Statistical Relationship between IMF Conditions and the Helicity Sign of FTE flux ropes

R. Kieokaew[1], B. Lavraud[1,2], N. Fargette[1], A. Marchaudon[1], V. Génot[1], C. Jacquey[1], D. Gershman[3], B. Giles[3], R. Torbert[4], and J. Burch[5]

1 Institut de Recherche en Astrophysique et Planétologie, CNRS, UPS, CNES, Université de Toulouse, Toulouse, France
2 Laboratoire d'Astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, allée Geoffroy Saint-Hilaire, 33615 Pessac, France
3 NASA Goddard Space Flight Center, Greenbelt, MD, USA
4 Space Science Center, University of New Hampshire, Durham, NH, USA
5 Southwest Research Institute, San Antonio, TX, USA

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(rkieokaew@irap.omp.eu)

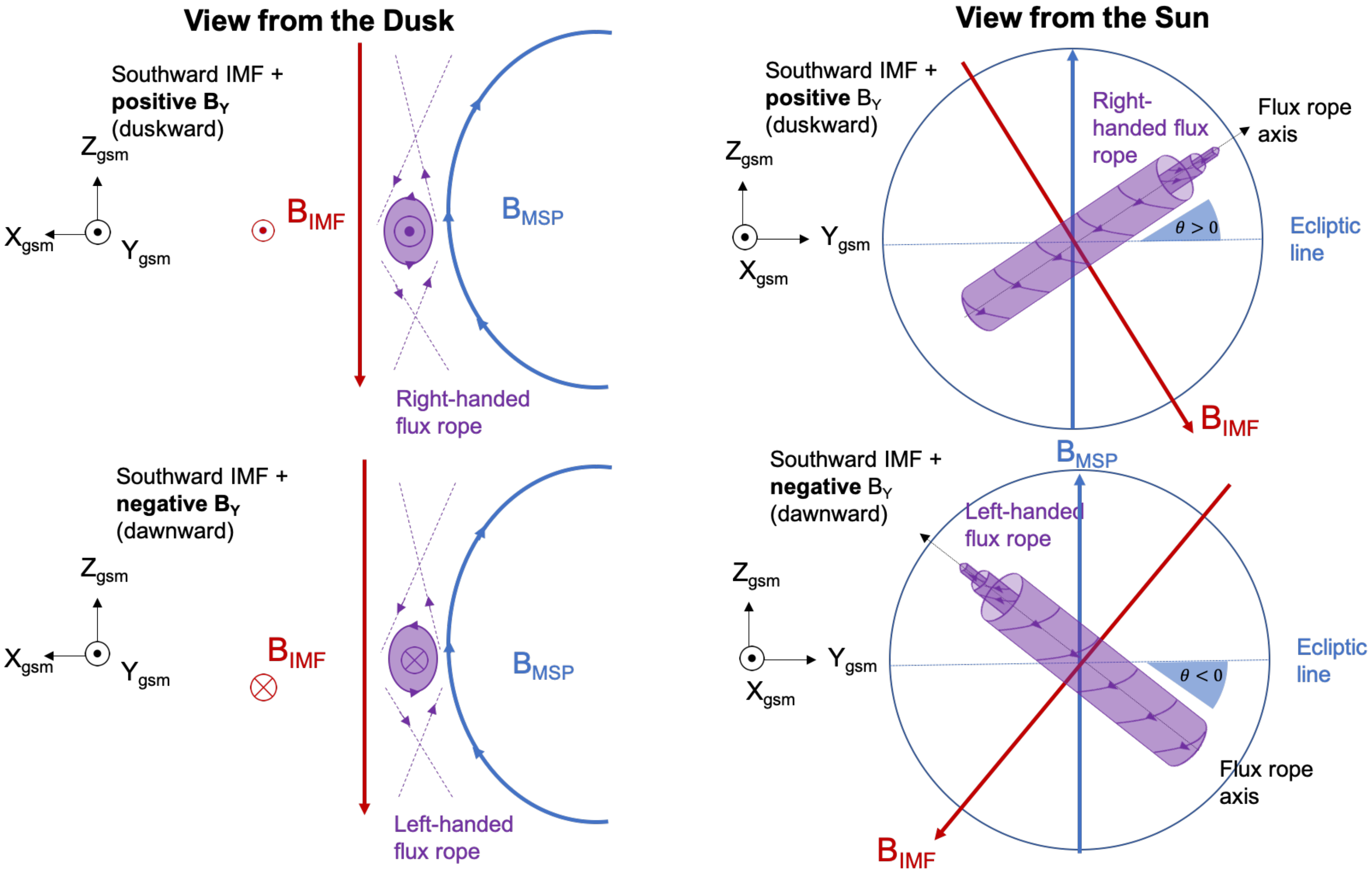
Flux Transfer Events and IMF B_Y

Flux Transfer Events are transient phenomena, believed to form due to the multiple X-line reconnection under southward IMF.

Based on a topological consideration, the twist direction of FTE flux ropes should be determined by the non-zero IMF B_Y.

Duskward IMF
$B_Y > 0$

Dawnward IMF
$B_Y < 0$



RH flux rope

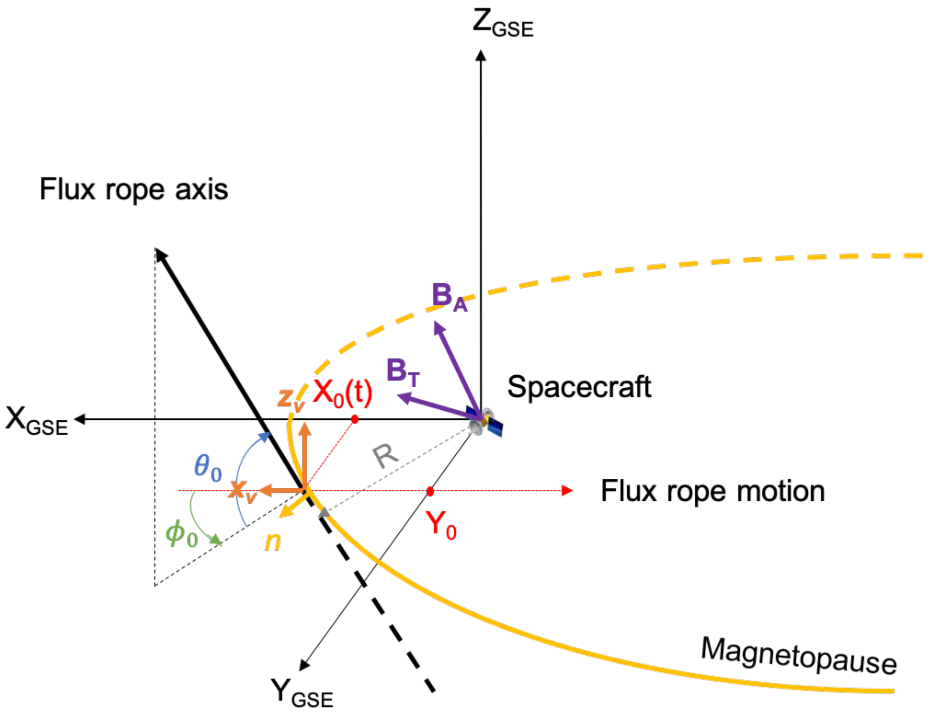
LH flux rope

Flux Rope Model and Sign of Helicity

Burlaga (1988) model

Cylindrically symmetric and force-free $\nabla \times B = \alpha B$ with a constant α. The solution was found by Lundquist (1950) in terms of 0th and 1st order Bessel functions

Axial component: $B_A = B_0 J_0(\alpha R)$
Tangential component: $B_T = B_0 H J_1(\alpha R)$
Radial component: $B_R = 0$



Magnetic Helicity and Its Sign

- Twisting features of FTEs have been theoretically evaluated in terms of magnetic helicity *[Song & Lysak, 1989; Wright and Berger, 1989; 1990]*.
- Magnetic helicity is a measure that can quantify magnetic field topology into twist, shear, linking, and kinking of magnetic fields. It is defined as

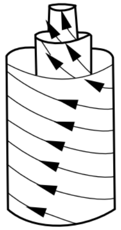
$$H = \int_V \mathbf{A} \cdot \mathbf{B} d^3 r$$

where H is the total helicity of the magnetic field in a volume
A is the vector potential of B $(\mathbf{B} = \nabla \times \mathbf{A})$
B is the magnetic field

Here we use the definition of magnetic helicity to describe the twist of an FTE flux rope and we will only consider its sign.

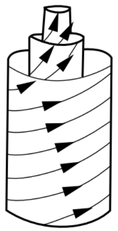
H = -1

Left-handed (LH) Flux rope



H = 1

Right-handed (RH) Flux rope

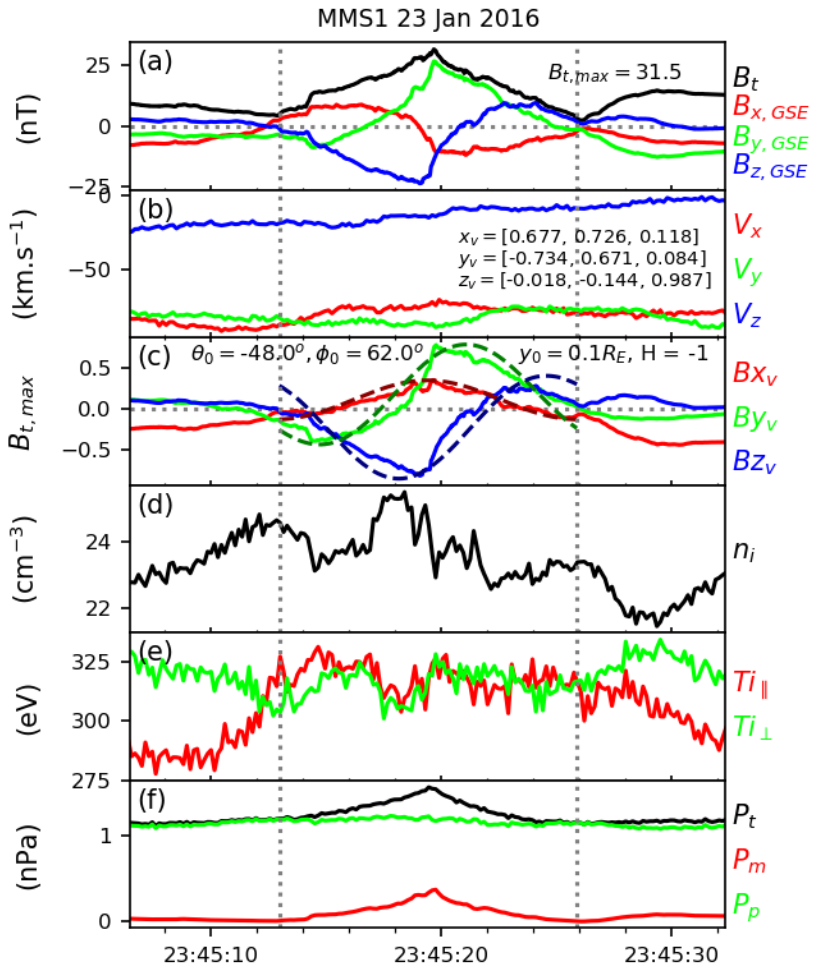


Event illustrations

Event 1 LH

IMF Clock Angle -162° (Southward, Dawnward)

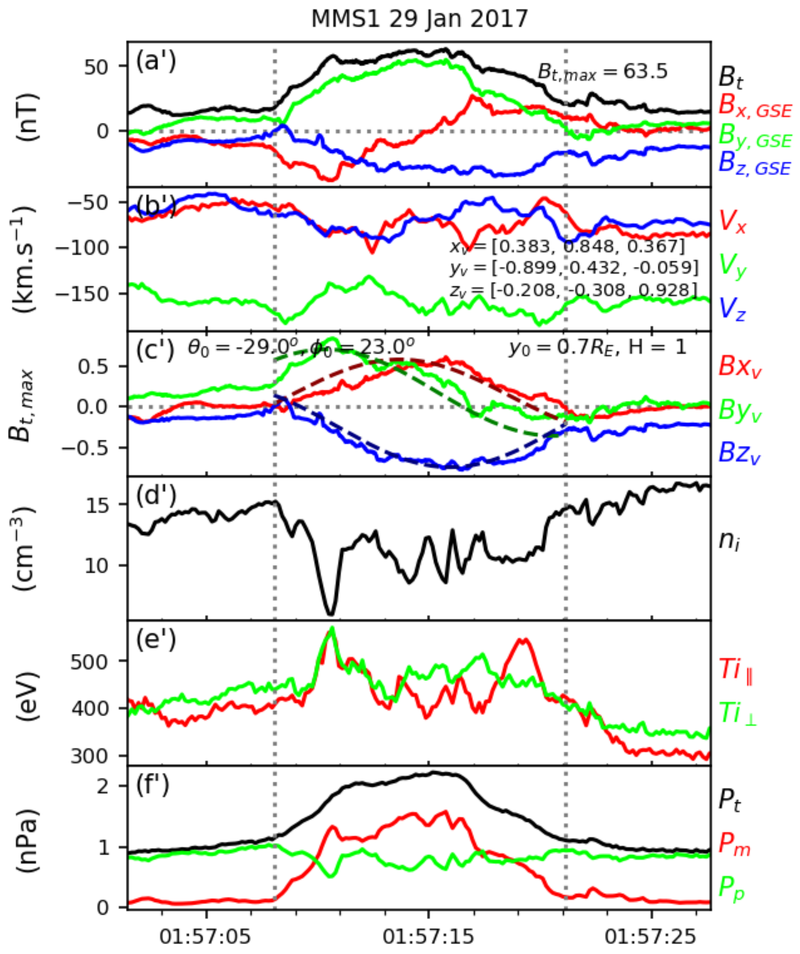
MMS1 location: $[7.3, -9.4, -1.1]_{GSE}\ R_E$



Event 2 RH

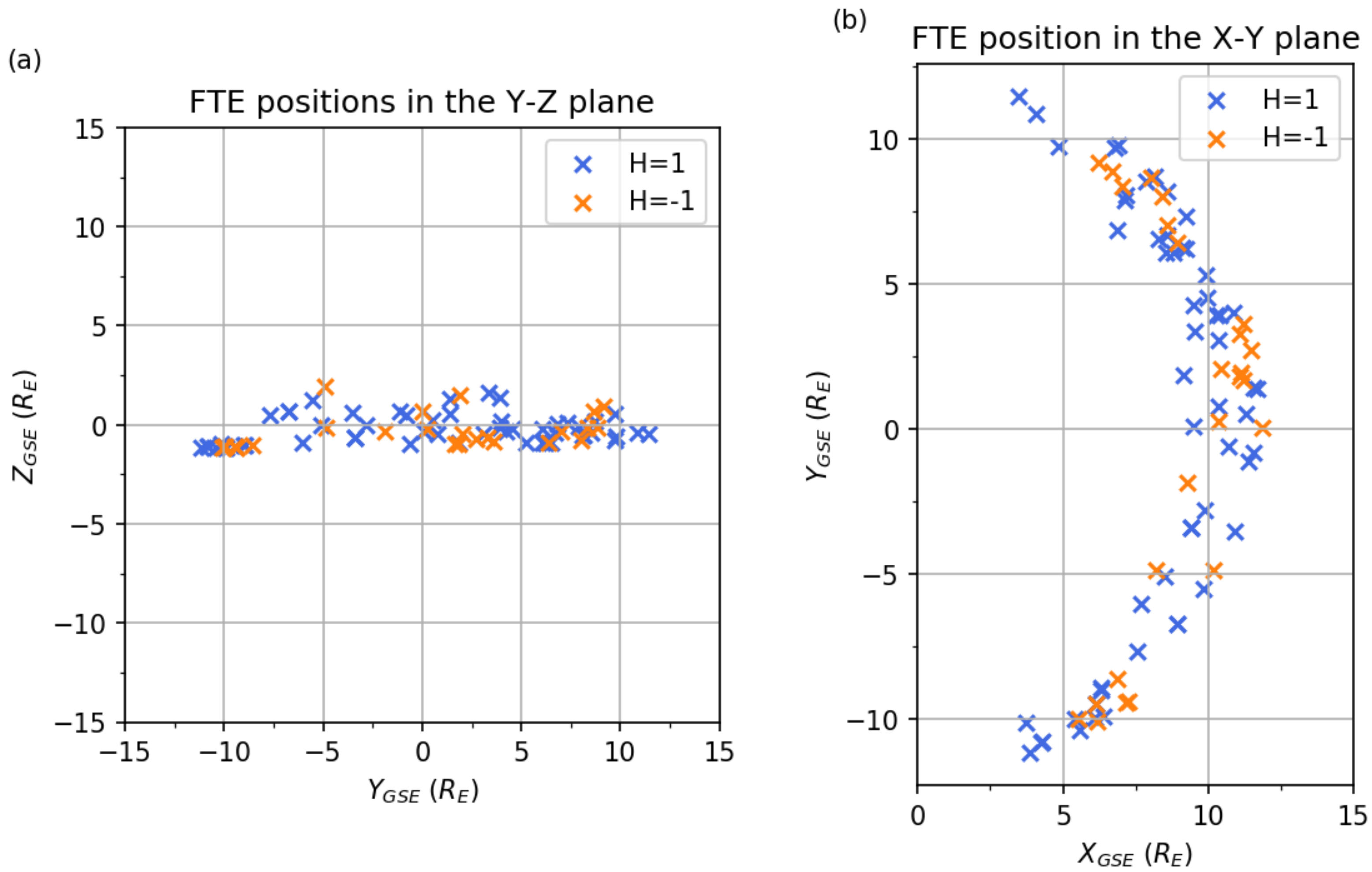
IMF Clock Angle 114° (Southward, Duskward)

MMS1 location: $[9.9, -5.5, 1.2]_{GSE}\ R_E$



84 flux ropes are found to fit well to the model with 59 (70%) being RH and 25 (30%) being LH

FTE Spatial distribution

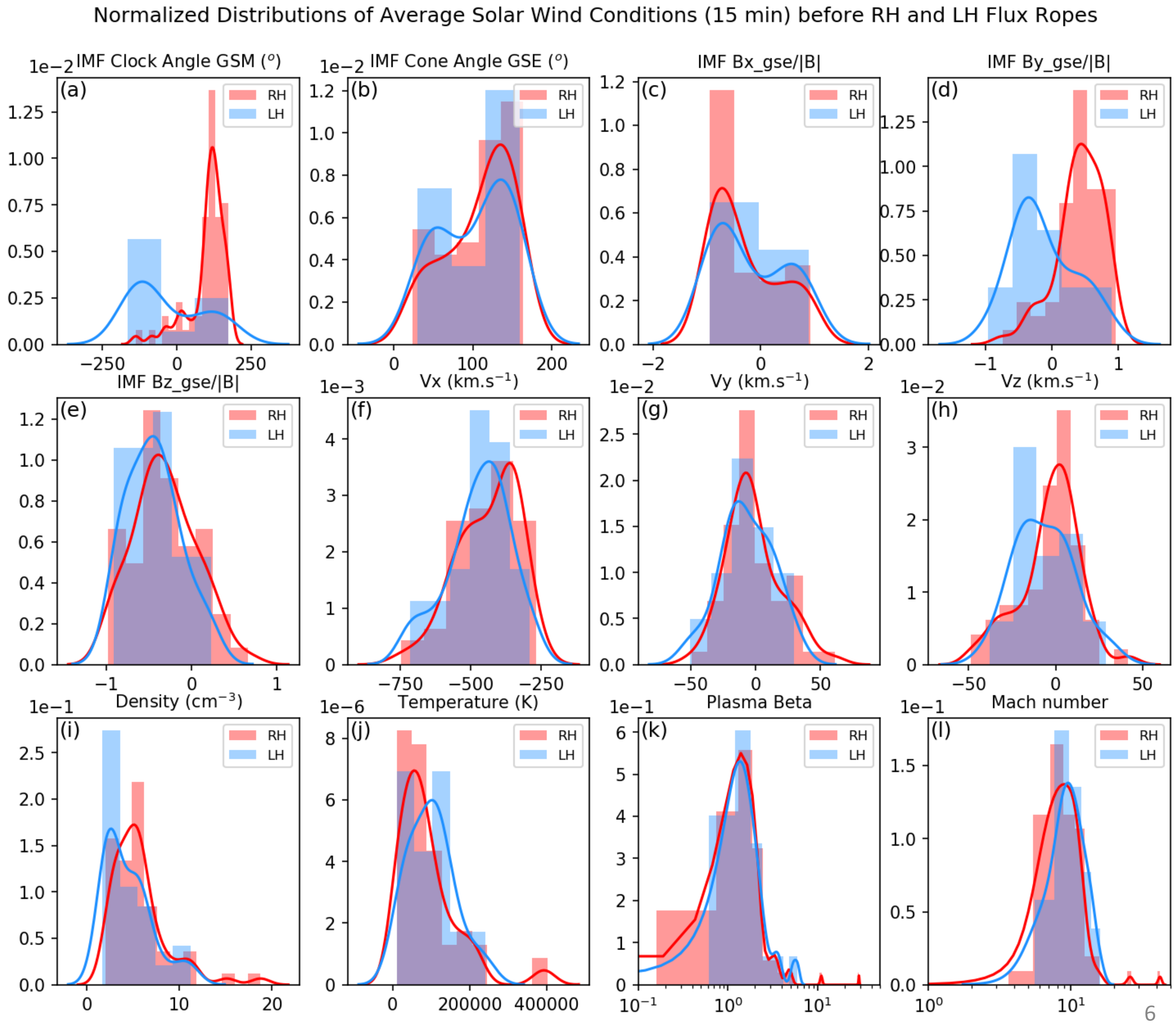


RH, LH flux ropes spatially distribute with no preference in north/south hemisphere or dawn/dusk sector

Parametric Survey: SW conditions before RH, LH flux ropes

IMF Clock Angle (and so IMF B_Y) preceding the events show distinct distributions between the two types

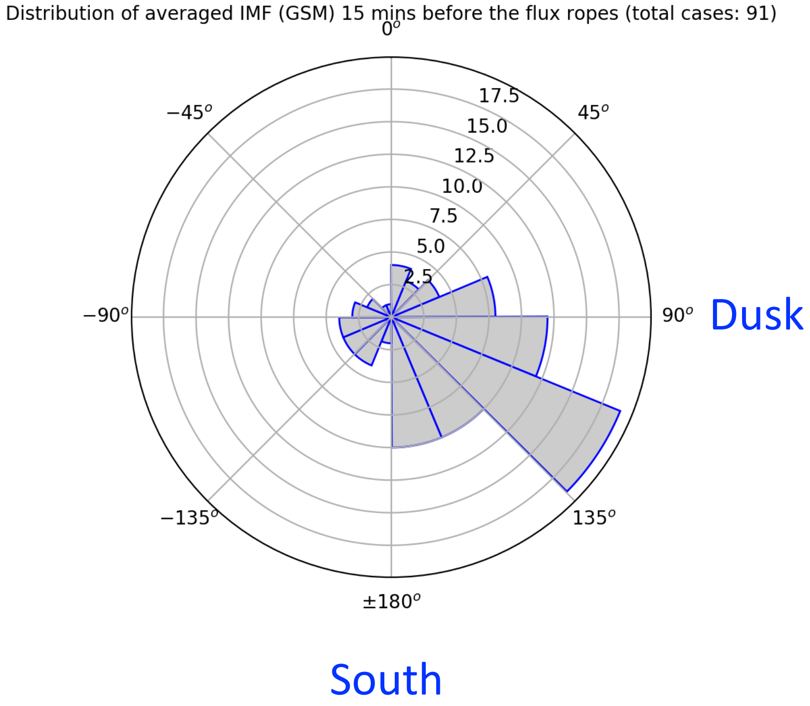
Other SW parameters do not show distinct distributions



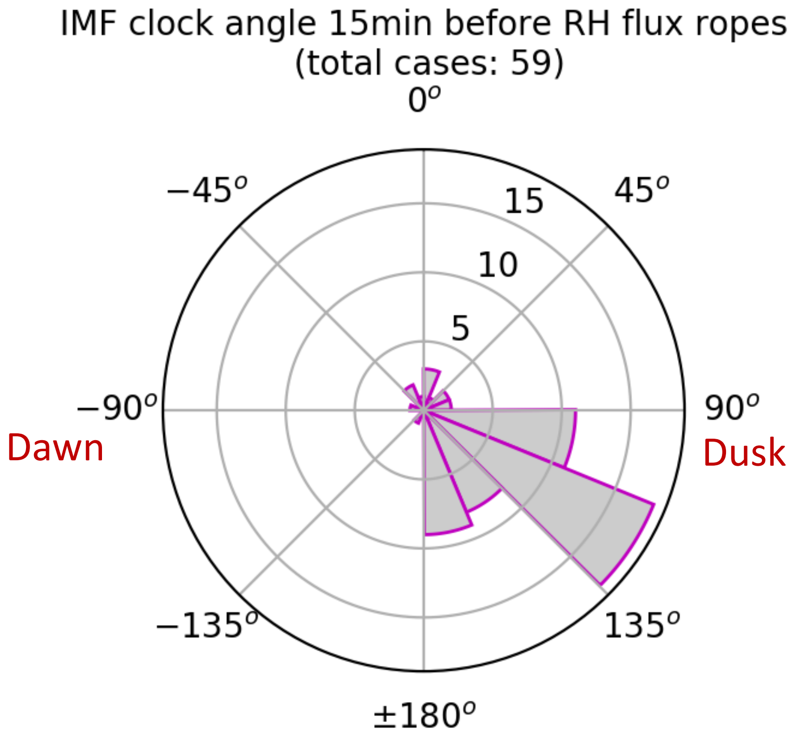
IMF clock angle distributions

Average IMF (GSM) clock angle 15 mins before the flux rope.

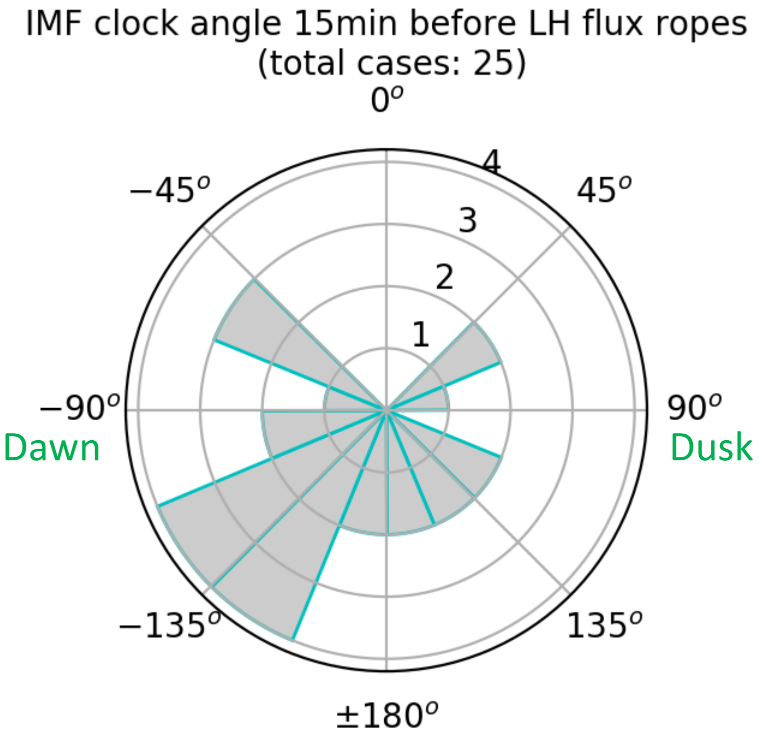
All cases



Right-handed cases
(H = +1)



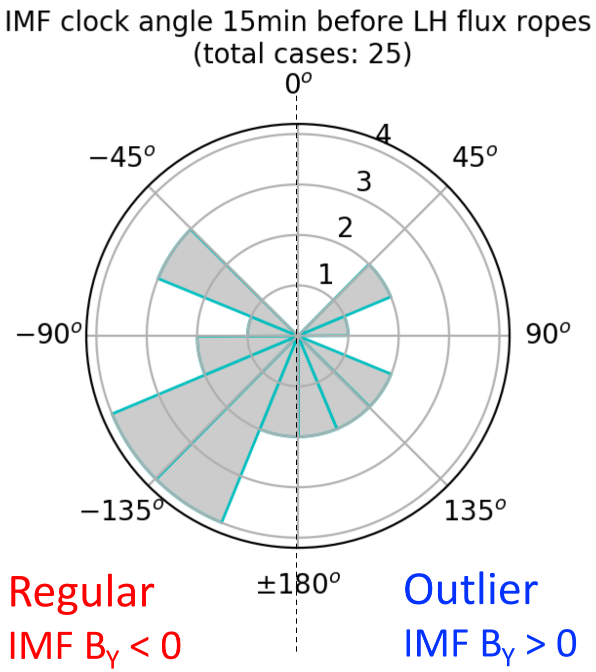
Left-handed cases
(H = -1)



The results are similar for the average IMF clock angle 5, 10, 20, 25 minutes before the FTEs.

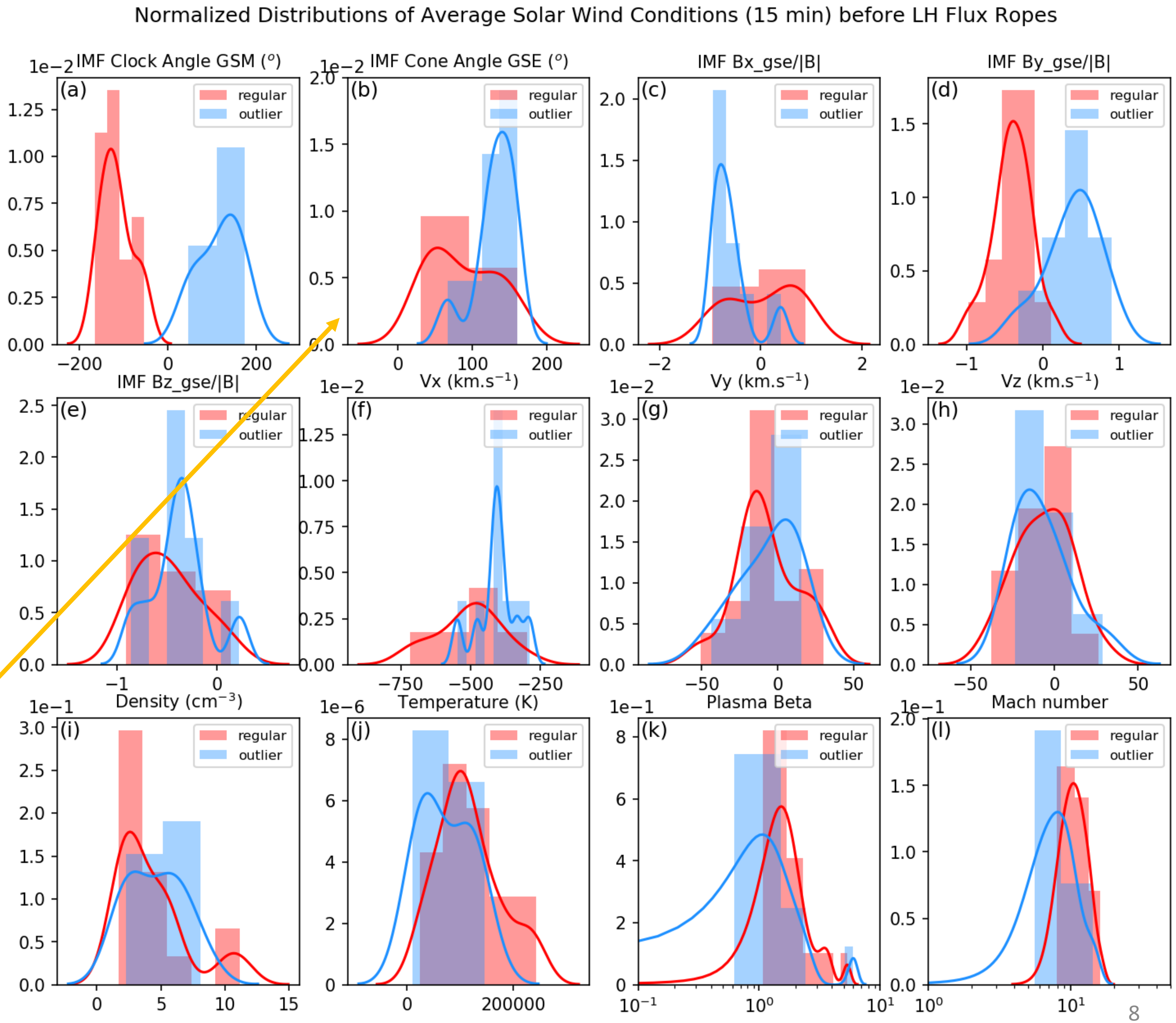
RH flux ropes are mainly preceded by IMF $B_Y > 0$ (duskward)
LH flux ropes are mostly preceded by IMF $B_Y < 0$ (dawnward)
However, there are 9 out of 25 LH flux ropes that are preceded by IMF $B_Y > 0$, why?

Parametric Survey of SW conditions before LH flux ropes: regular and outlier groups



Regular
IMF $B_Y < 0$

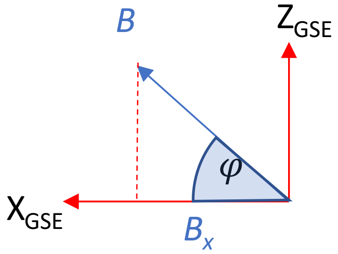
Outlier
IMF $B_Y > 0$



The outlier group has a bigger IMF cone angle (Bx < 0 with strong magnitude) average

IMF Cone Angle before LH flux ropes

IMF Cone Angle definition



$$\varphi = \arccos(\frac{B_x}{|B|})$$

$\varphi < 90^o$: sunward (positive Bx)

$\varphi > 90^o$: anti-sunward (negative Bx)

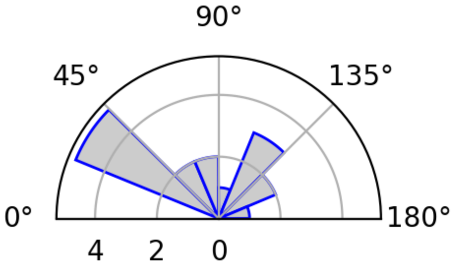
<u>Defining 2 groups of LH flux ropes:</u>

Regular group – preceded by IMF $B_Y < 0$

Outlier group – preceded by IMF $B_Y > 0$

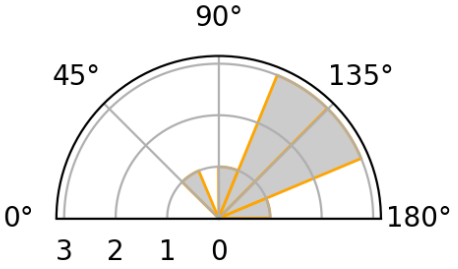
IMF Cone Angle before LH flux ropes

IMF cone angle (GSE)
before regular LH flux ropes
(total cases: 16)



regular

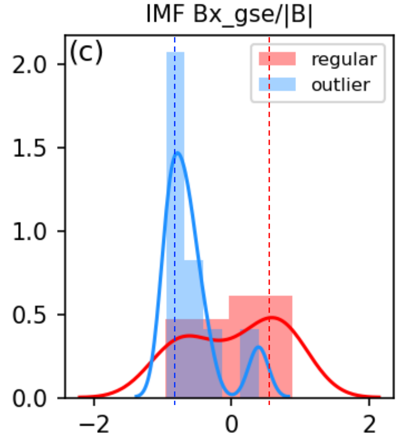
IMF cone angle (GSE)
before outlier LH flux ropes
(total cases: 9)



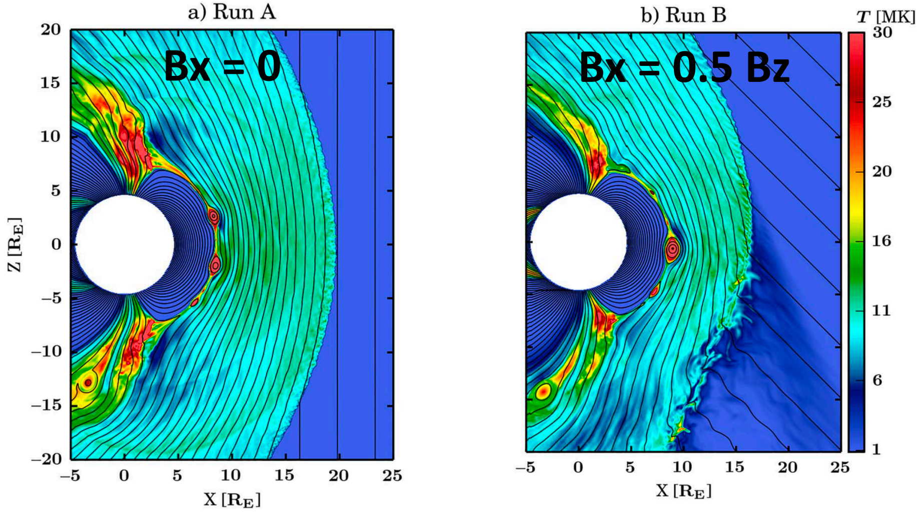
outlier

The regular group is mostly preceded by IMF cone angle < 90°,
The outlier group is mainly preceded by IMF cone angle > 90°
and with a stronger IMF Bx/|B| magnitude

This means there are LH flux ropes that are produced by duskward IMF with strong anti-sunward Bx. How?

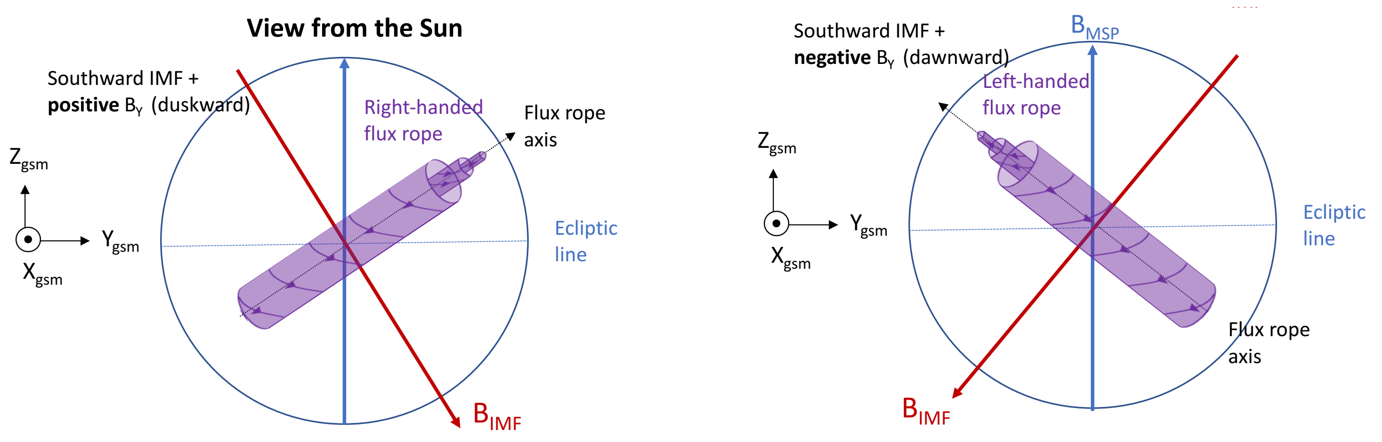


Global simulation by Hoilijoki et al. (2019)



Summary

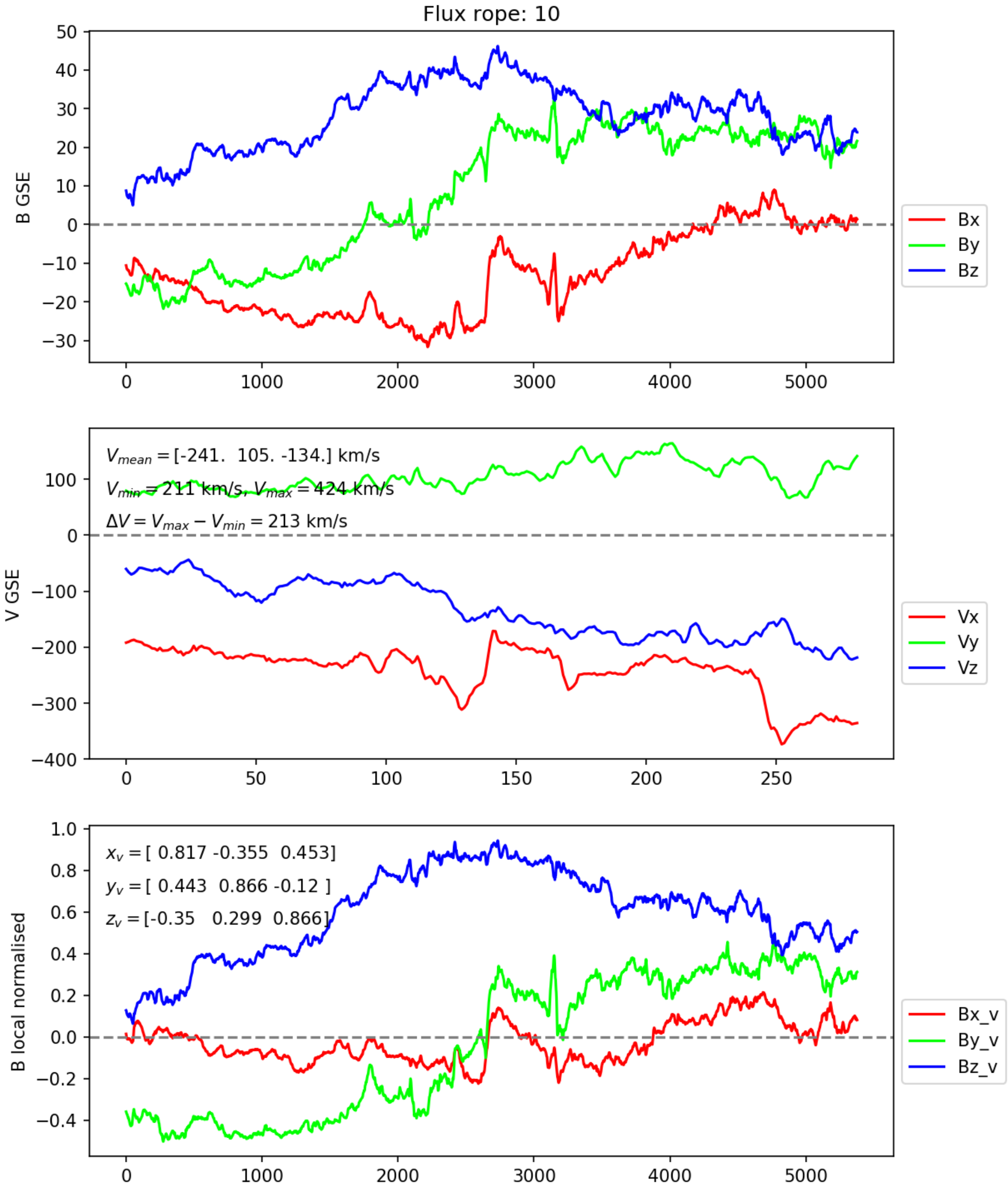
- We studied the helicity sign of 84 Flux Transfer Events observed by MMS near the winter solstice during 2015 - 2017 using a cylindrically symmetric force-free flux rope model fitting with constant α
- Right-handed (left-handed) FTE flux ropes are mostly preceded by positive (negative) IMF B_Y. This IMF B_Y control of the helicity sign is compatible with the multiple X-line formation mechanism



- There is an outlier population, especially for LH flux ropes, that are preceded by unexpected IMF B_Y polarity. The outlier LH flux ropes are mostly preceded by strong, negative IMF B_X. This effect may combine with the large dipole tilt that can complicate the reconnection and thus the FTE formation

(rkieokaew@irap.omp.eu)

Fitting a flux rope into the model



1. Take the magnetic fields (and velocity fields) in the GSE coordinates

2. Transform the magnetic fields into the flux rope frame

$$x_v = -\frac{v_{mean}}{|v_{mean}|}$$

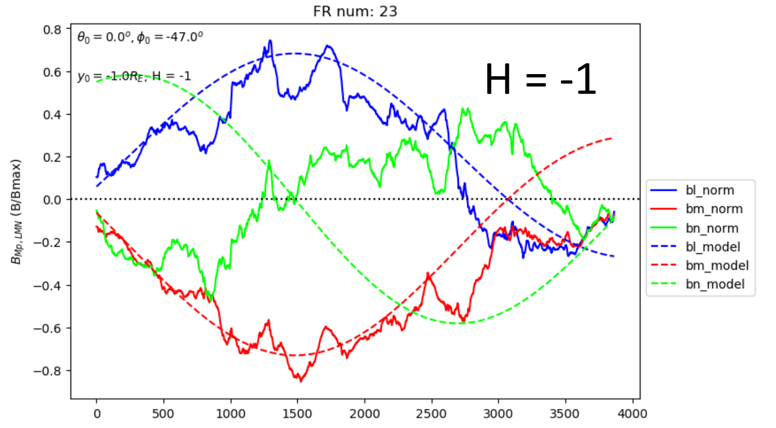
$$z_v = +x_v \wedge n \qquad \text{if } v_{y_{mean}} > 0$$

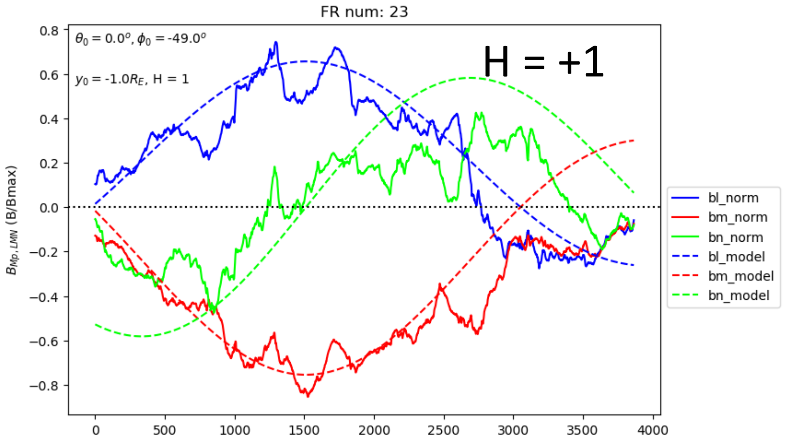
$$z_v = -x_v \wedge n \qquad \text{if } v_{y_{mean}} < 0$$

$$y_v = z_v \wedge x_v$$

3. Normalise each component with the maximum field strength in the interval

Next, I input the normalised B fields in the **local FR coordinates** into the fitting algorithm. I try both H=-1 and H=+1 for each flux rope





Then I compare the chi2 values of both