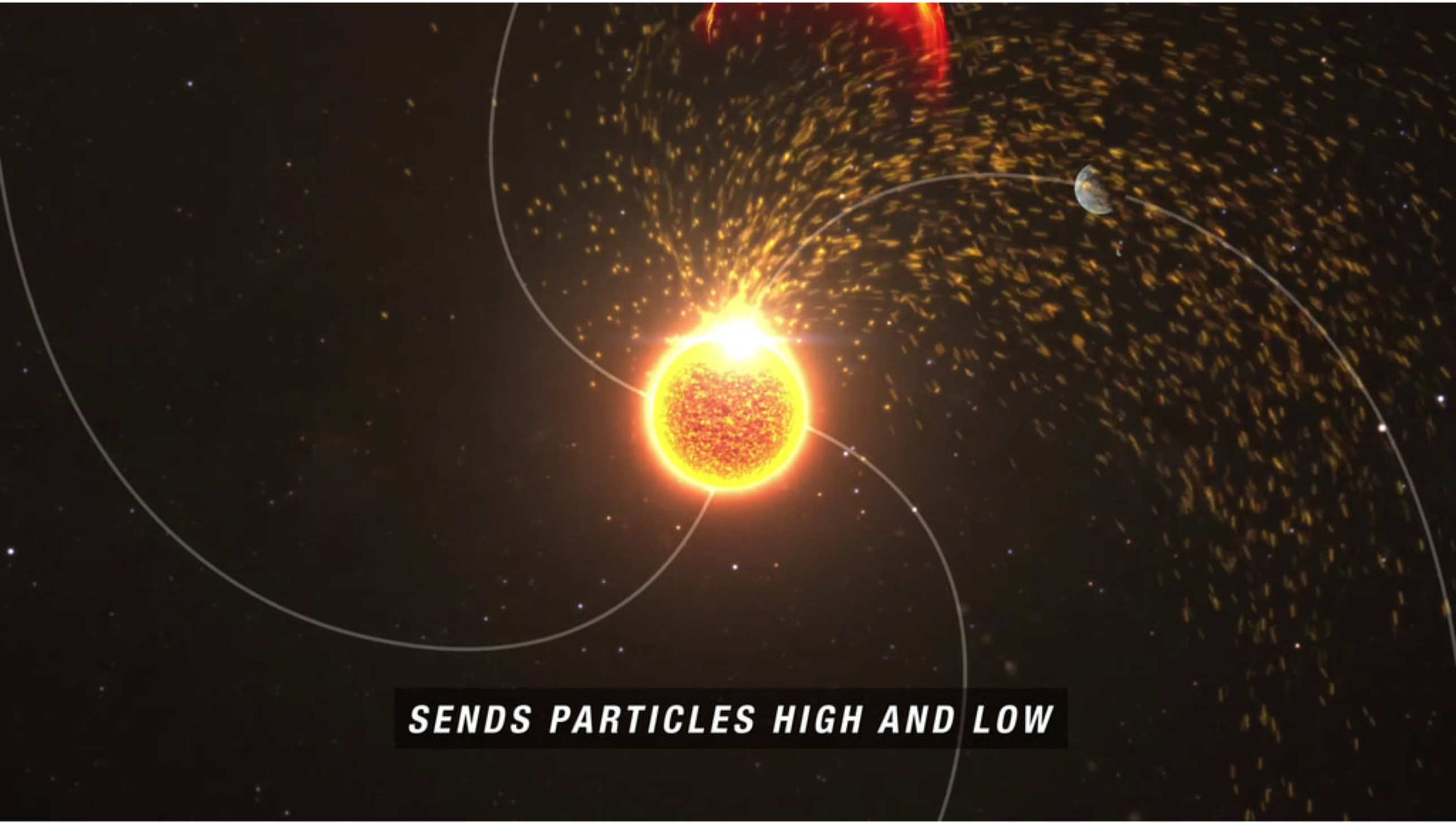
SPACE WEATHER INTRODUCTORY COURSE

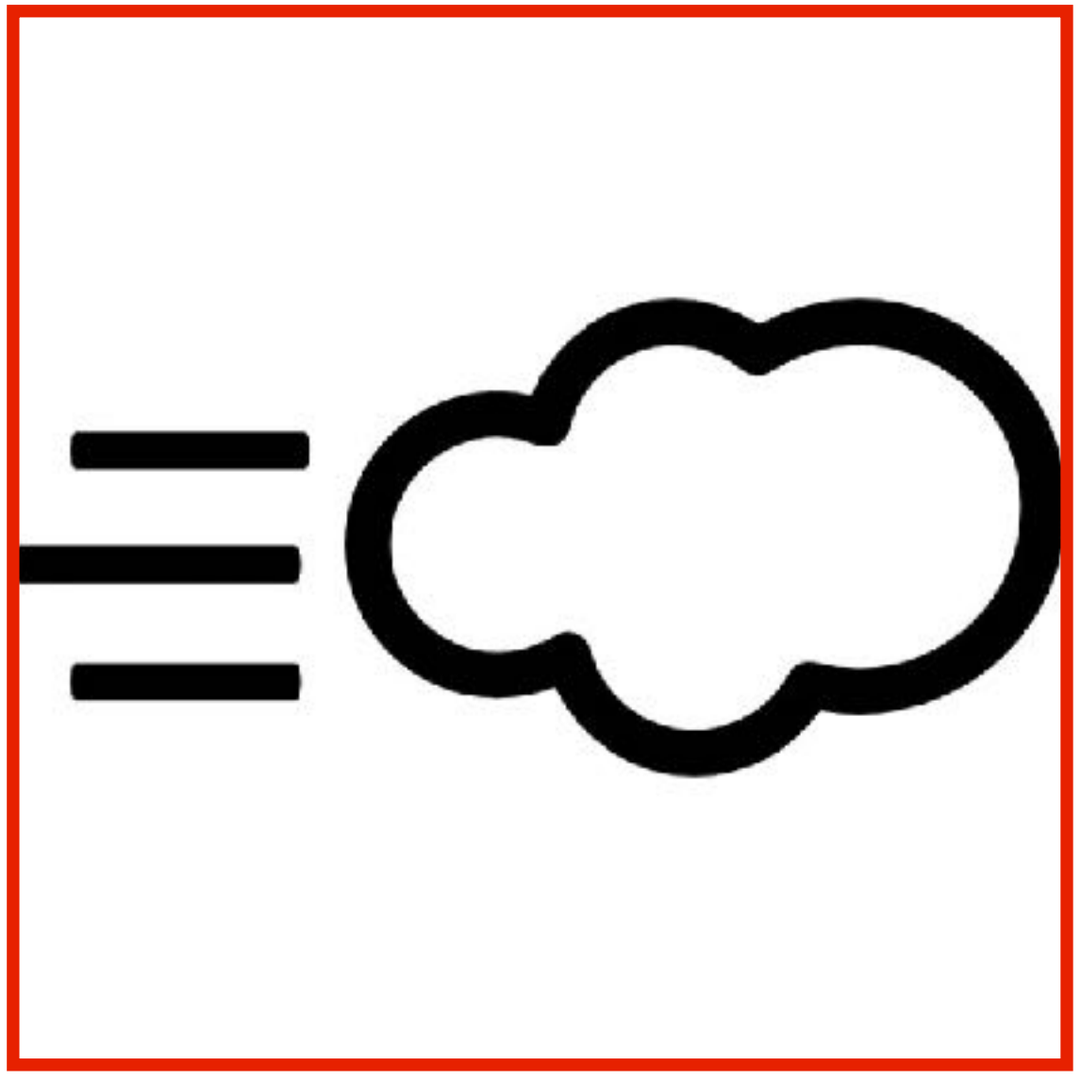
Collaboration of

Solar-Terrestrial Centre of Excellence

Koninklijke luchtmacht

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu


SENDS PARTICLES HIGH AND LOW



SOLAR WIND

What

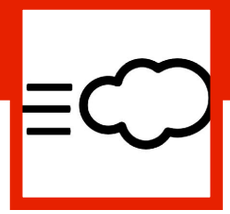
3 SPACE WEATHER PHENOMENA

The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

How and where the interaction occurs depends on the type of energy.

LIGHT

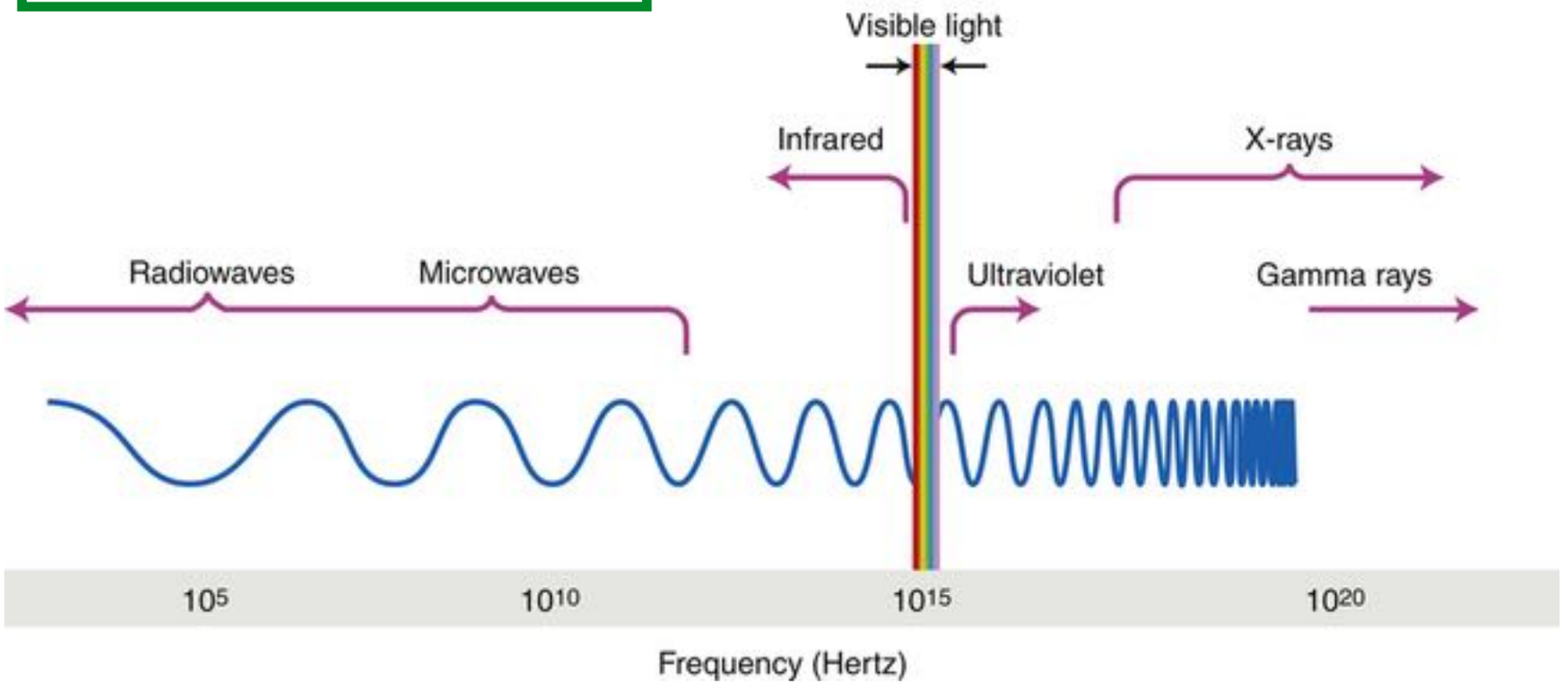
WIND



RAIN

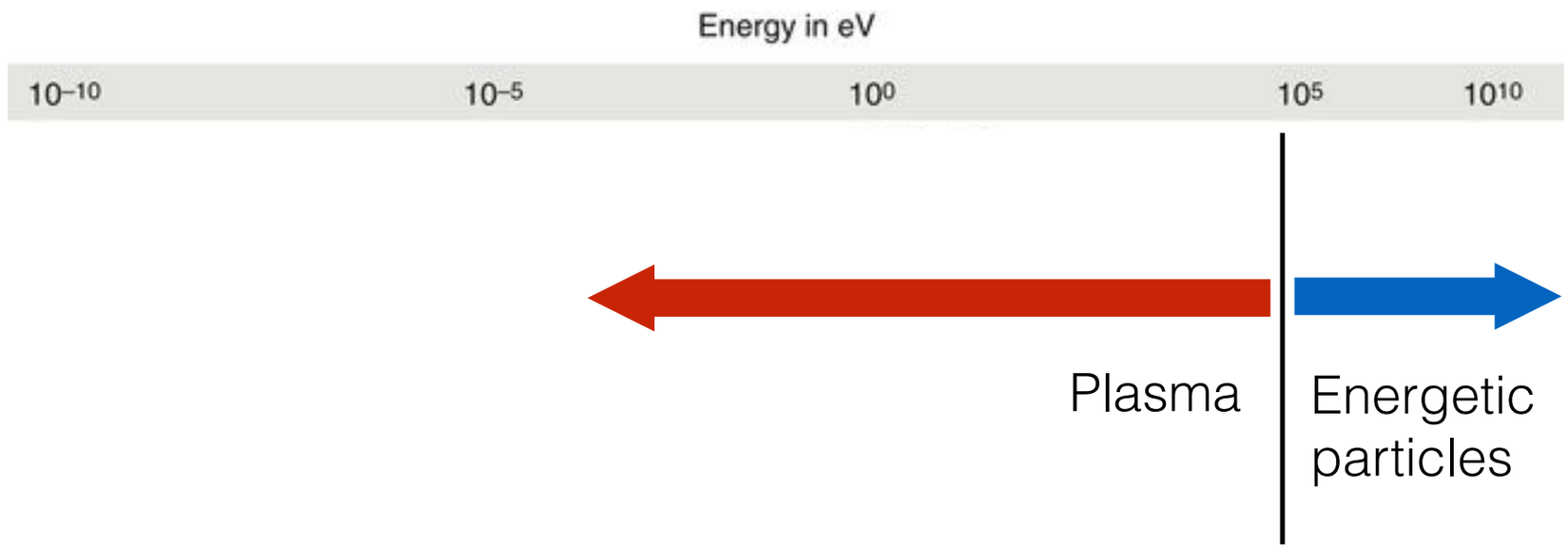
Electromagnetic radiation

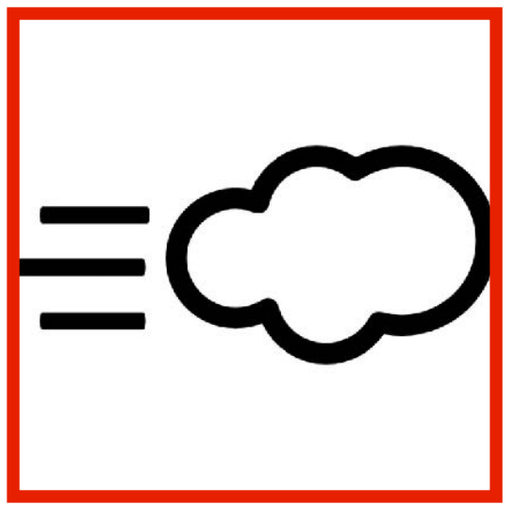
- Photons / electromagnetic waves
- Speed of light



Particles

- Atomic & sub-atomic particles
- m/s to fractions of speed of light

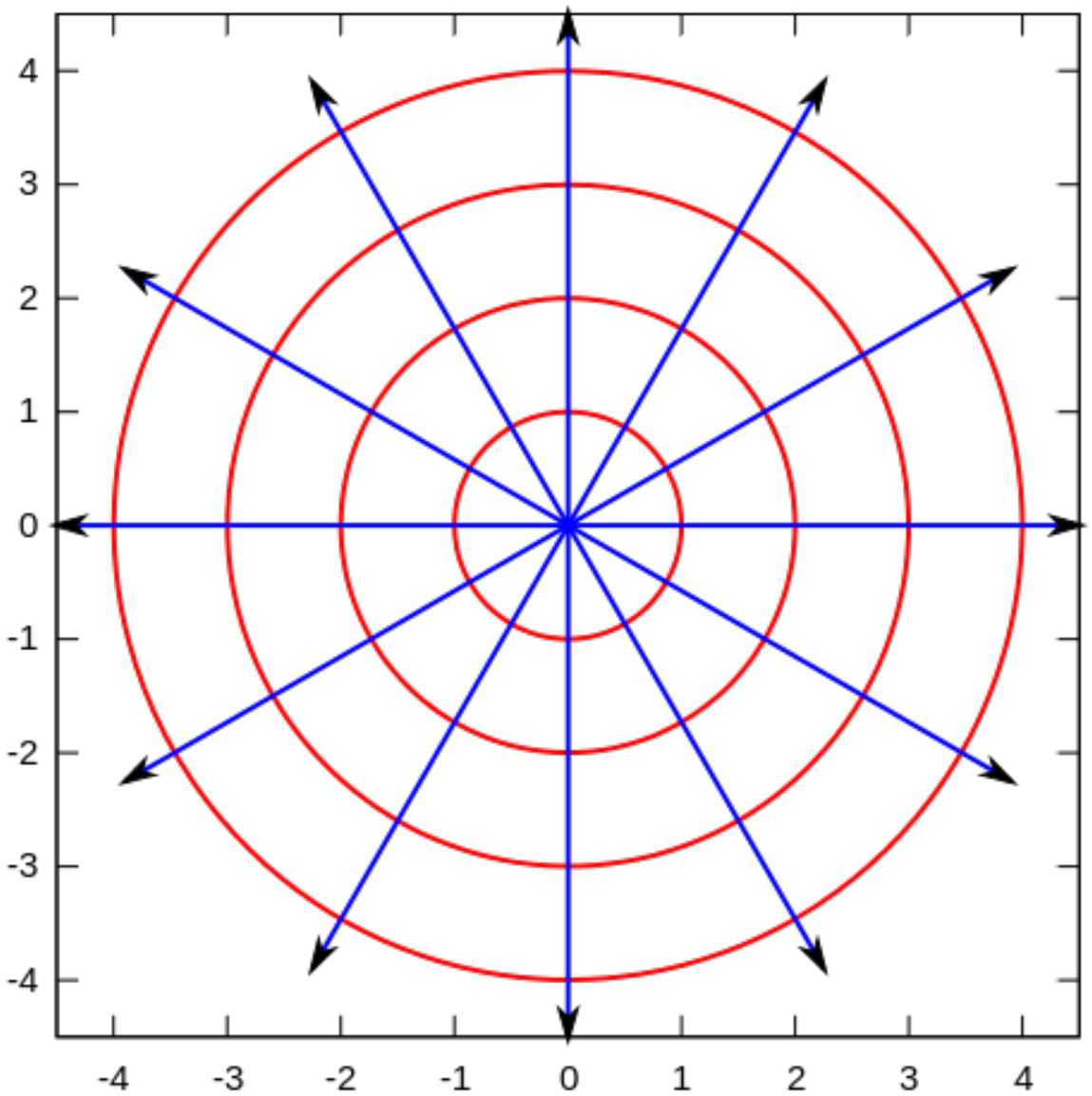


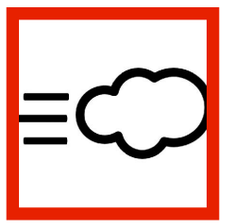


Outward moving plasma

RADIAL SOLAR WIND

The solar wind carries out solar material and solar magnetic field. The solar material and magnetic field becomes less dense the further away from the Sun.





We need to understand the Interplanetary Magnetic field that is spread in the heliosphere.

Image: Siberia 20080801
J.M.P., W. G. Wagner and H. Druckmüllerová

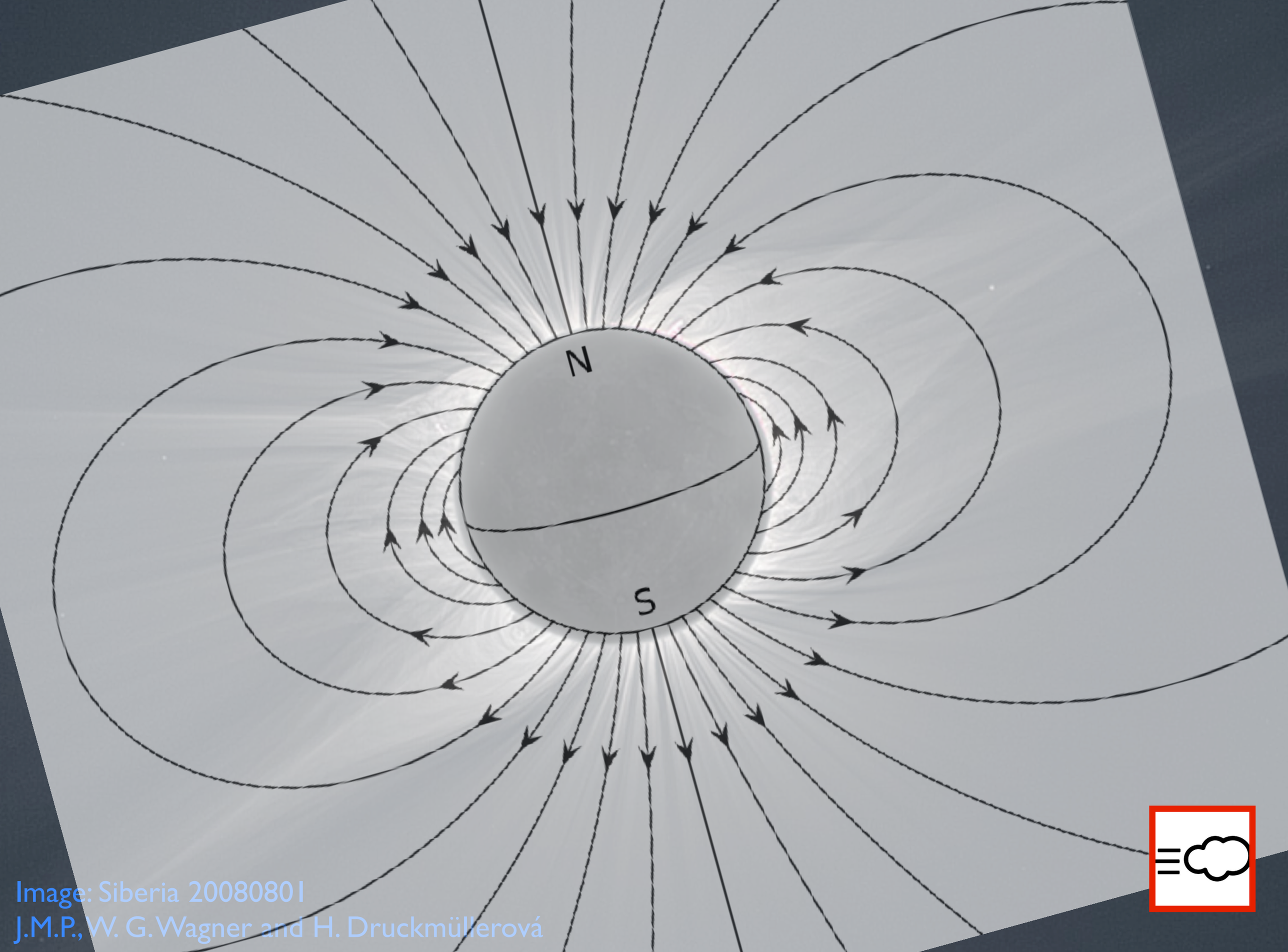
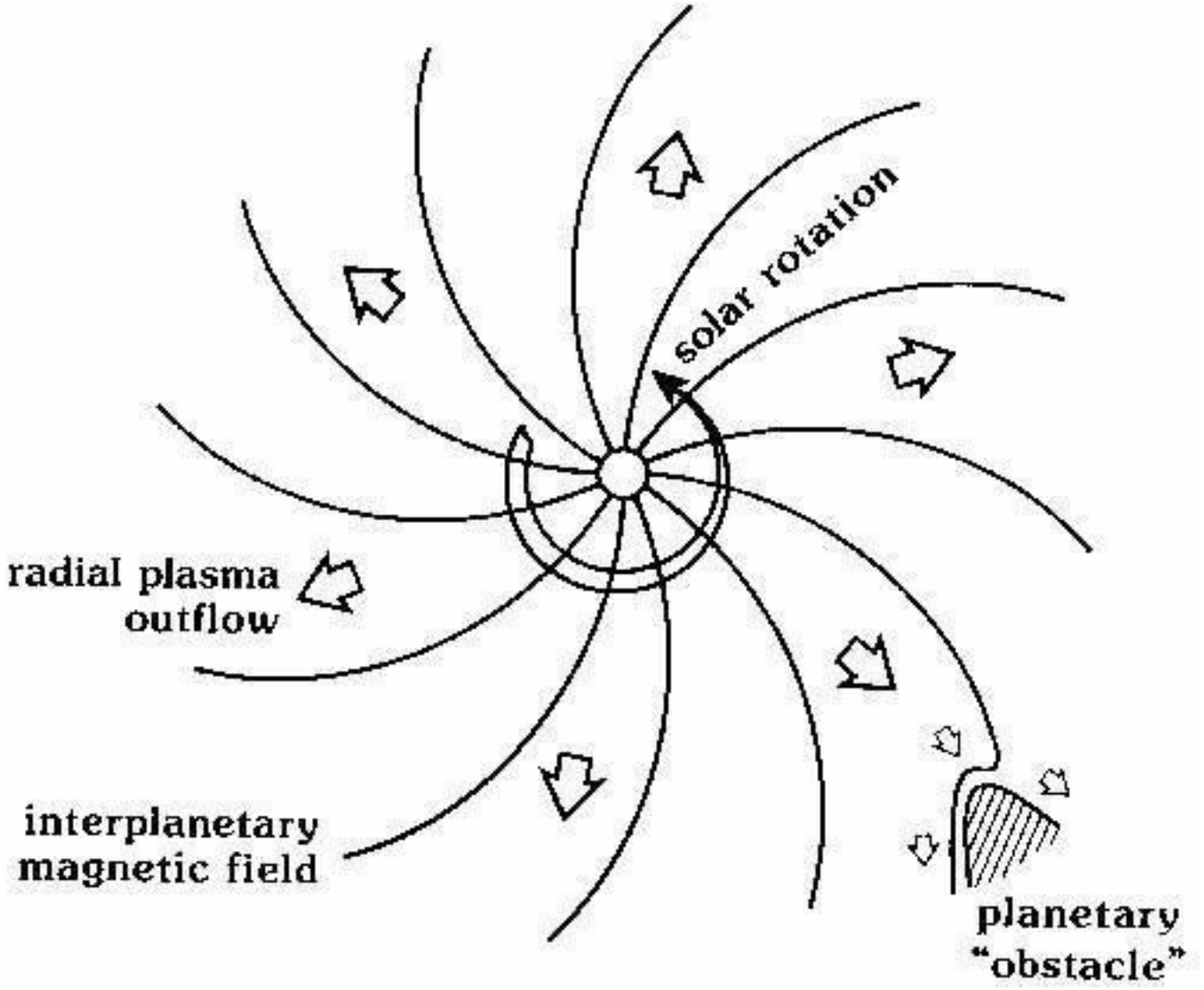
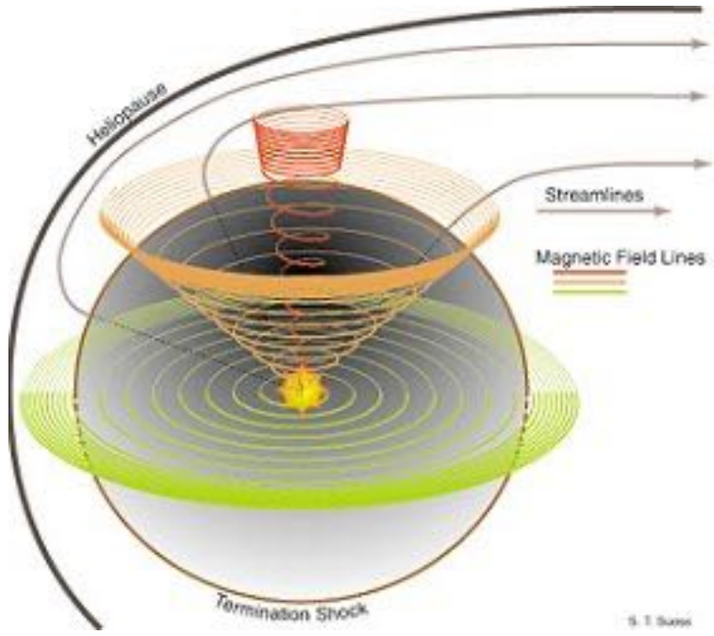


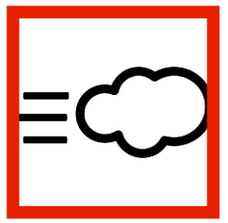
Image: Siberia 20080801
J.M.P., W. G. Wagner and H. Druckmüllerová

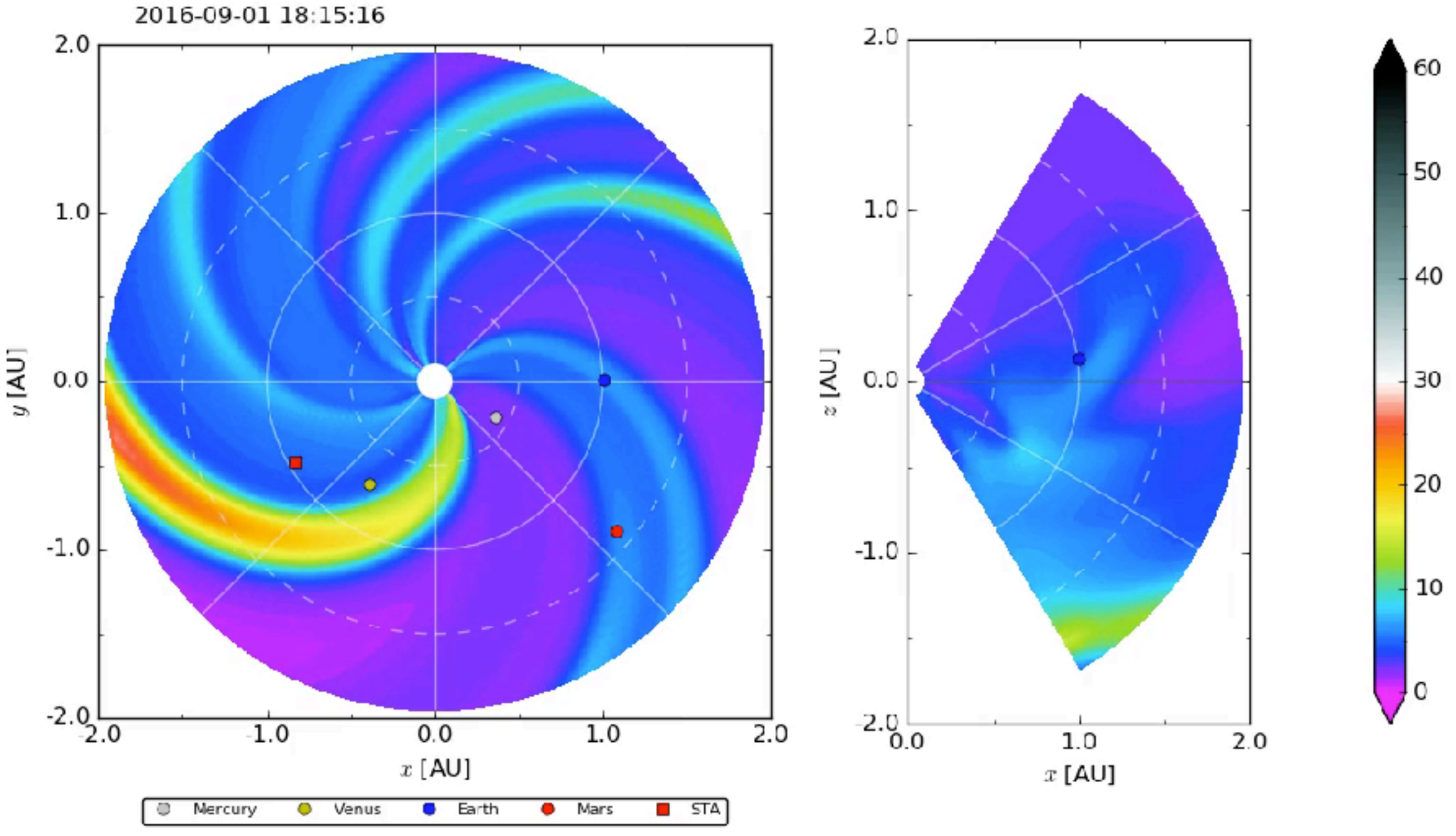
PARKER SPIRAL

The magnetic field stays connected to the Sun. As the Sun rotates, the magnetic field gets bent.

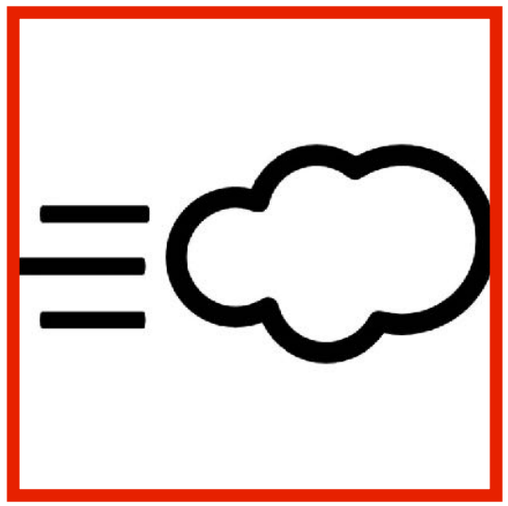








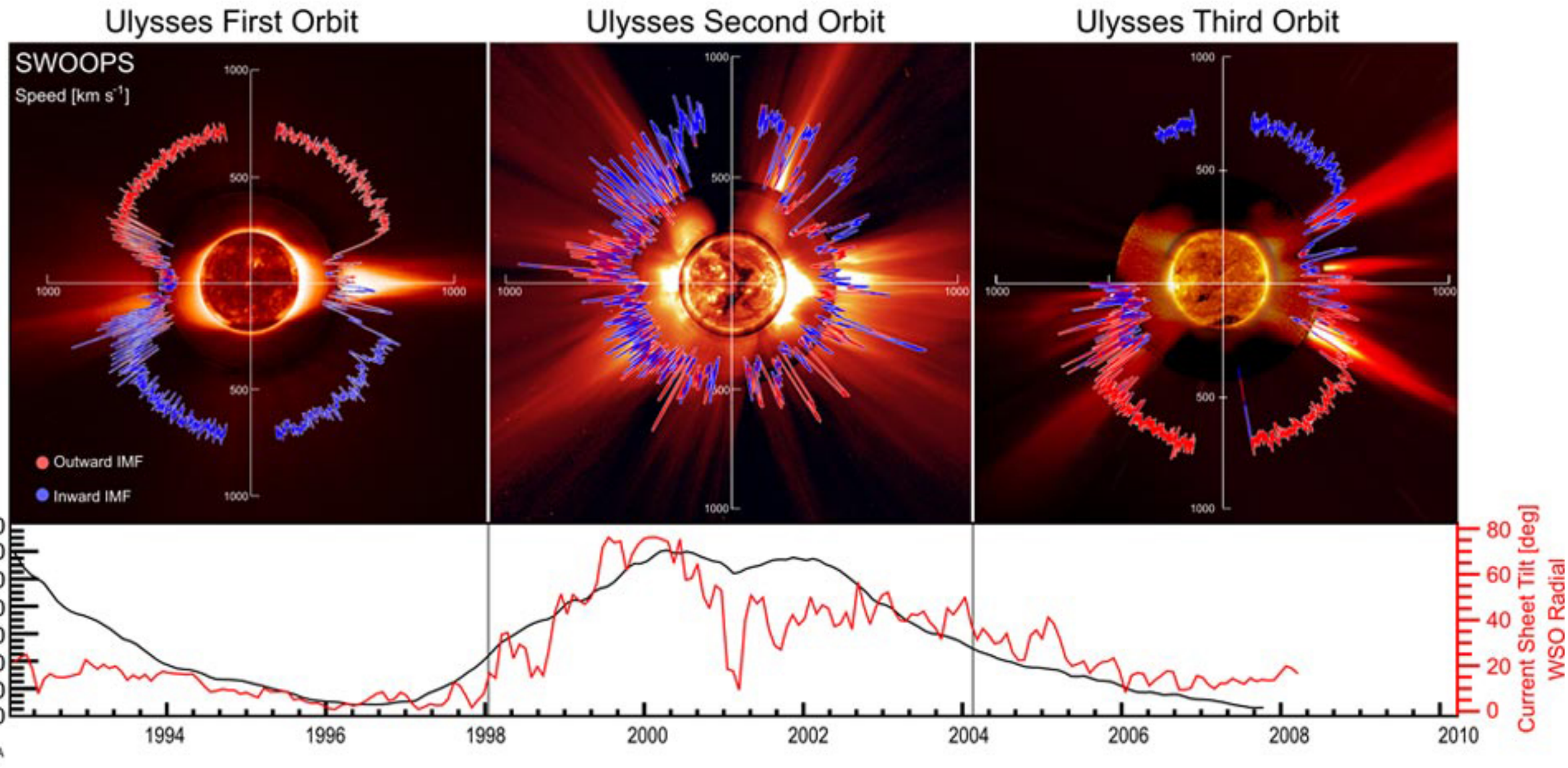
EUHFORIA, realtime simulations of the inner heliosphere



The moving plasma and the IMF together form the solar wind.

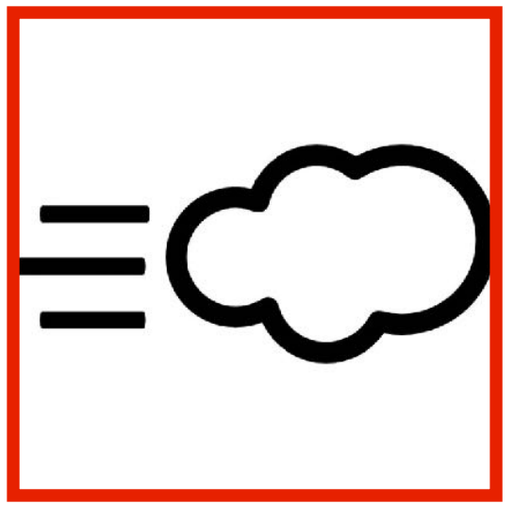
The solar wind is linked to open solar magnetic field lines.

SLOW versus FAST



SLOW versus FAST

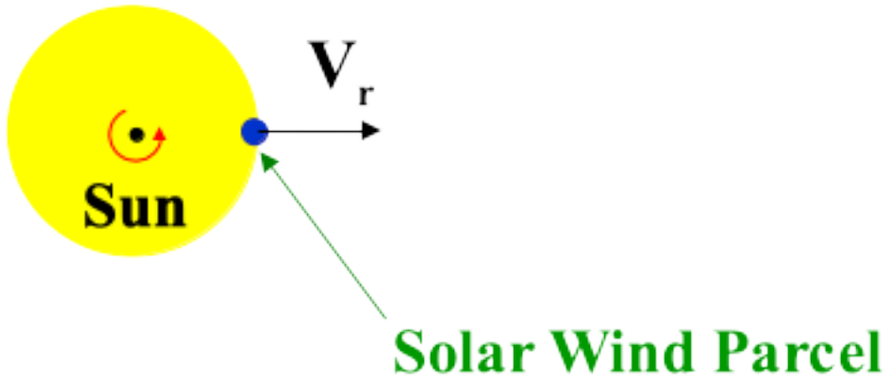
250-400	km/s	400-800
High: ~10	Density, cm^{-3}	Low: ~3
Low: ~10^4K, ~1eV	Temperature	High: ~10^5K, ~10eV
Variable	Behaviour	Stationary



IMF is bent and the plasma flow is radial.

Euh?

The Solar Wind and the Interplanetary Magnetic Field
(Formation of the Parker Spiral)



Arge, 2018

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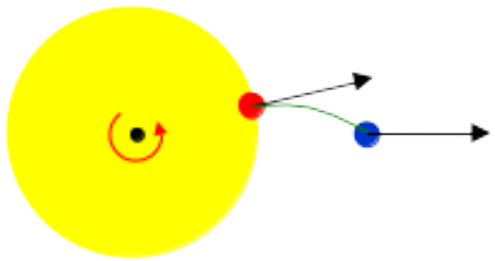

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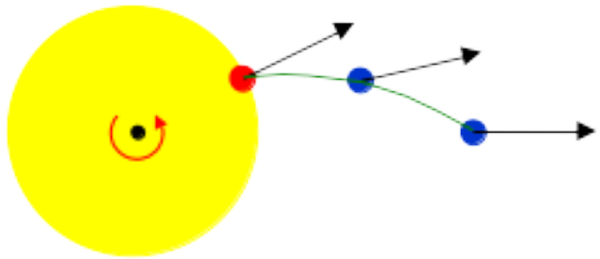

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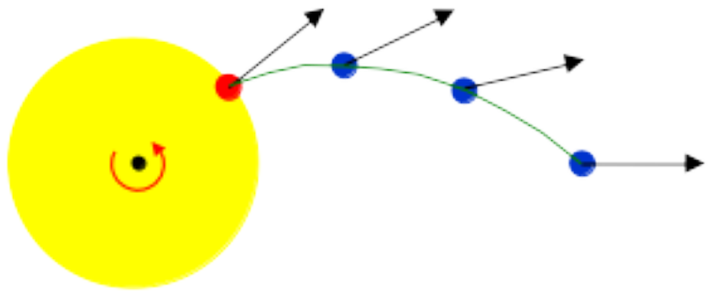

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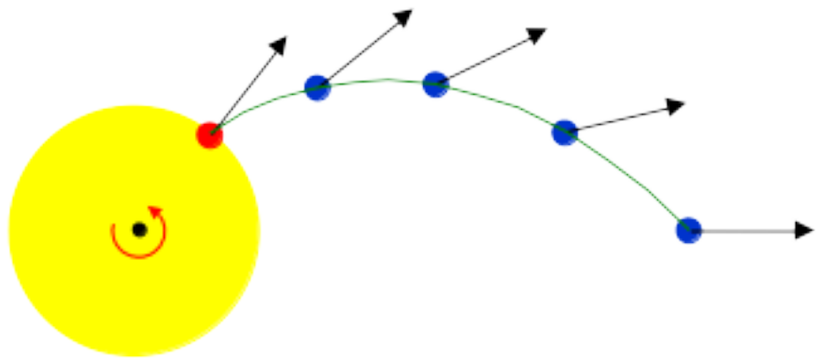

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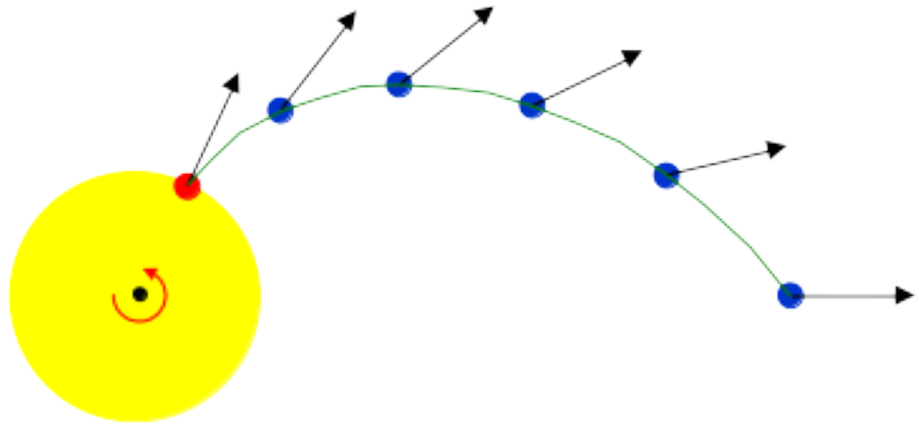

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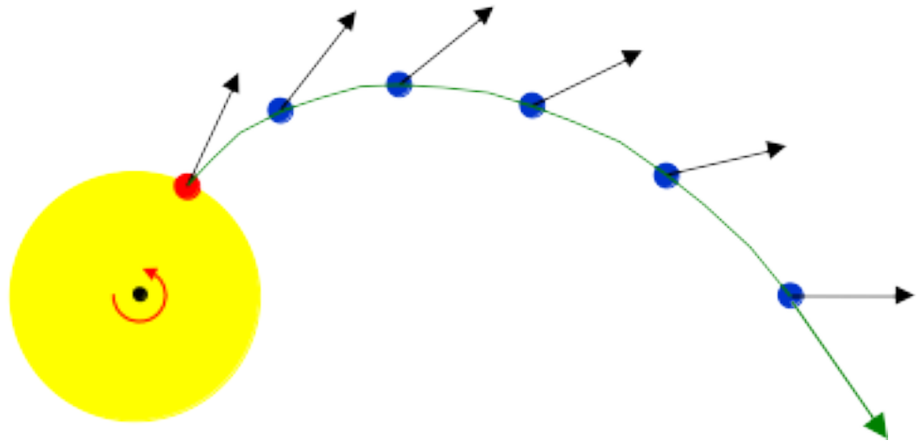
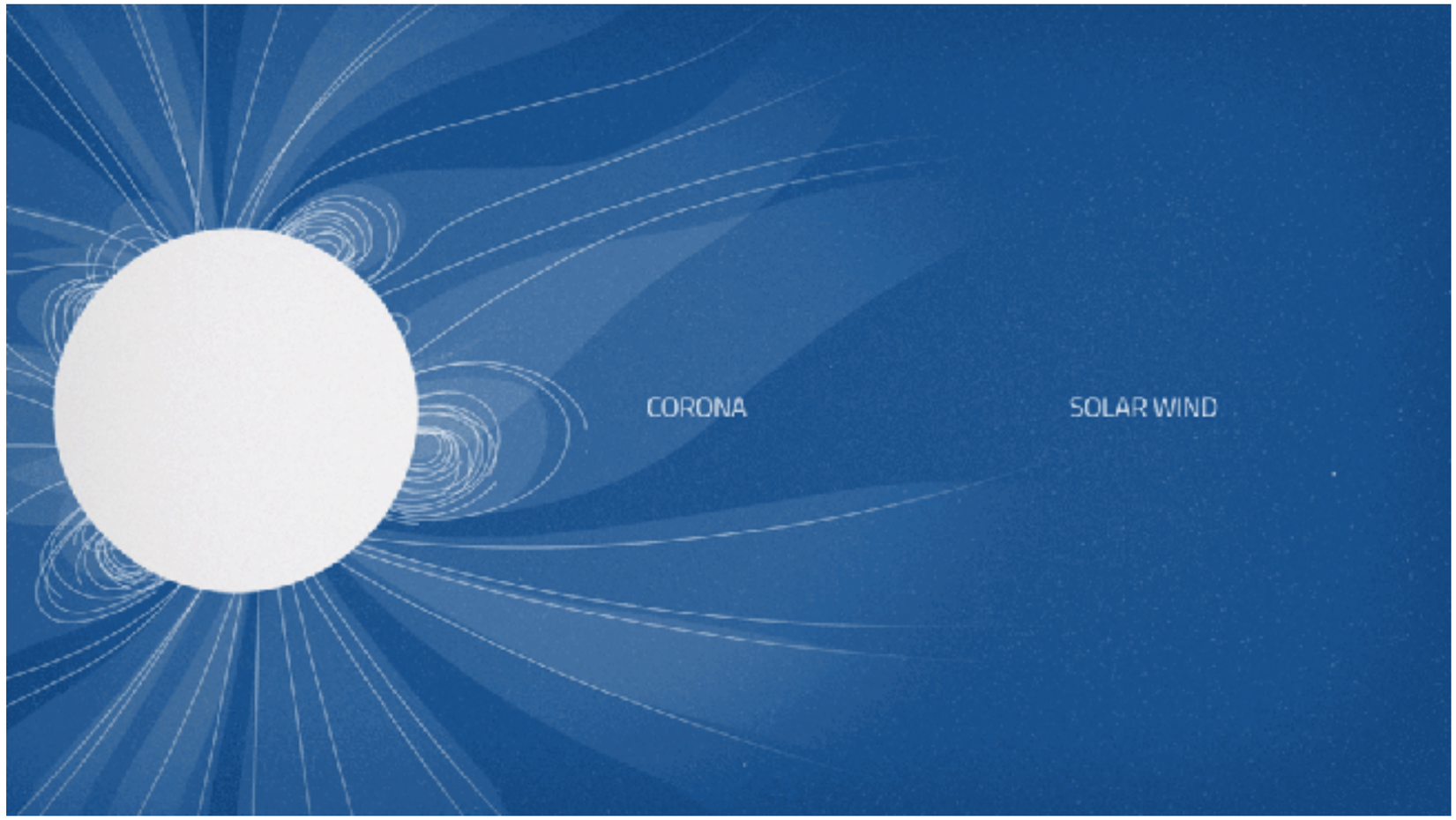


Arge, 2018

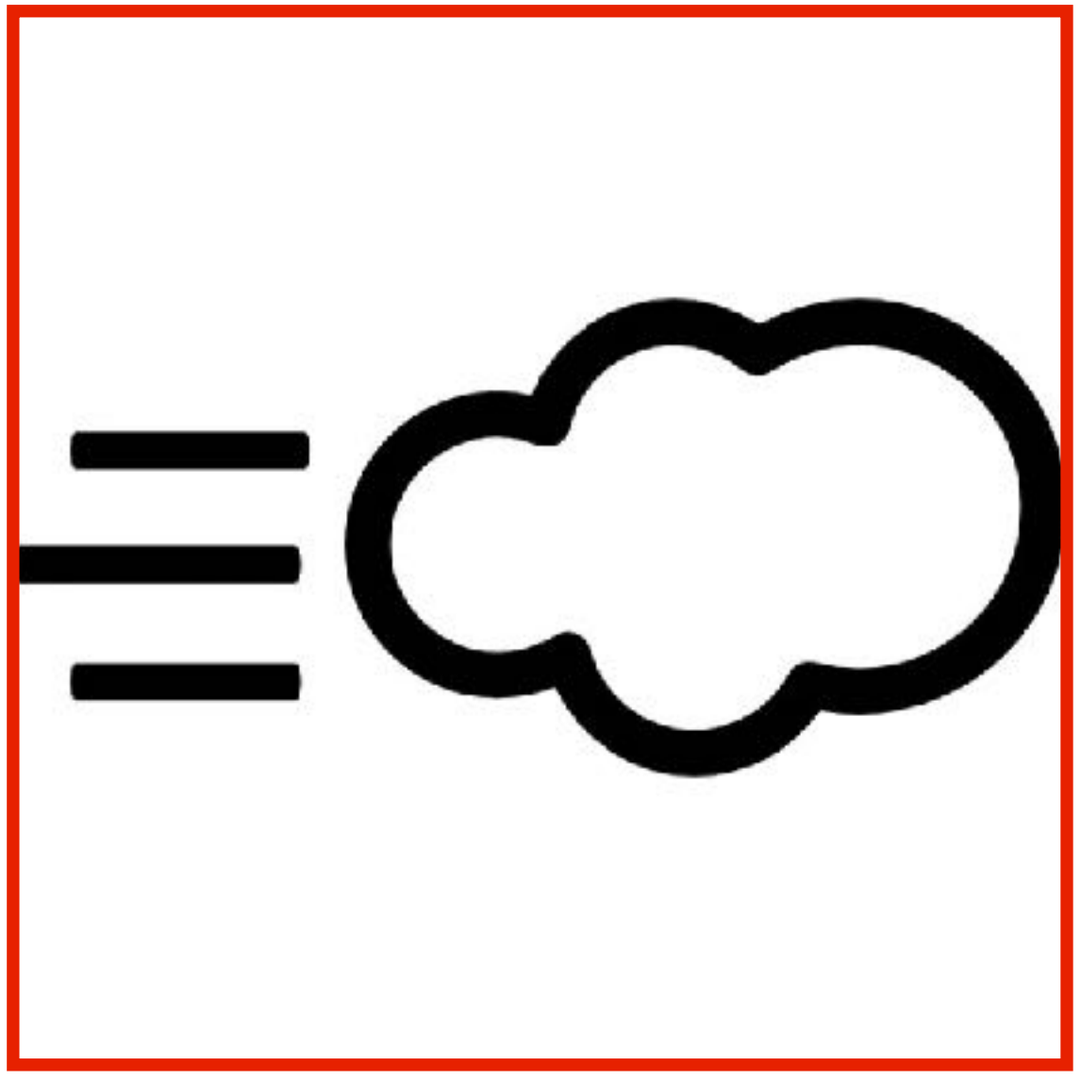


Continuous radial outflow of gas - Consists of charged particles

Shapes the IMF - Can carry magnetic structures.

Is the IMF Straight/Bent?

IMF are open/closed magnetic field lines?



SOLAR WIND

Near Earth

NOAA Satellite and Information Service

IN SITU SOLAR WIND

L4

DSCOVR

92 MILLION MILES

1 MILLION MILES

L3

L1

L2

L5

SWPC

2023-10-18 00:00:00

Mag + Solar Wind

30 days@30 min

2023-11-17 00:00:00

[Active] ACE+DSCOVR

Bt Bz GSM (nT) +x +y-

60
40
20
0
-20
-40
-60

Phi GSM (deg)

315
135

Away + Towards -

Density (1/cm³)

1000
100
10
1

Speed (km/s)

300
700
600
500
400
300
200

Temperature (°K)

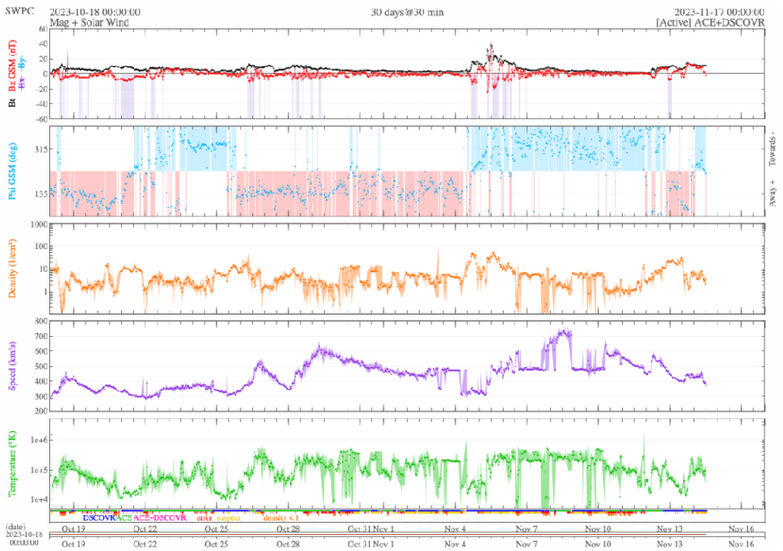
1e+6
1e+5
1e+4

DSCOVR ACE ACE+DSCOVR error suspect density < 1

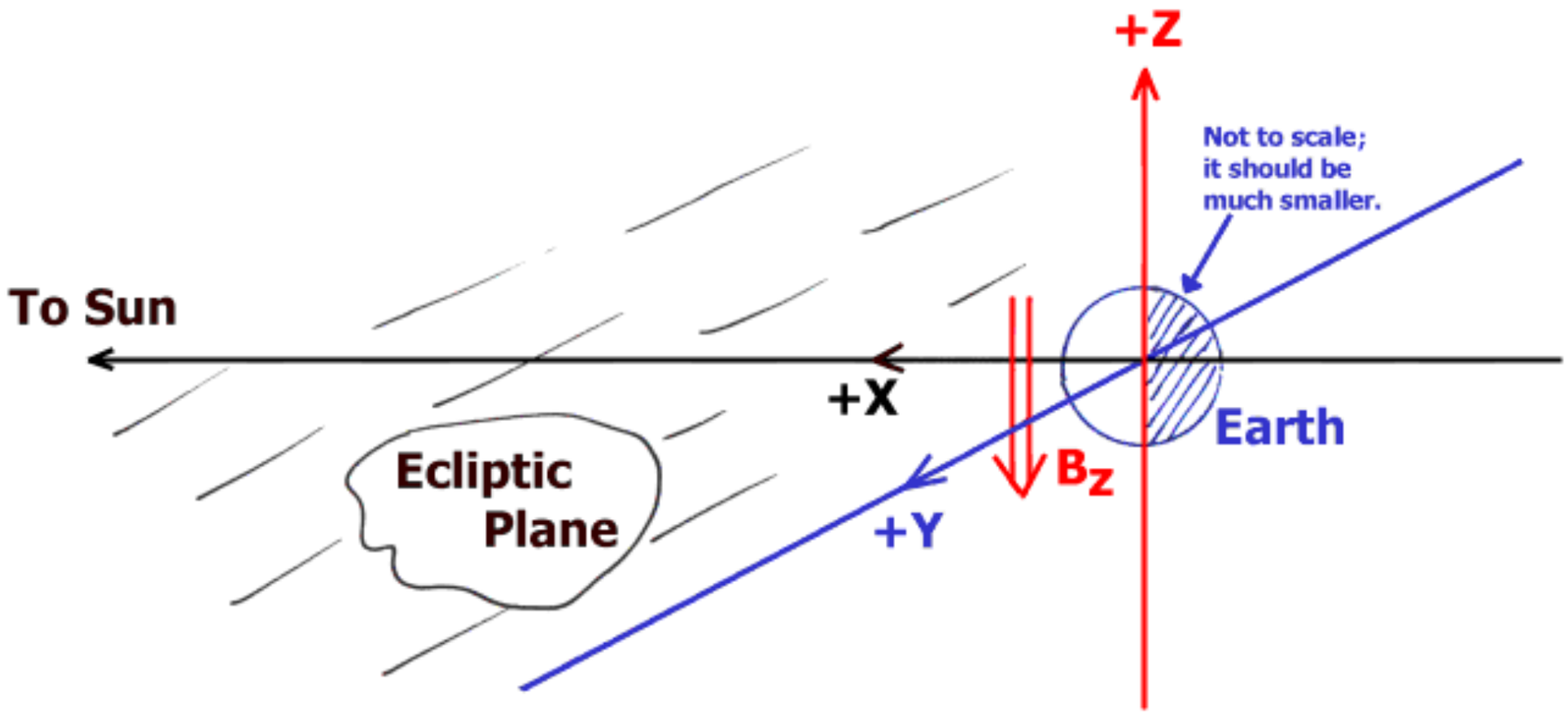
(date)
2023-10-18
00:00:00

Oct 19 Oct 22 Oct 25 Oct 28 Oct 31 Nov 1 Nov 4 Nov 7 Nov 10 Nov 13 Nov 16

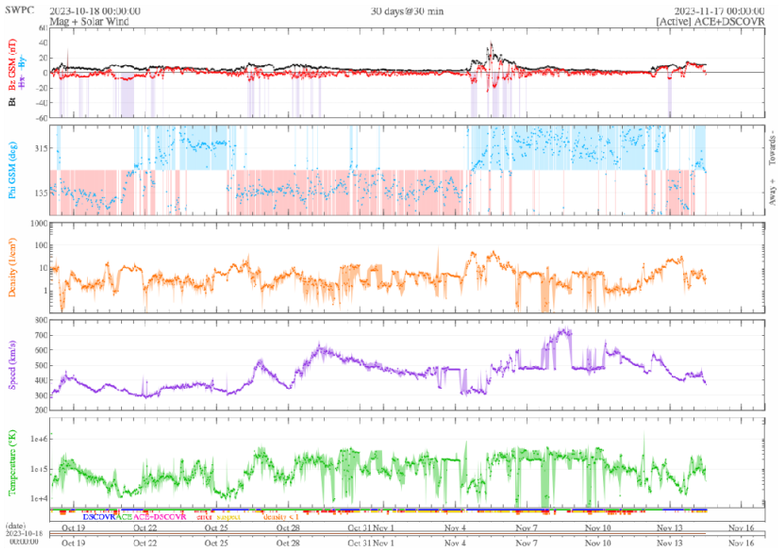
Oct 19 Oct 22 Oct 25 Oct 28 Oct 31 Nov 1 Nov 4 Nov 7 Nov 10 Nov 13 Nov 16



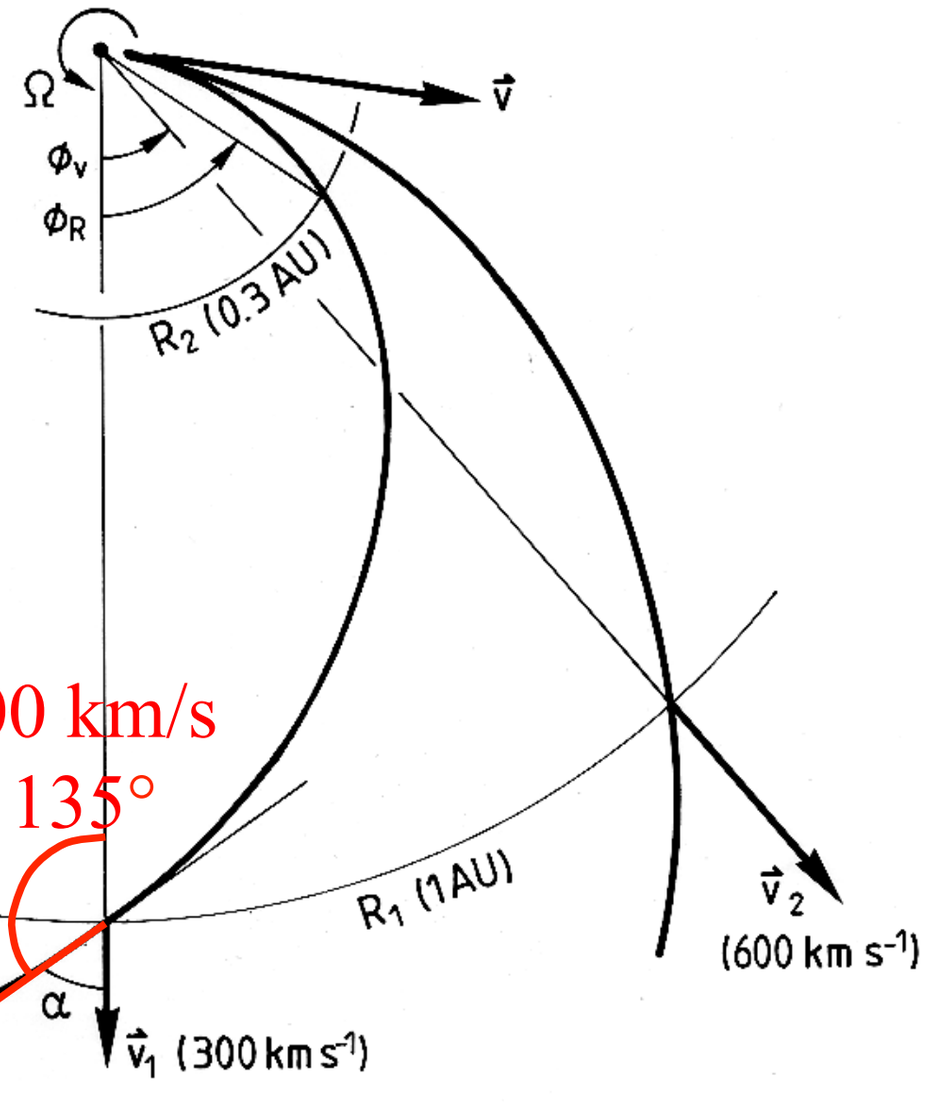
COORDINATE SYSTEM



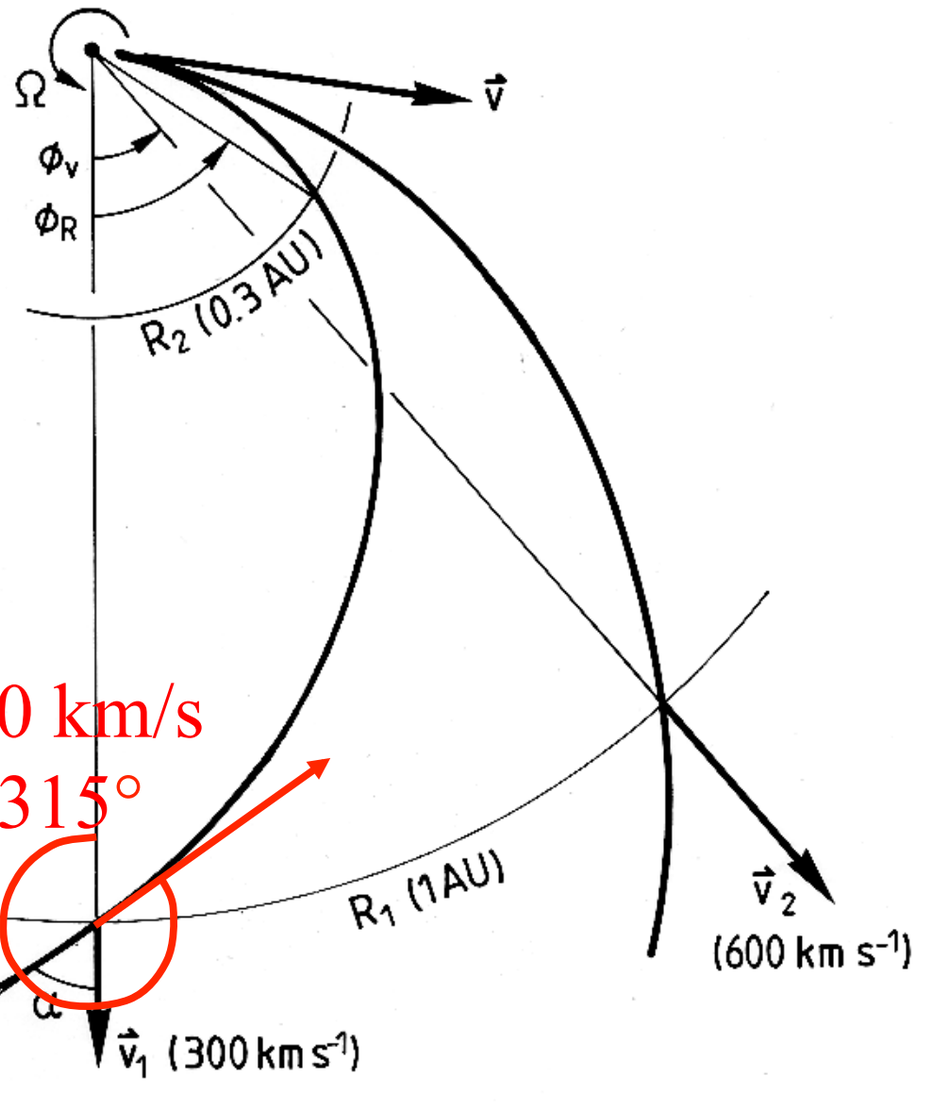
+Z is perpendicular to the Ecliptic Plane.



IMF POLARITY

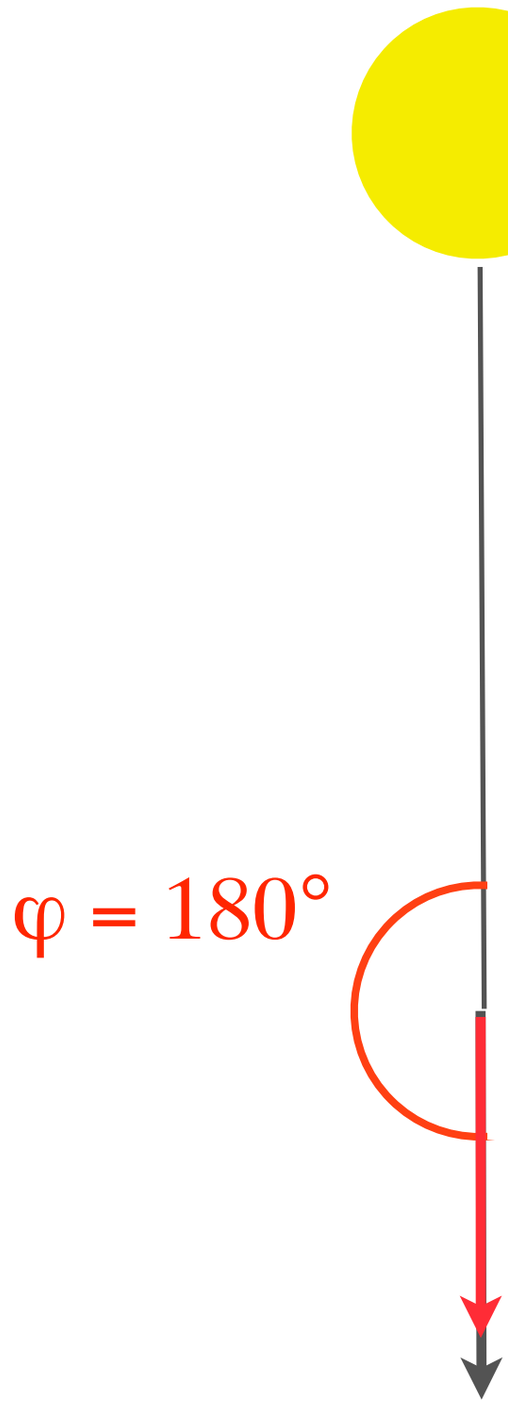


for 400 km/s
φ ~ 135°

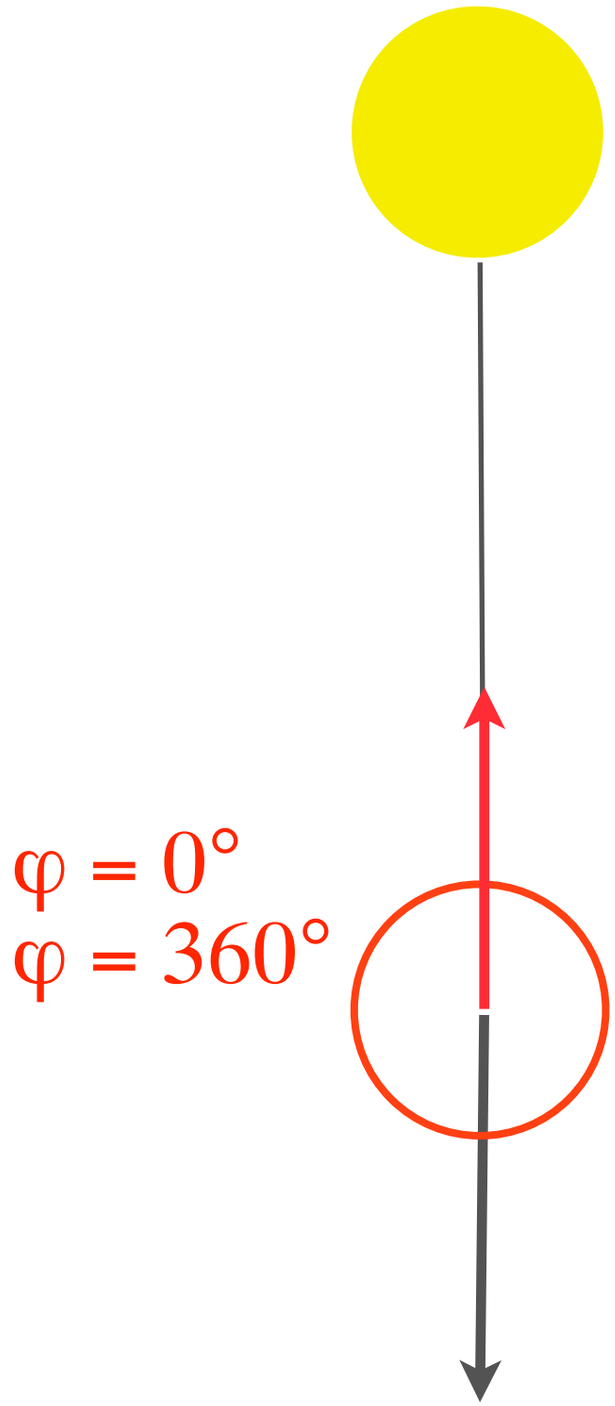


for 400 km/s
φ ~ 315°

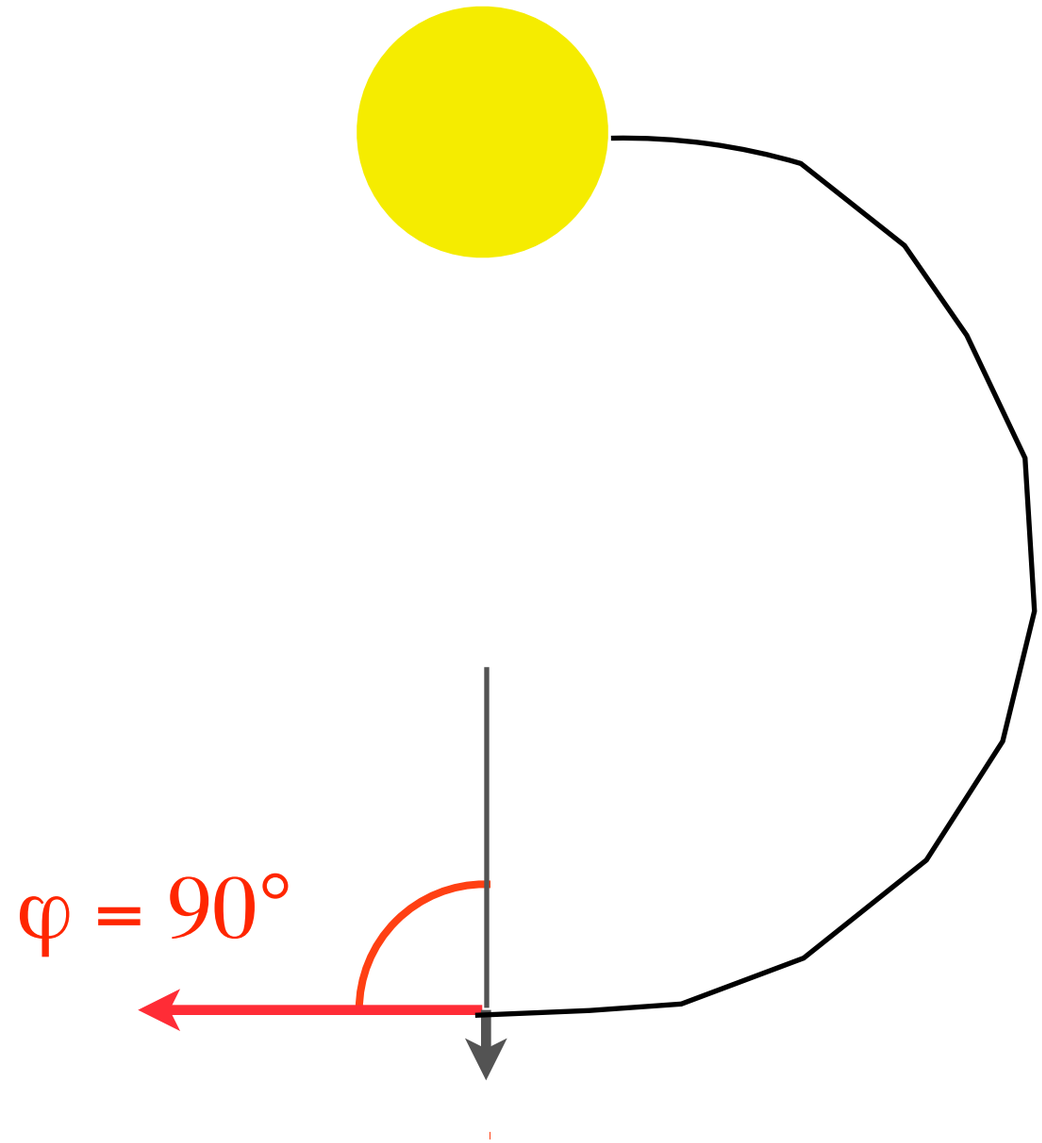
EXTREME FAST

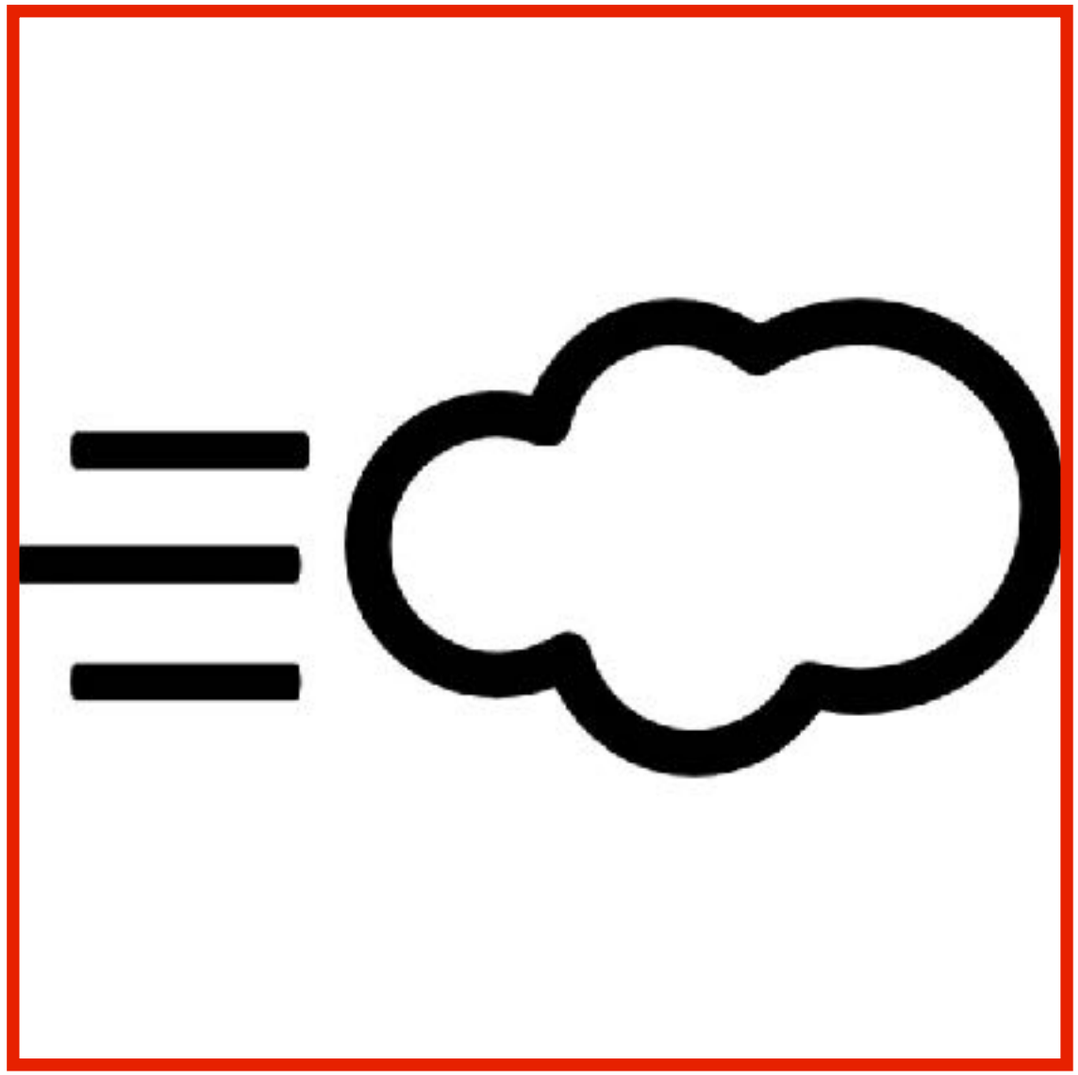


EXTREME FAST



EXTREME SLOW





SOLAR WIND

Transients

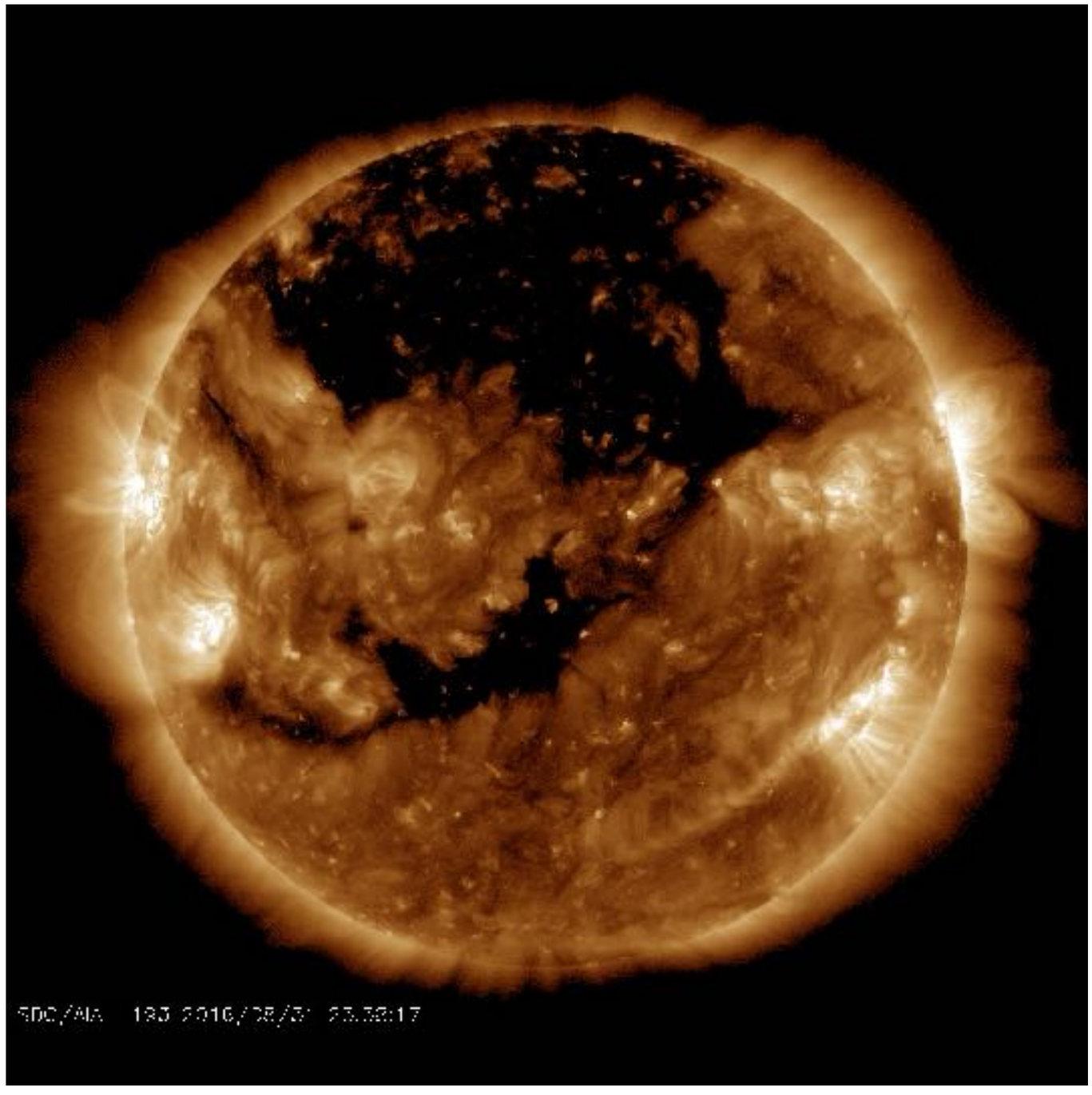
Transients

High Speed Streams (HSSs)

And

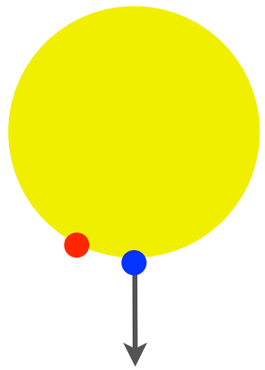
Co-rotating Interaction Regions (CIRs)

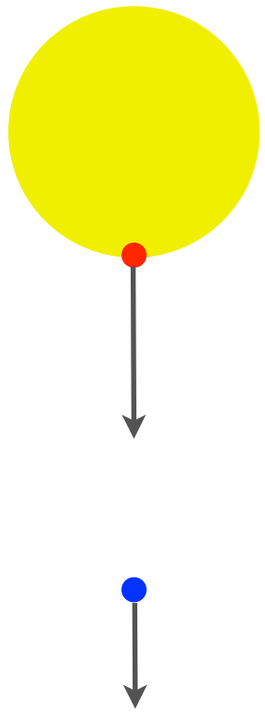
Coronal Hole

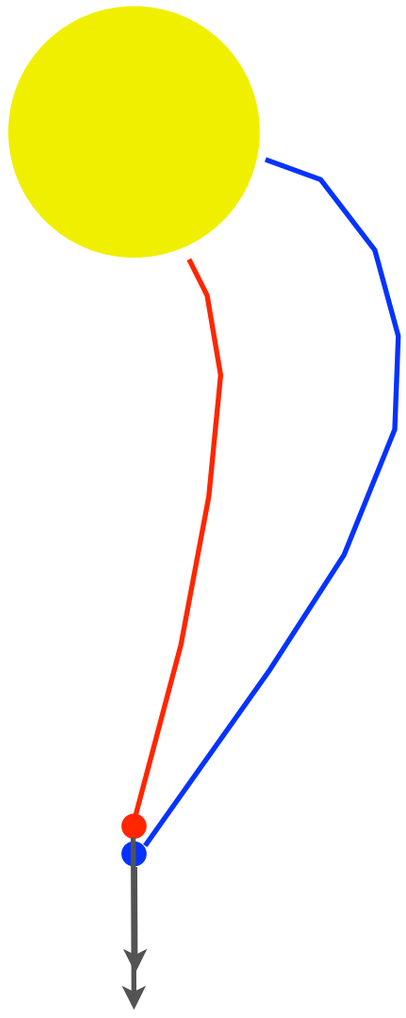


WHAT HAPPENS WHEN FAST CATCHES SLOW?

Top View



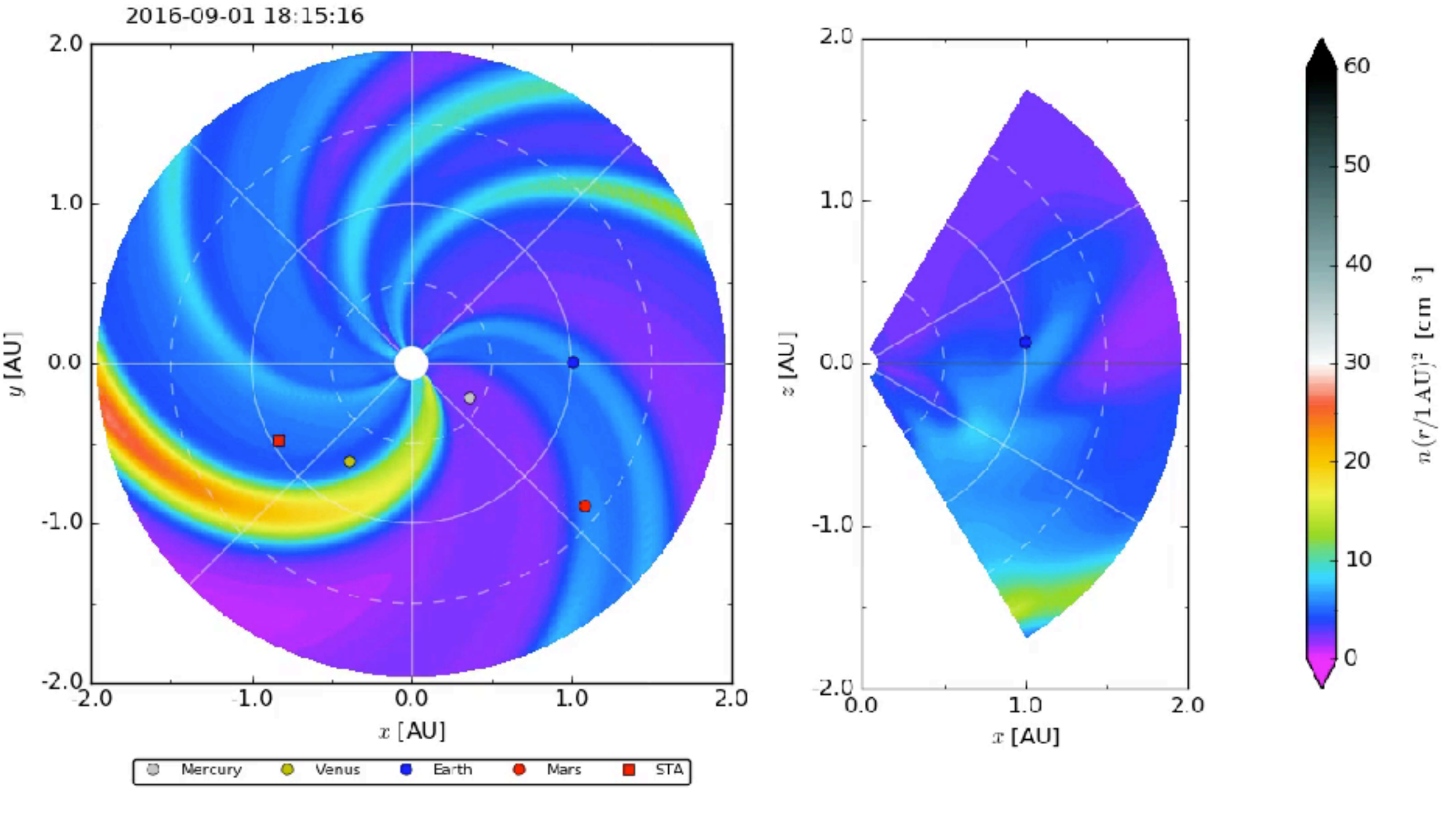




Interaction Region
Rotates together with the Sun

Co-rotating Interaction Region

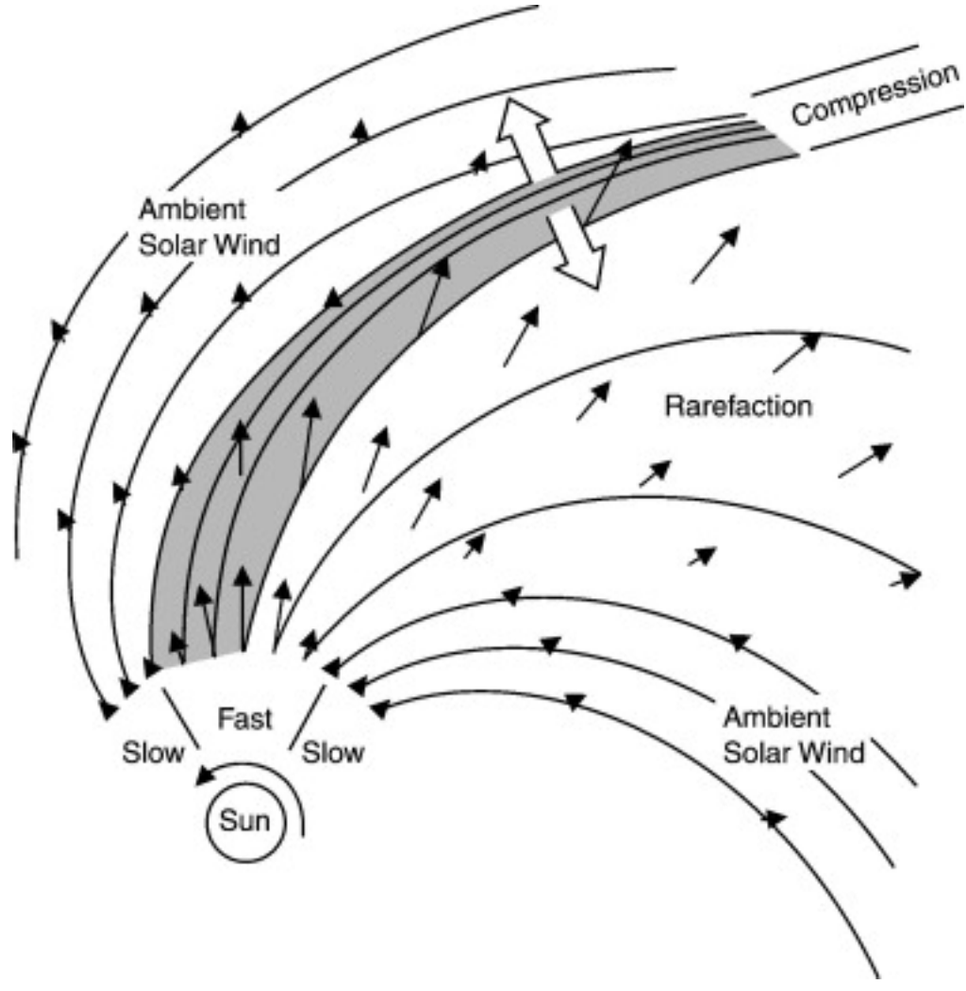
Co-rotating Interaction Region



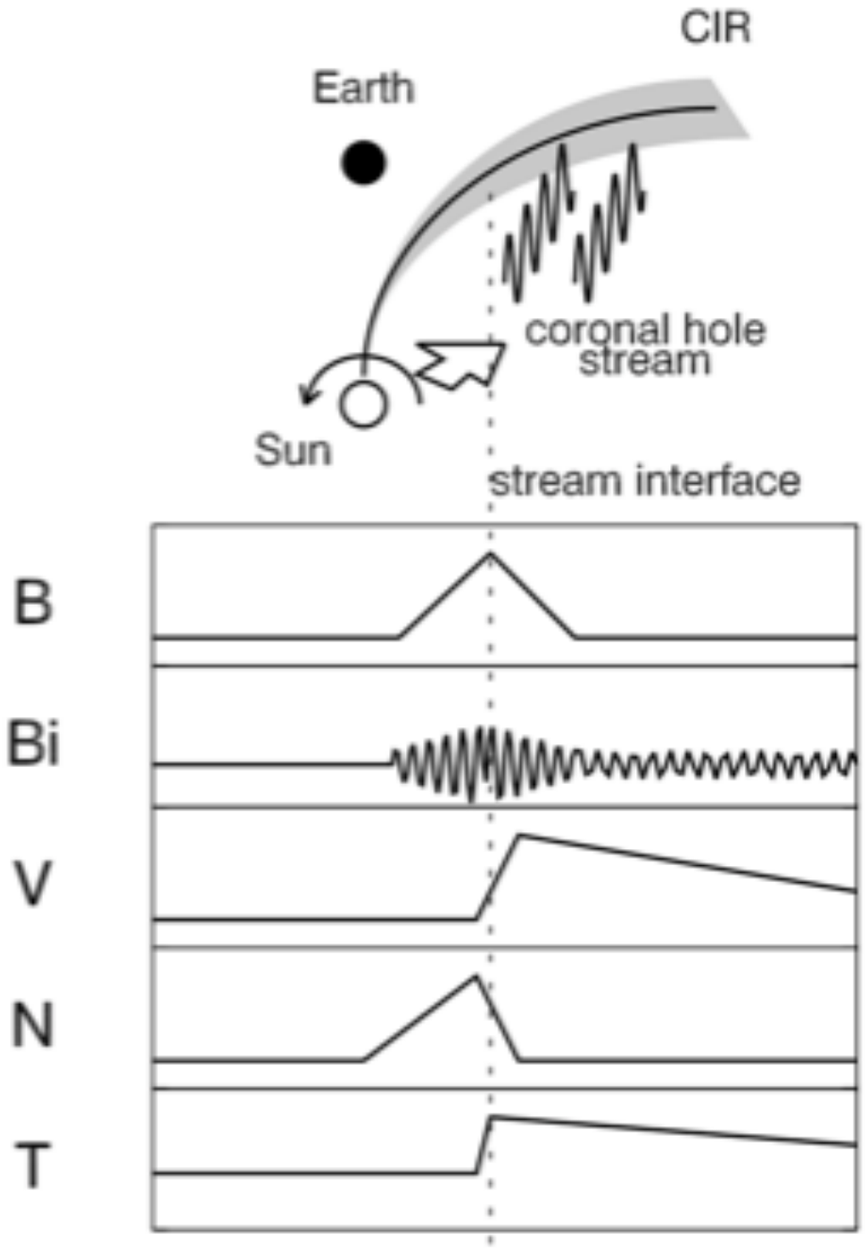
EUHFORIA, realtime simulations of the inner heliosphere

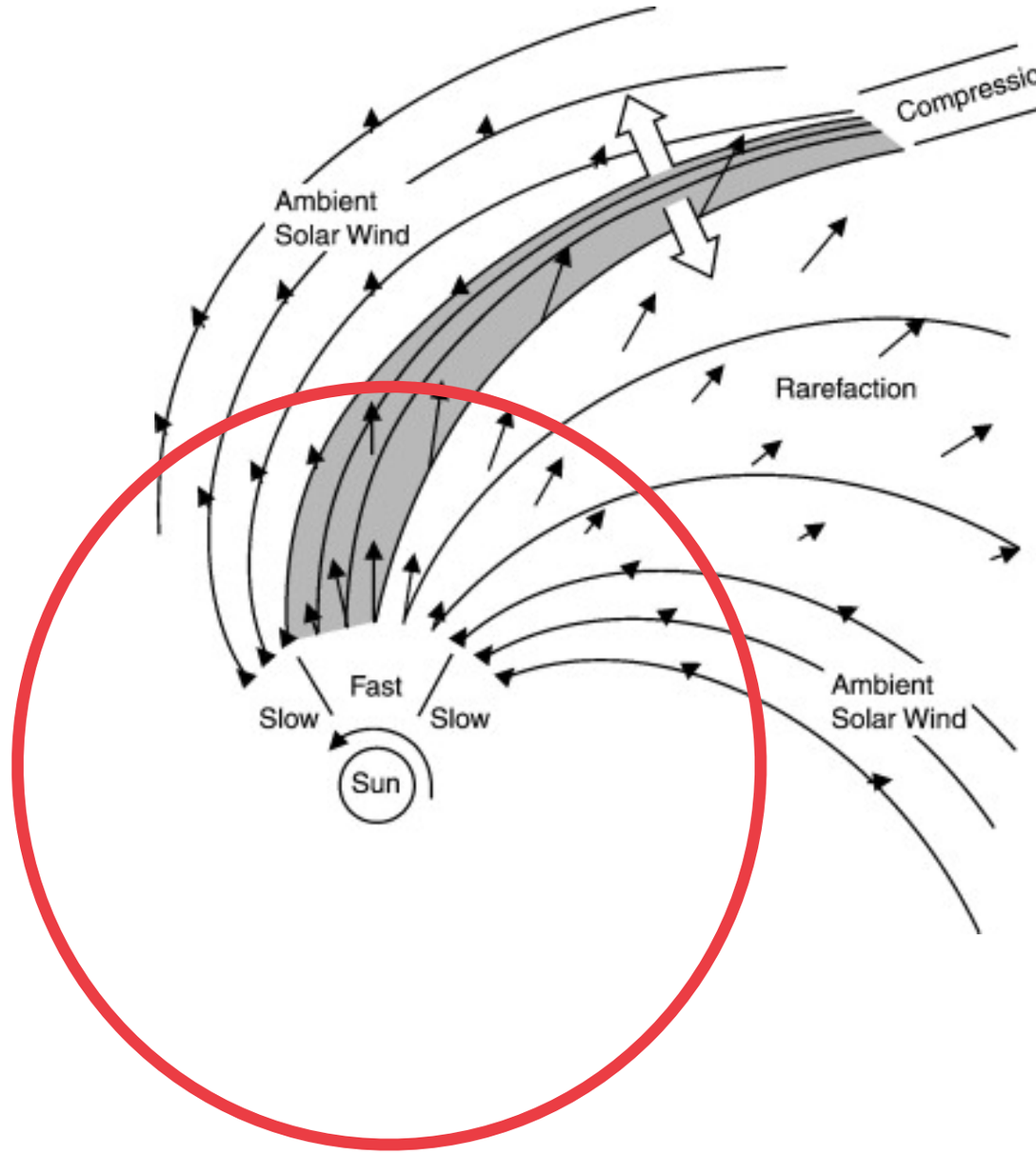
Co-rotating Interaction Region

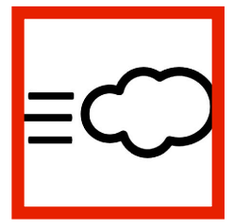
- A HSS co-rotates with the Sun, generating a CIR
- CH can appear everywhere on the Sun
- If close to the equator, the associated HSS will arrive +- 3 days at Earth (v~ 600 km/s)
- Radial!



Co-rotating Interaction Region

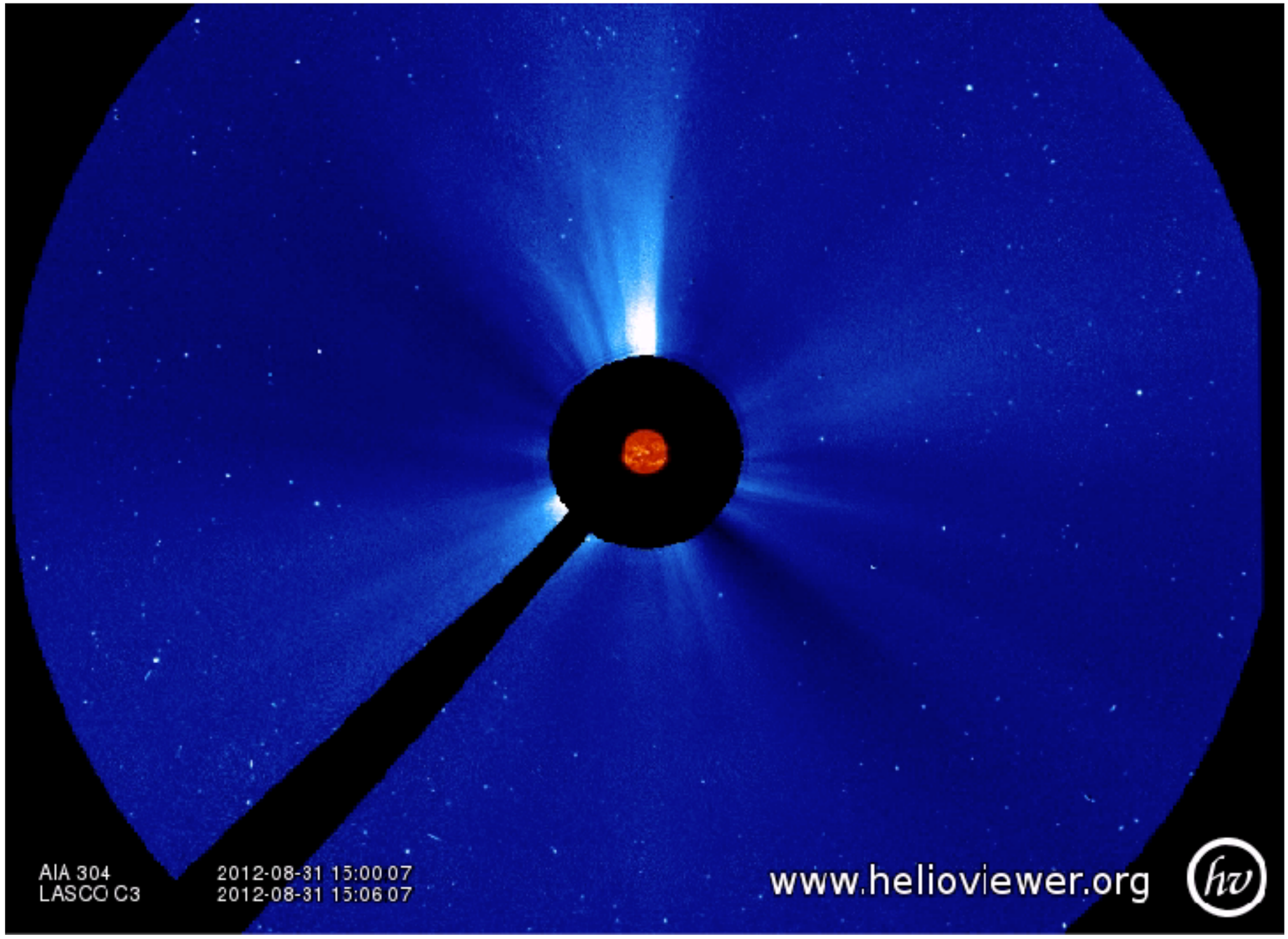






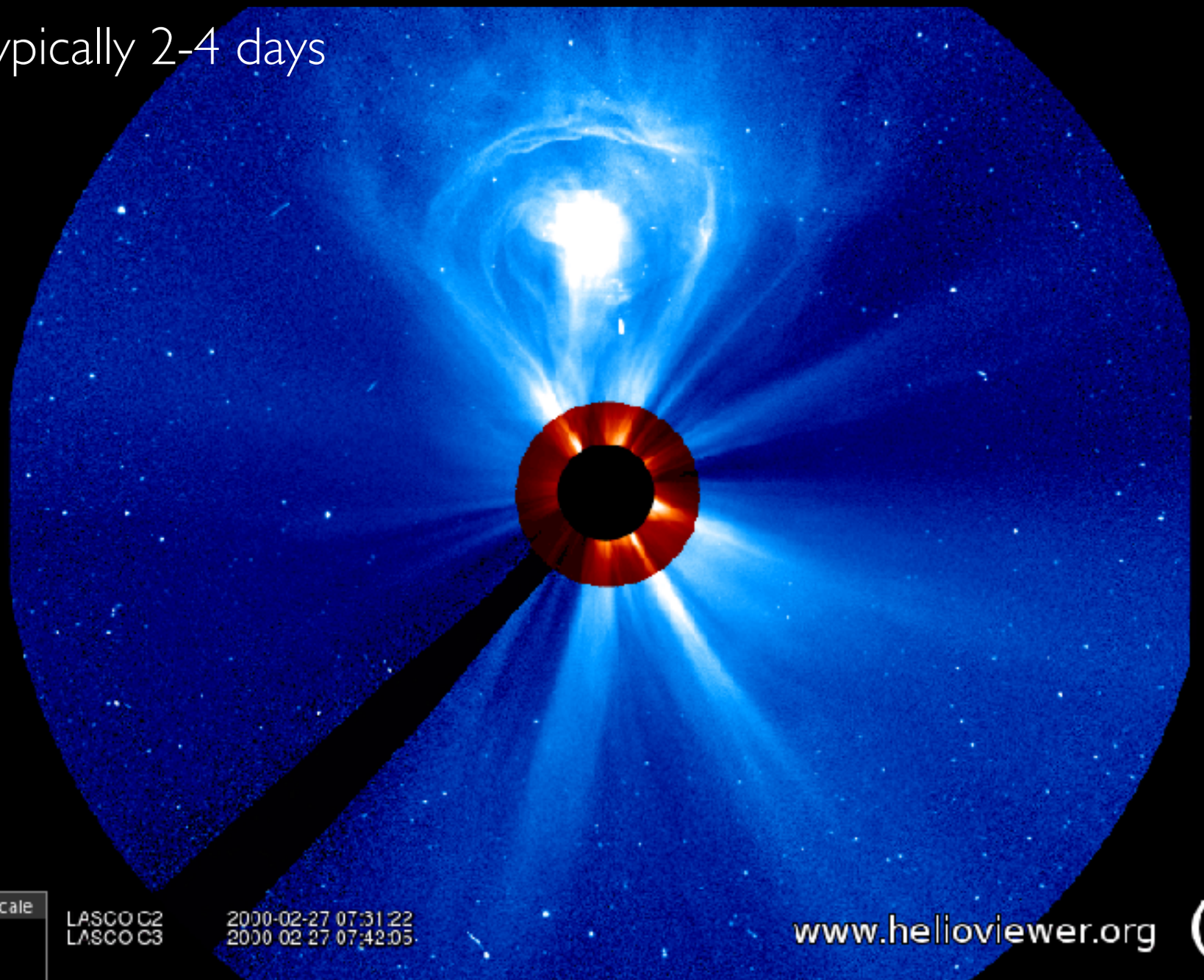
Transients

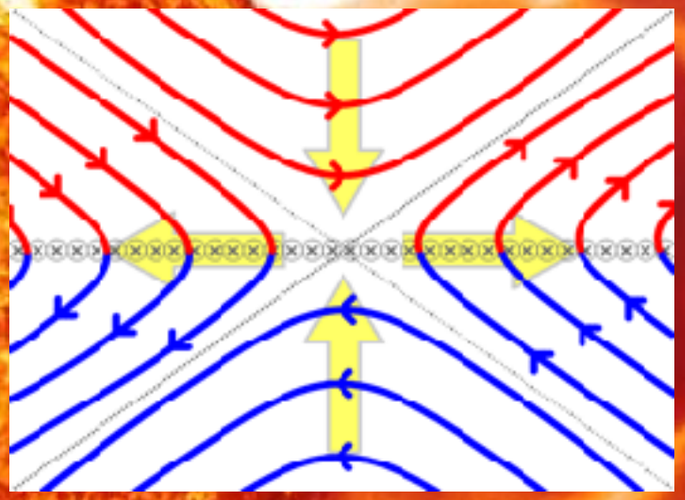
Coronal Mass Ejections

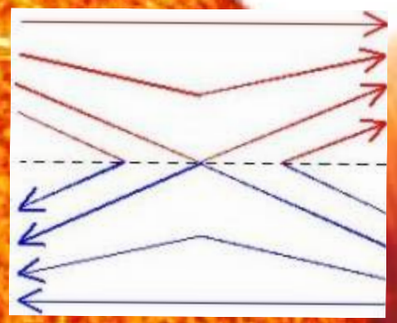


A new, discrete, bright white light feature in the coronagraph field-of-view with a predominantly, radial outward velocity.

- Trigger the strongest geomagnetic storms
- < 1/day during solar min, ~ 3 during solar max
- V between 400 and 2000 km/s
- Travel time typically 2-4 days

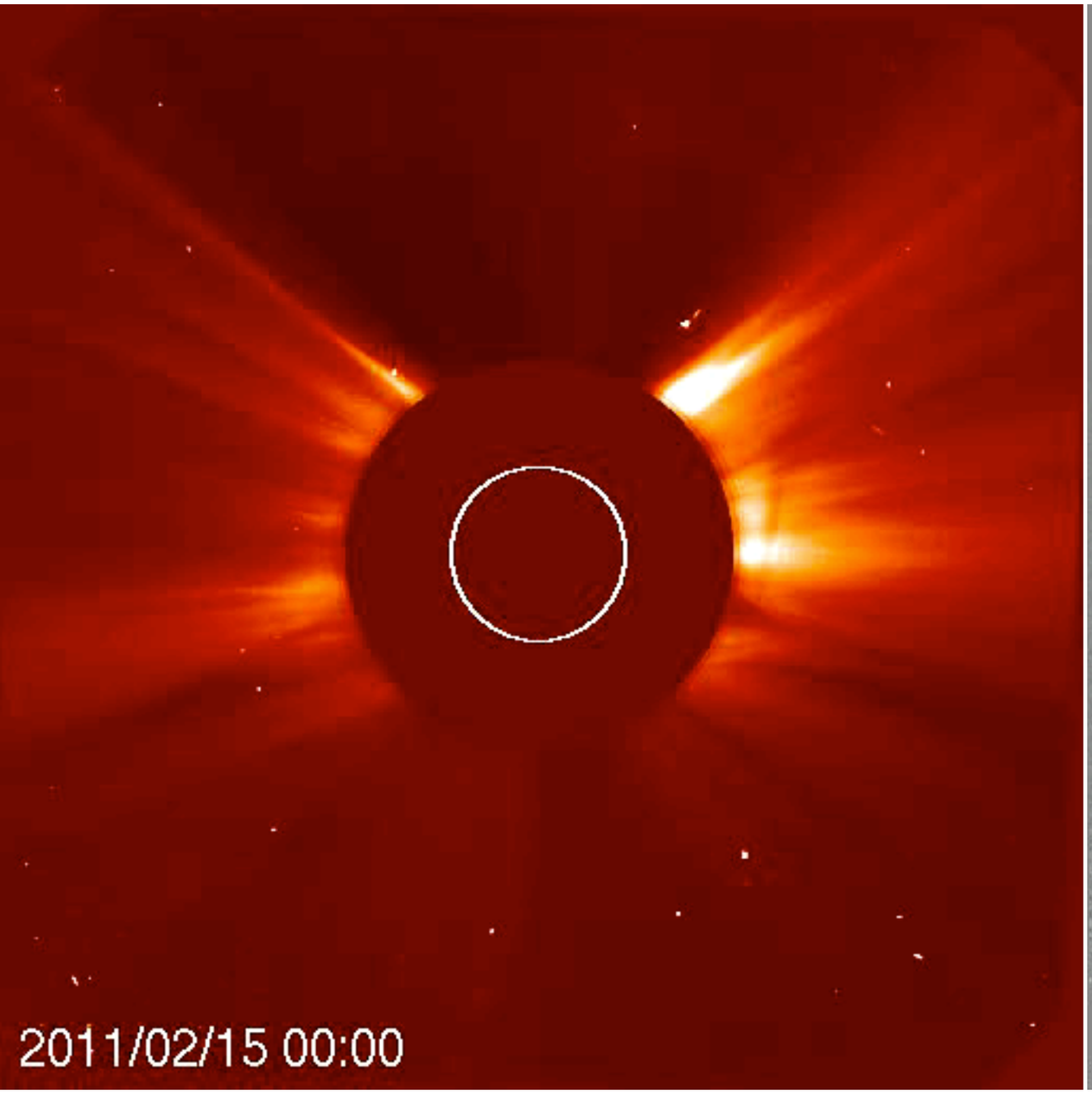


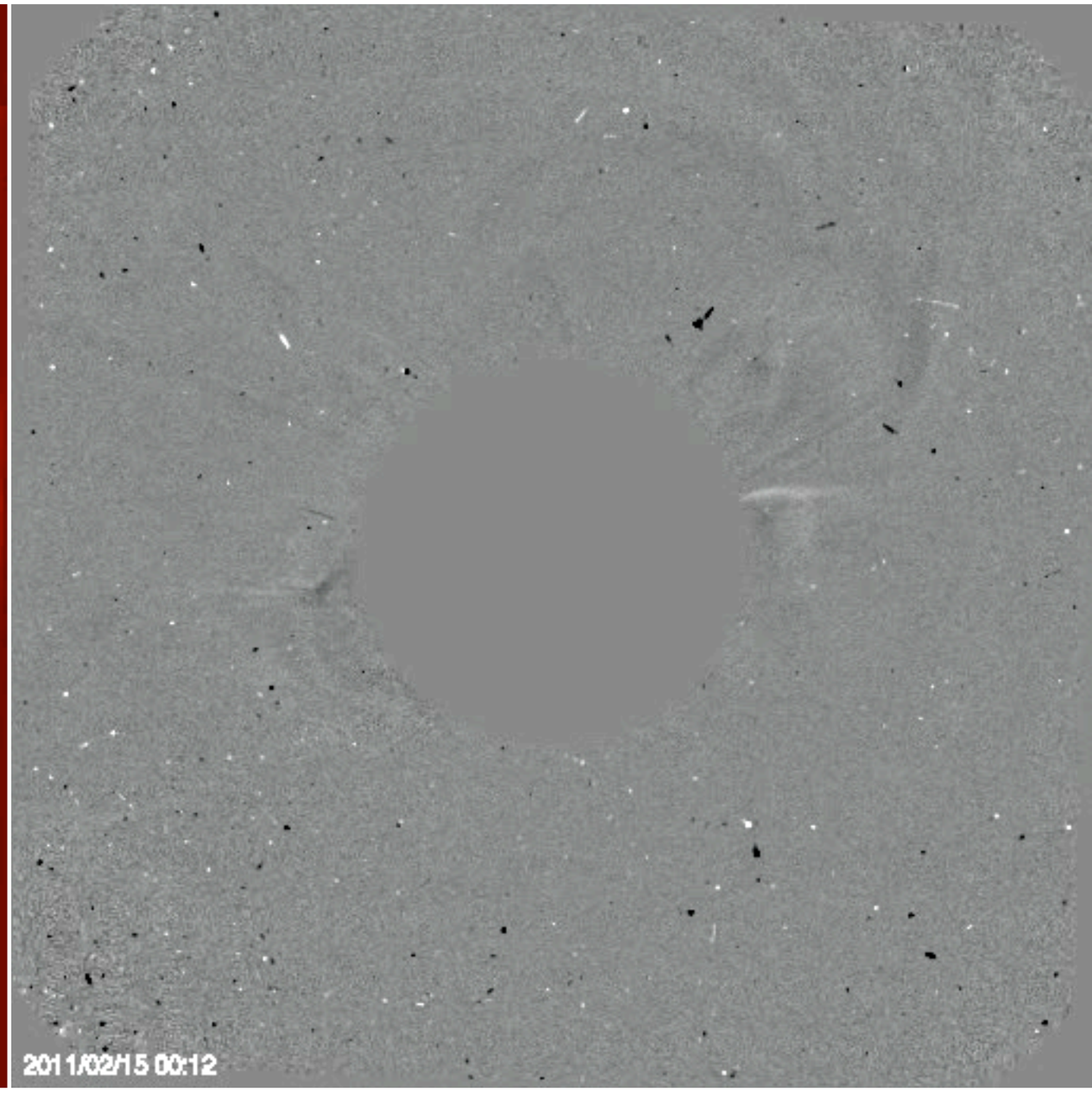




How do you know a CME occurred?

IN CORONAGRAPHS



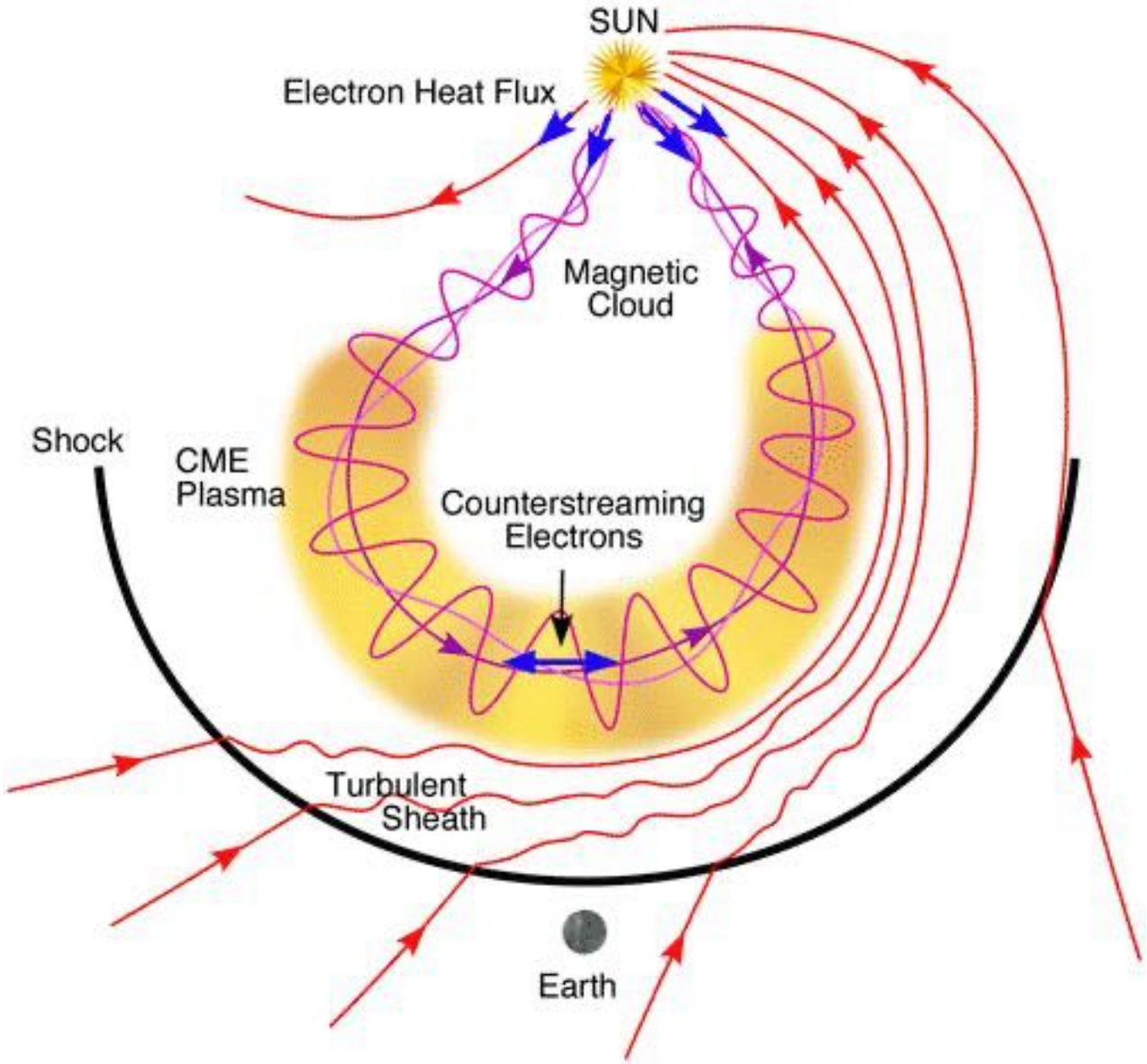


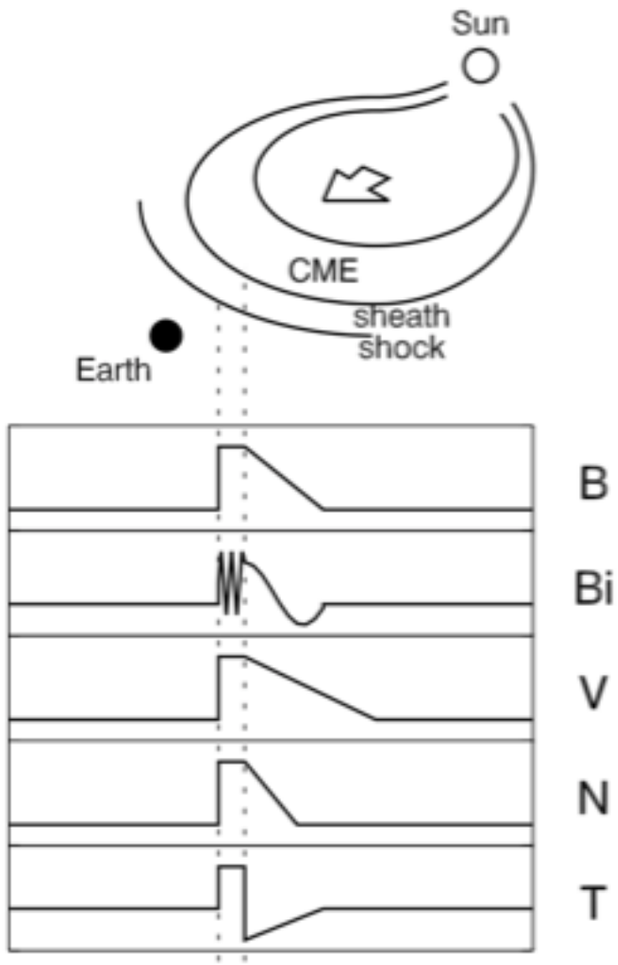
SOHO / LASCO C2

running difference

HALO CME ALERT + PRESTO

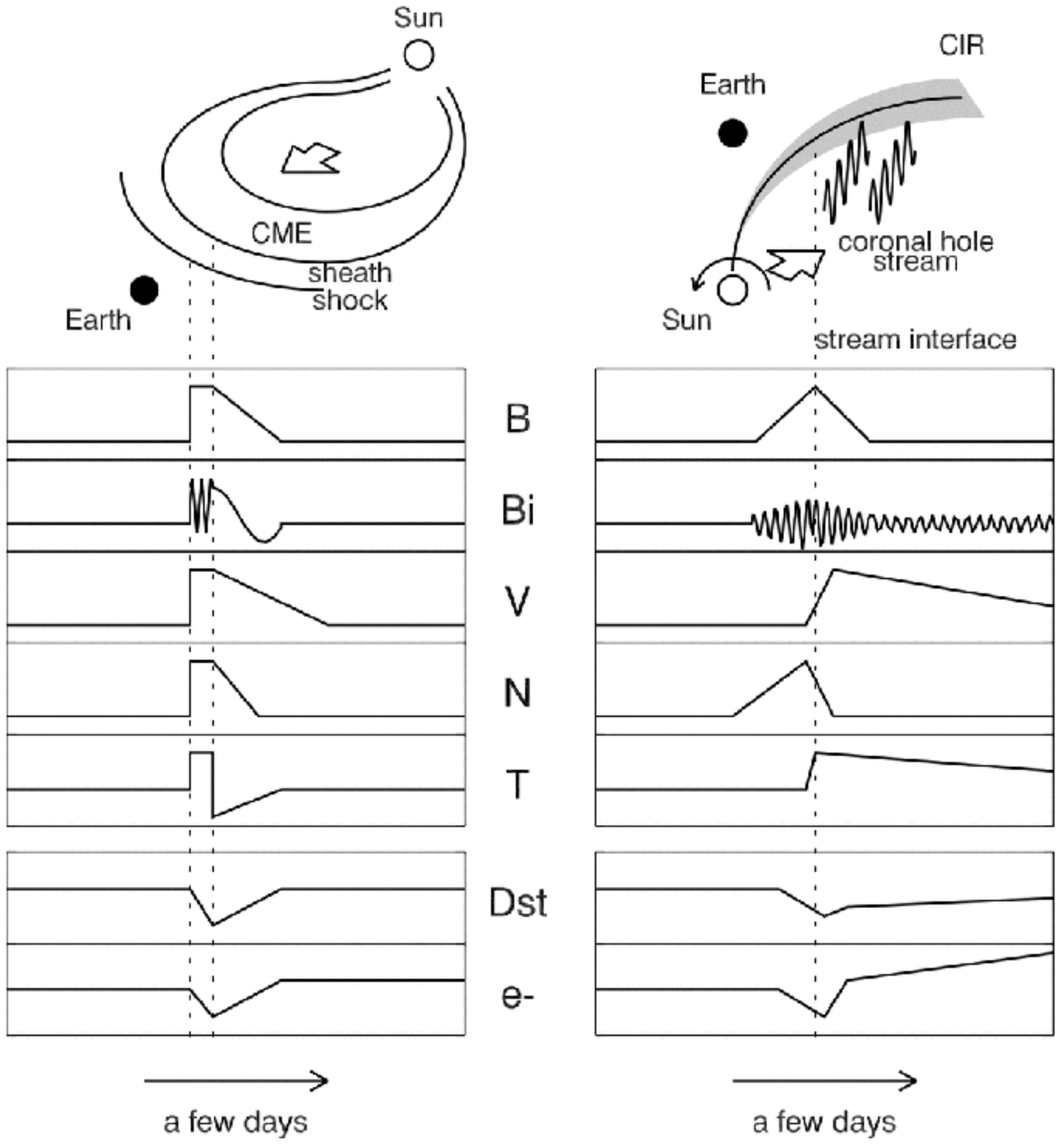
INTERPLANETARY CORONAL MASS EJECTION - ICME

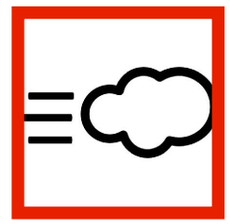




DIFFERENCES

ICME	CIR
Expanding	Compressing
Declining speed profile	Increasing speed profile
Low T (wrt V)	High T
High B (any value above 10 nT)	High B (until ~20nT)
CME	CH (also previous rotation)
Rotation in B	High variation in B
ICMEs and CIRs can interact	

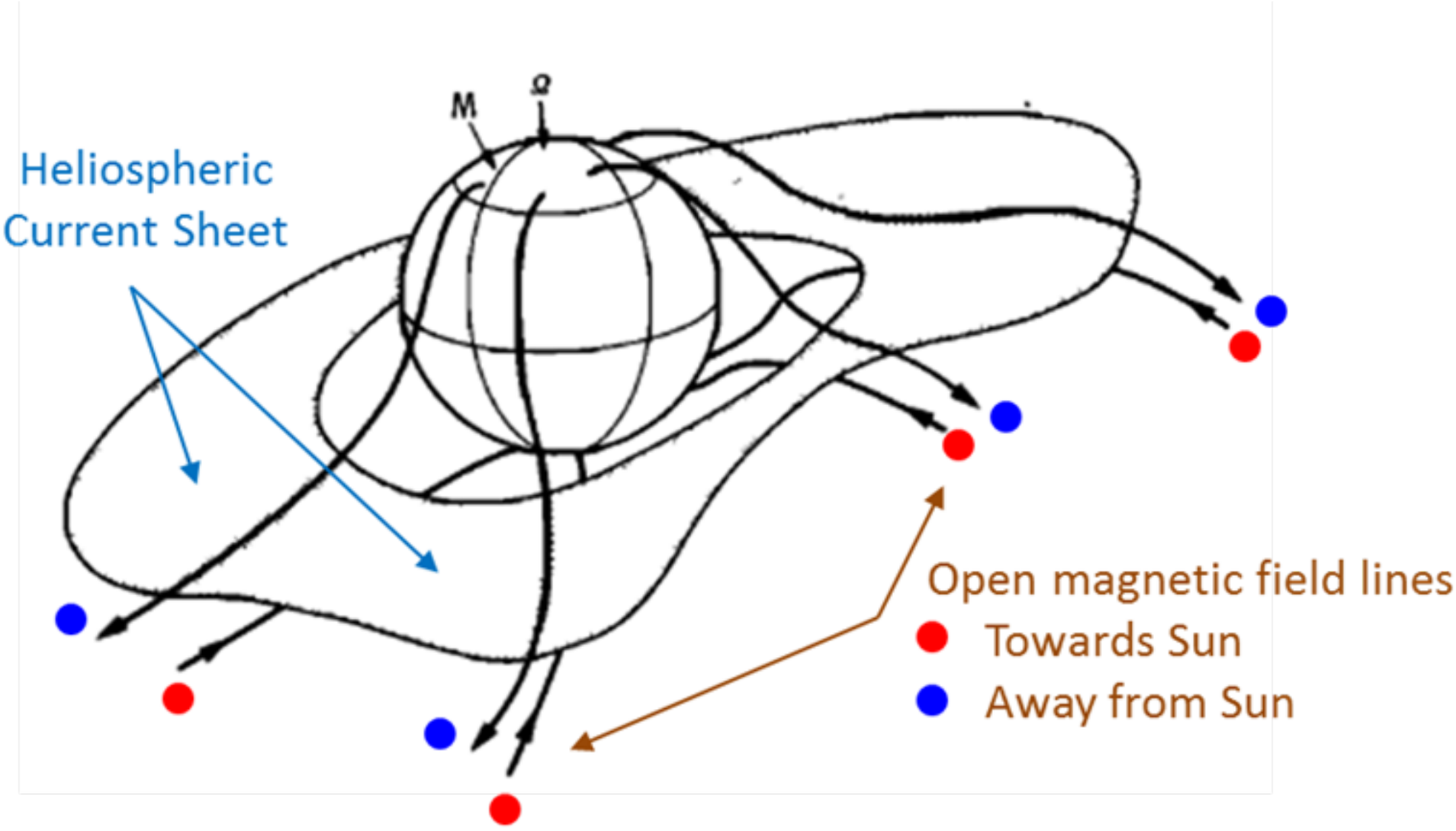

Sun
CME
sheath
shock
Earth
CIR
Earth
coronal hole
stream
Sun
stream interface
B
Bi
V
N
T
Dst
e-
a few days
a few days



Transients

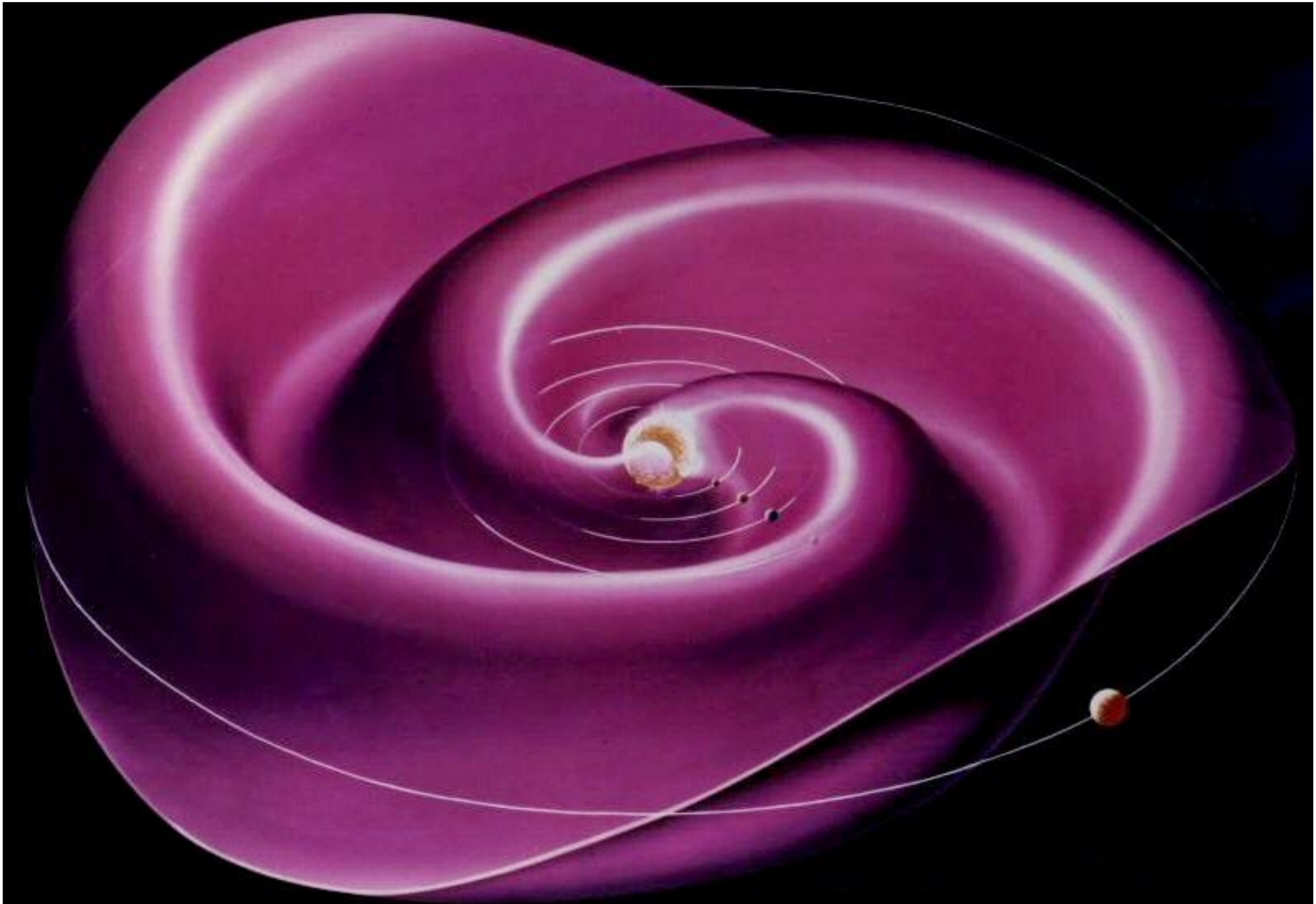
Sector Boundary Crossing

HELIOSPHERIC CURRENT SHEET

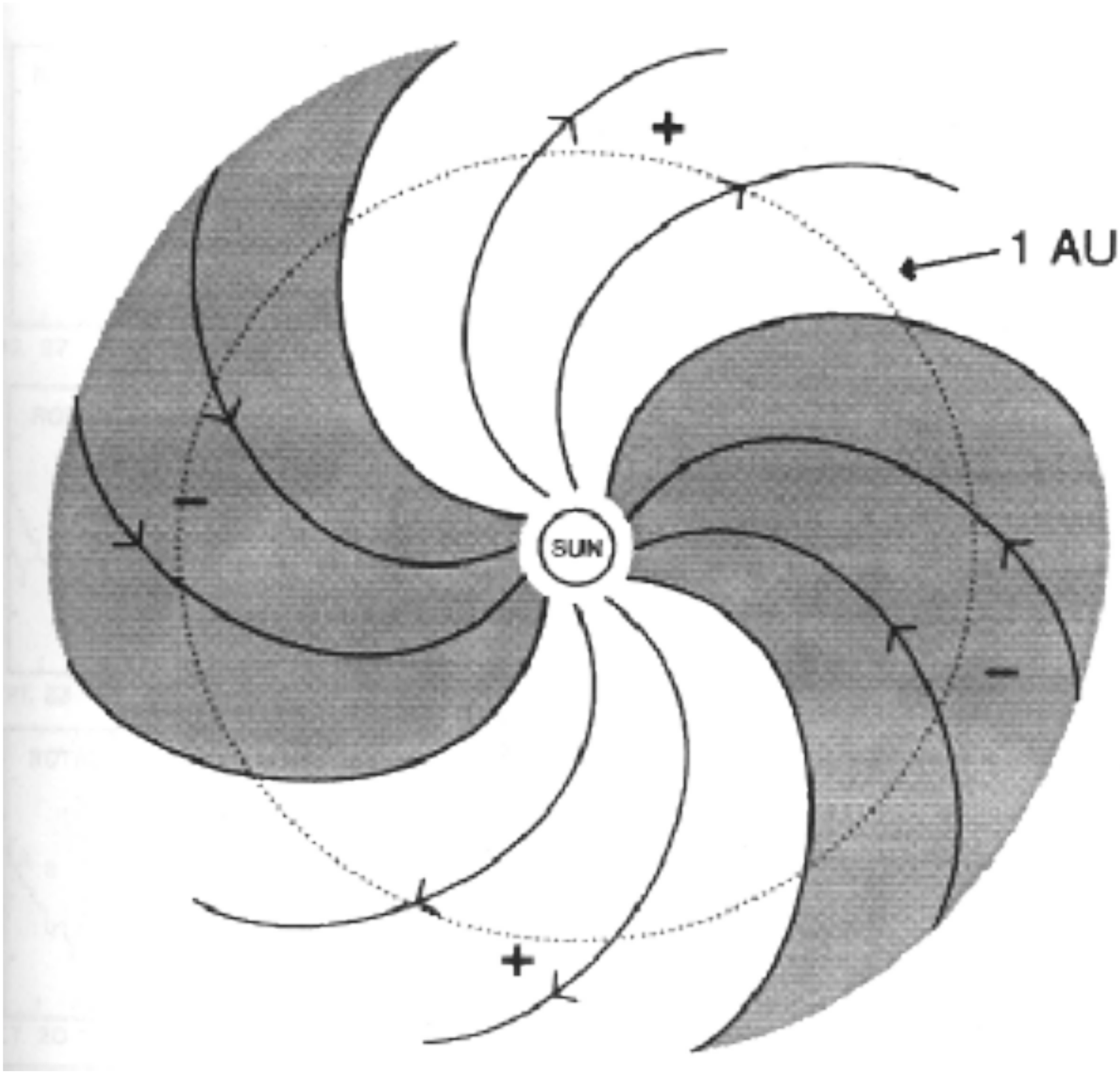


Adapted from Smith et al., 1978

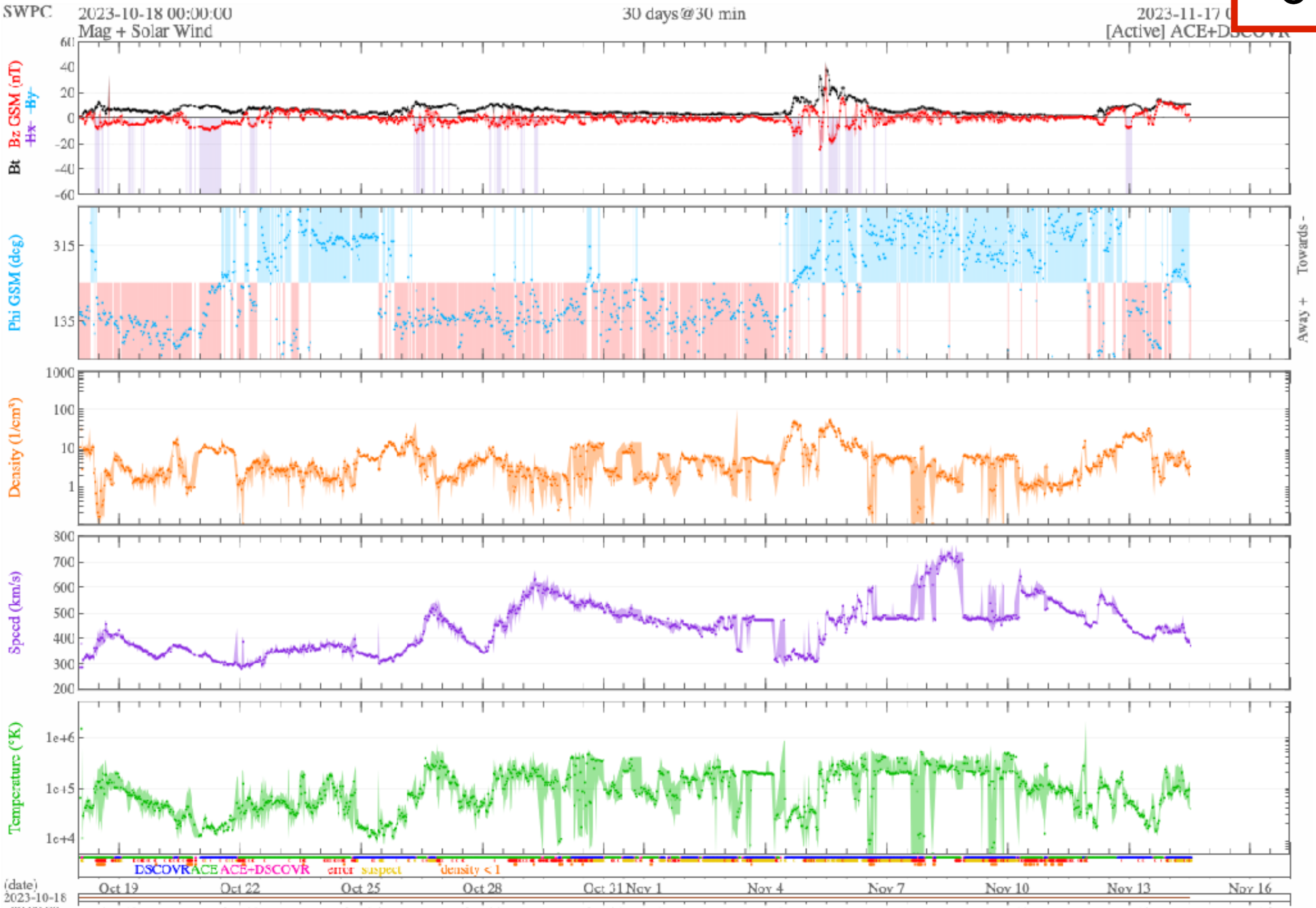
BALLERINA SKIRT

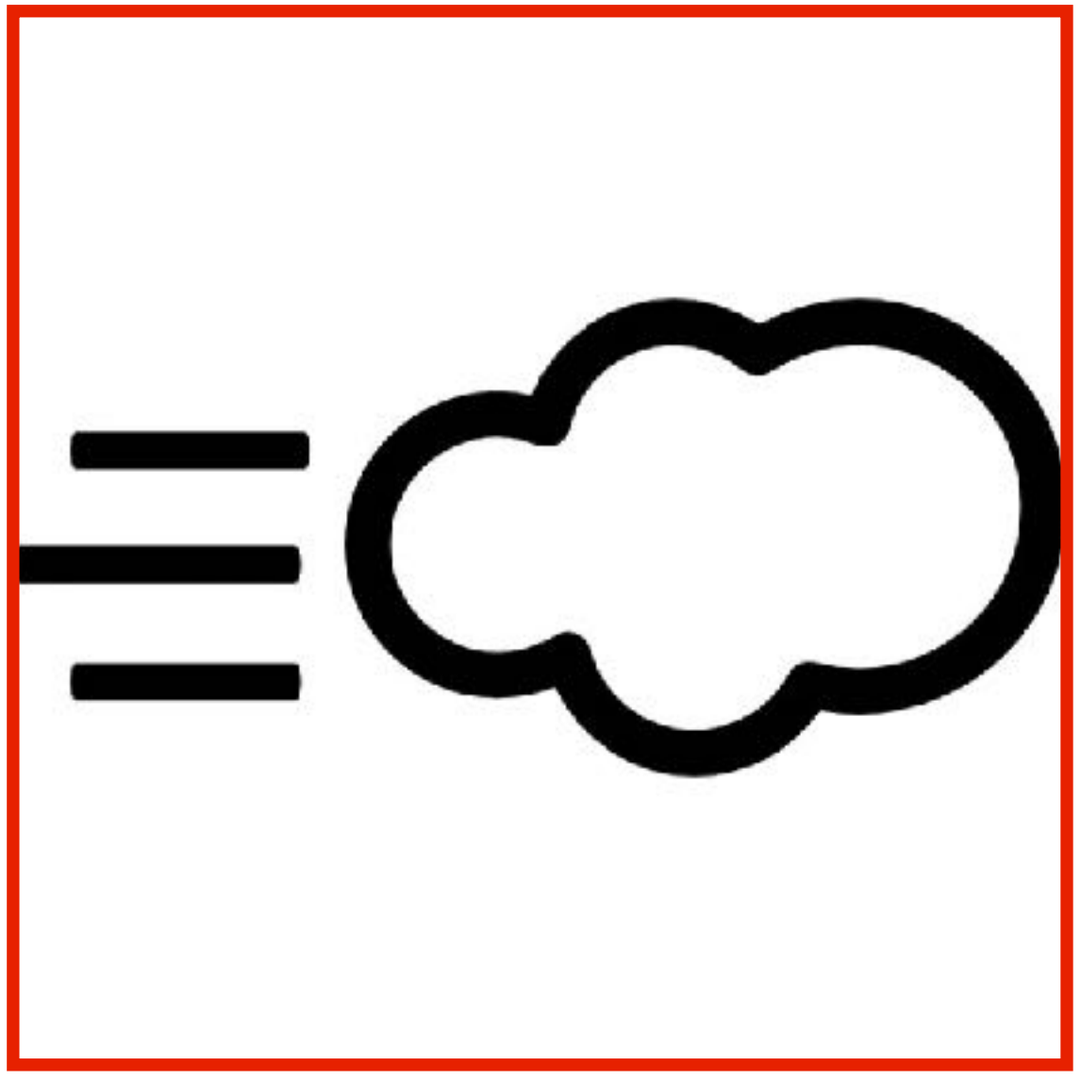


AWAY/TOWARDS SECTORS



IN SITU


SWPC
2023-10-18 00:00:00
30 days@30 min
2023-11-17 0
Mag + Solar Wind
[Active] ACE+DSCOVR
Bt
Bz GSM (nT)
Hx
By
60
40
20
0
-20
-40
-60
Phi GSM (dcg)
315
135
Away +
Towards -
Density (1/cm³)
1000
100
10
1
Speed (km/s)
800
700
600
500
400
300
200
Temperature (°K)
1e+6
1e+5
1e+4
DSCOVR
ACE
ACE+DSCOVR
error
suspect
density < 1
(date)
2023-10-18
00:00:00
Oct 19
Oct 22
Oct 25
Oct 28
Oct 31
Nov 1
Nov 4
Nov 7
Nov 10
Nov 13
Nov 16

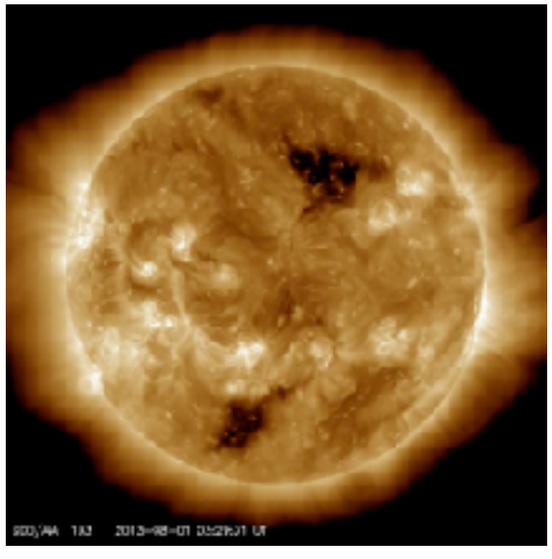


SOLAR WIND

Question

SOLAR WIND VARIATIONS

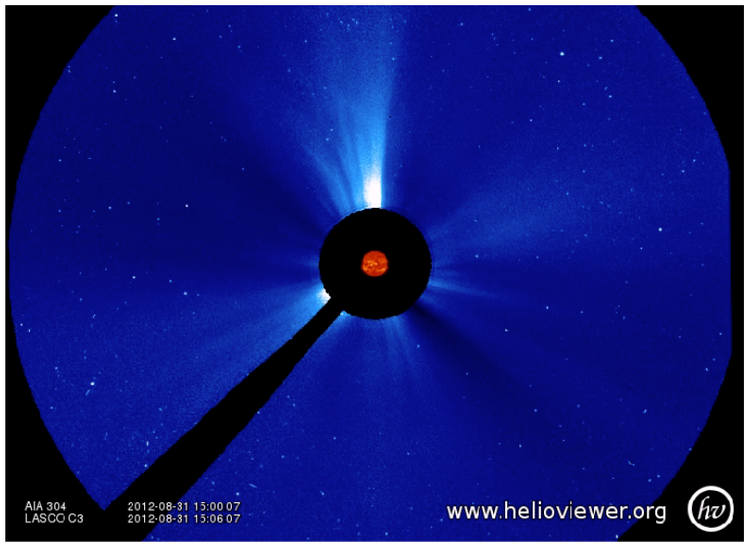
Coronal Hole



Non-eruptive

Eruptive

Coronal Mass Ejection



Magnetic reconnection

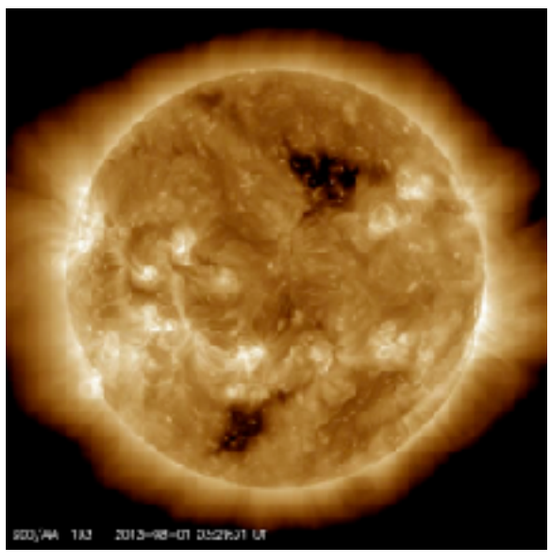
No magnetic reconnection

SOLAR WIND VARIATIONS

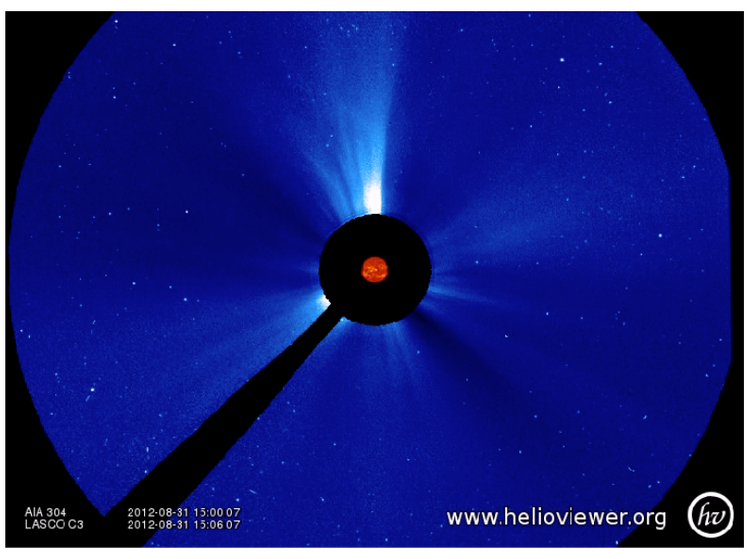
Non-eruptive
No B reconnection

Eruptive
B reconnection

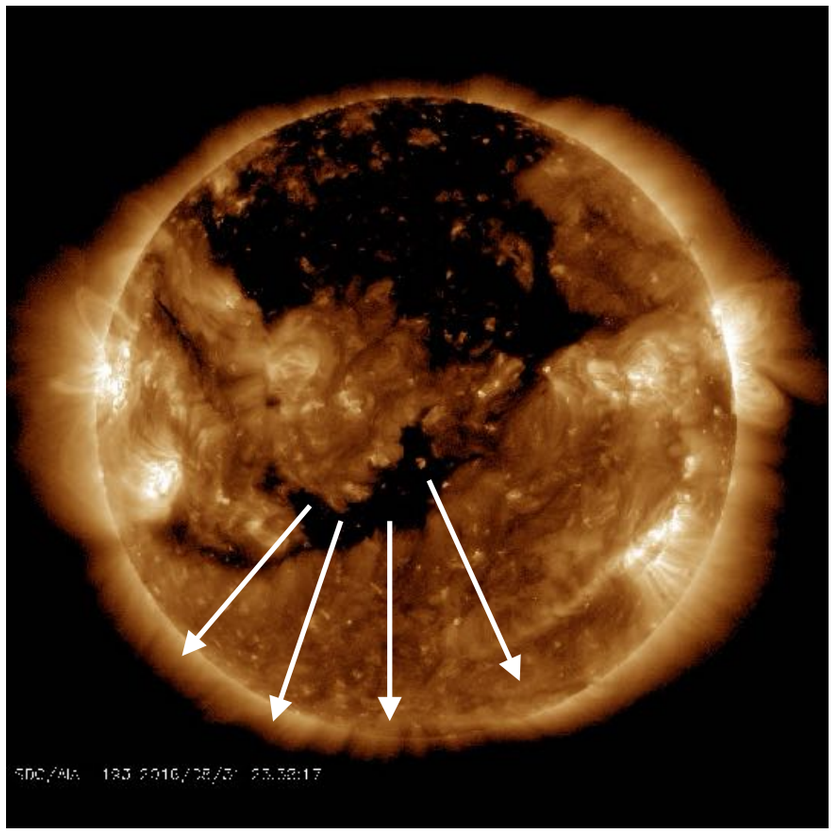
Coronal Hole

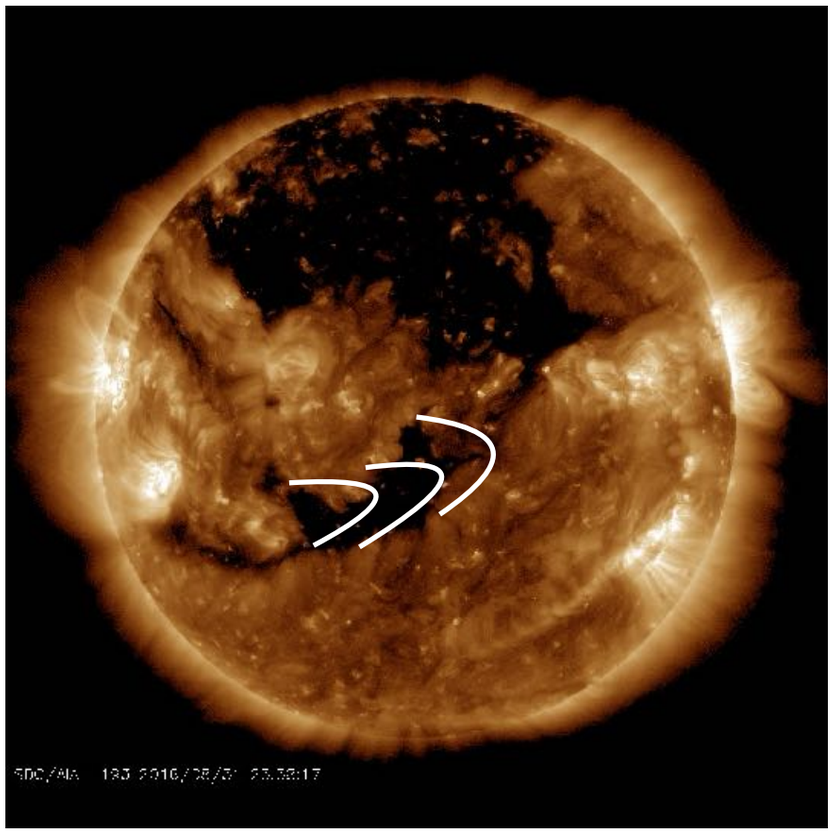


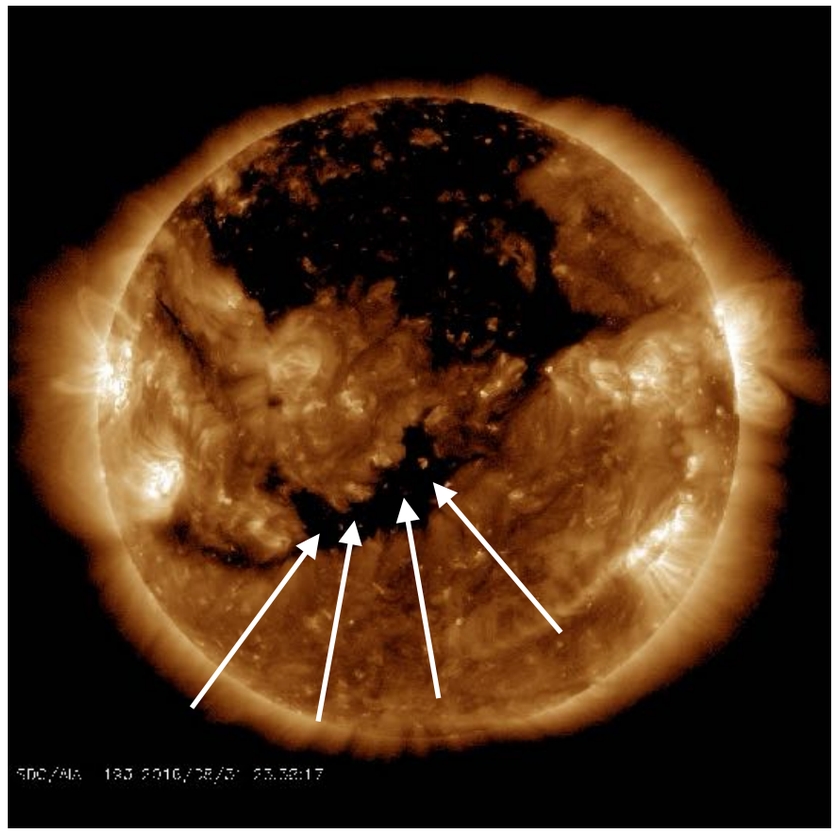
Coronal Mass Ejection

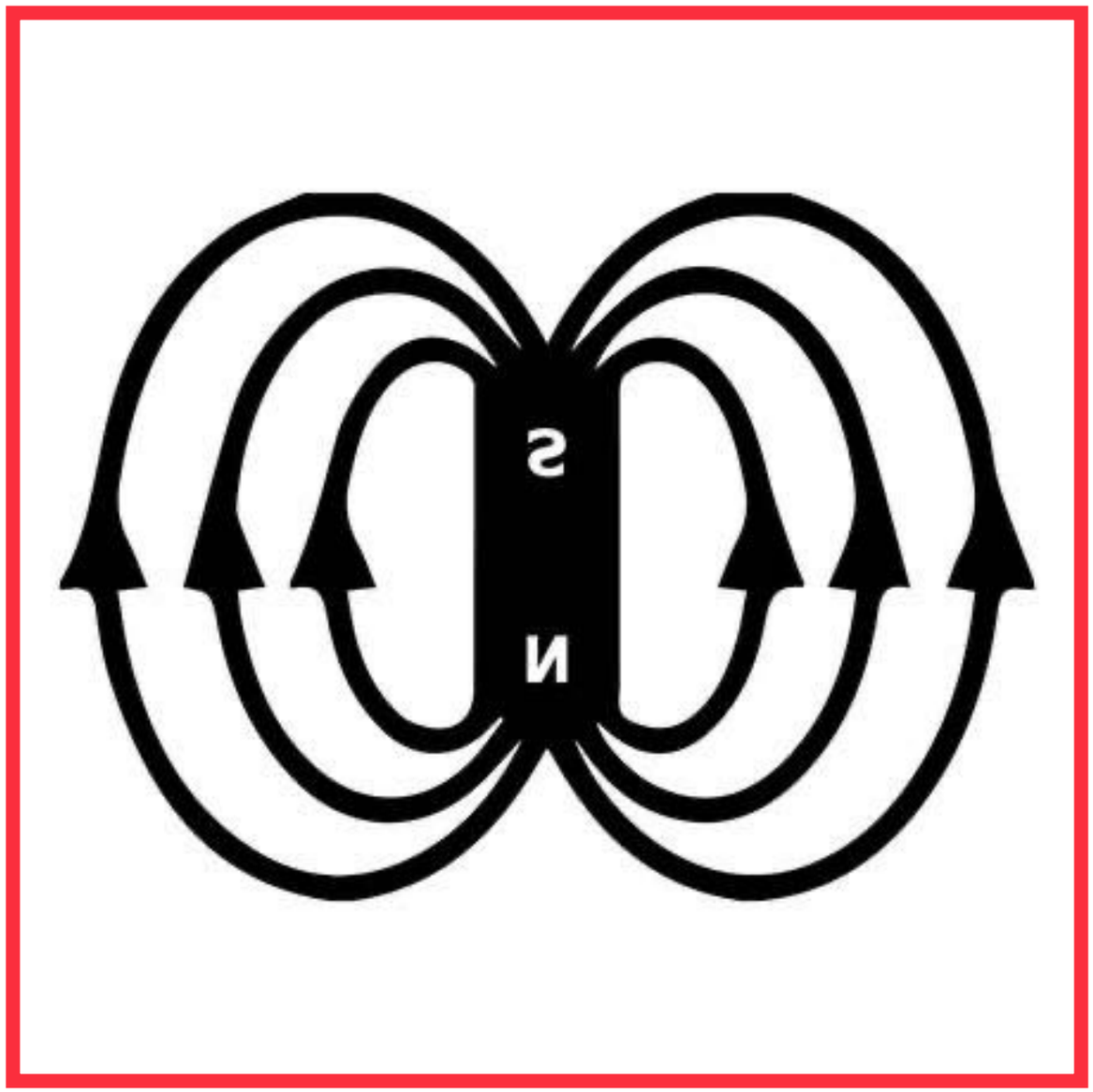


B OF CORONAL HOLE



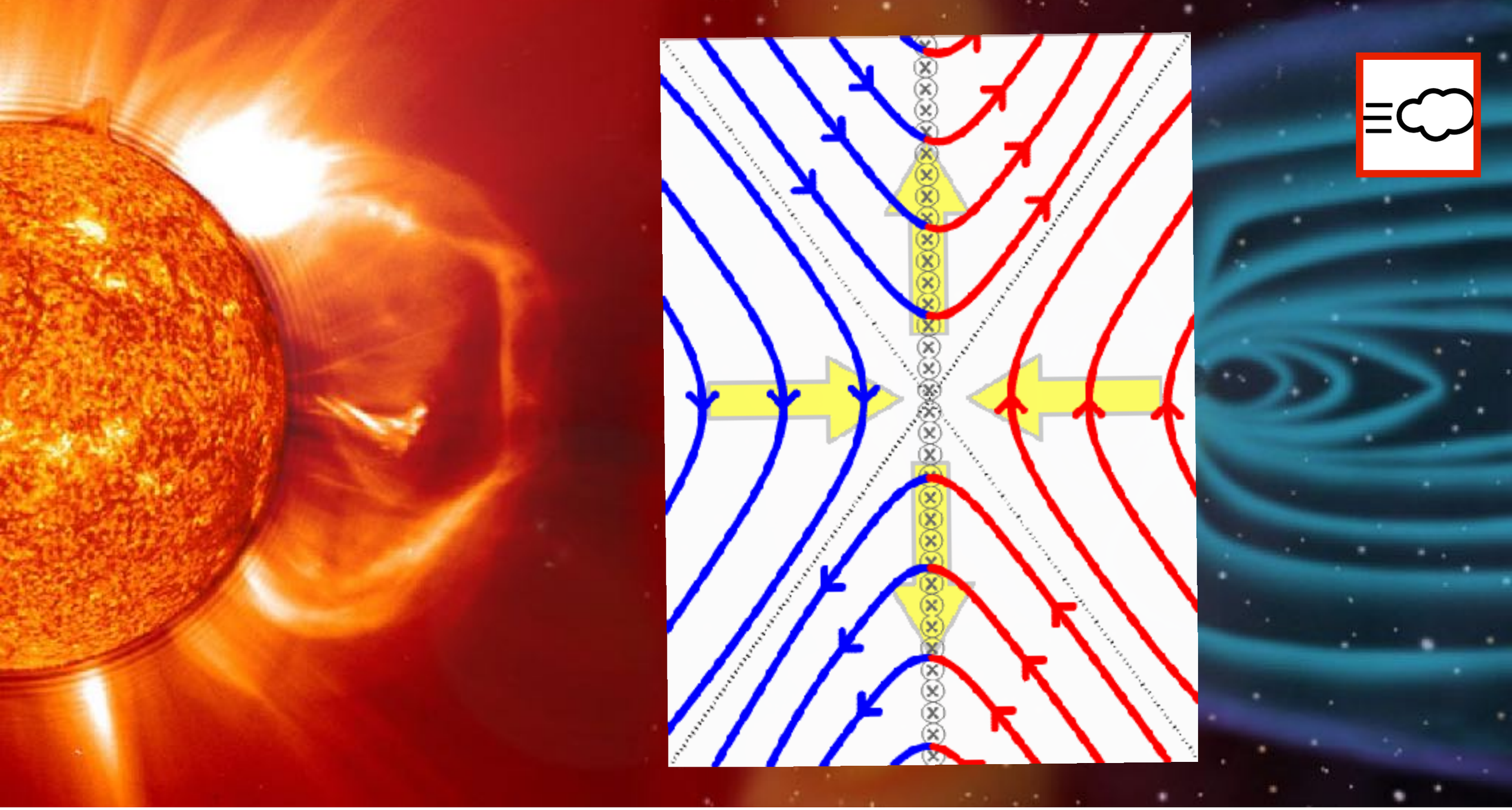






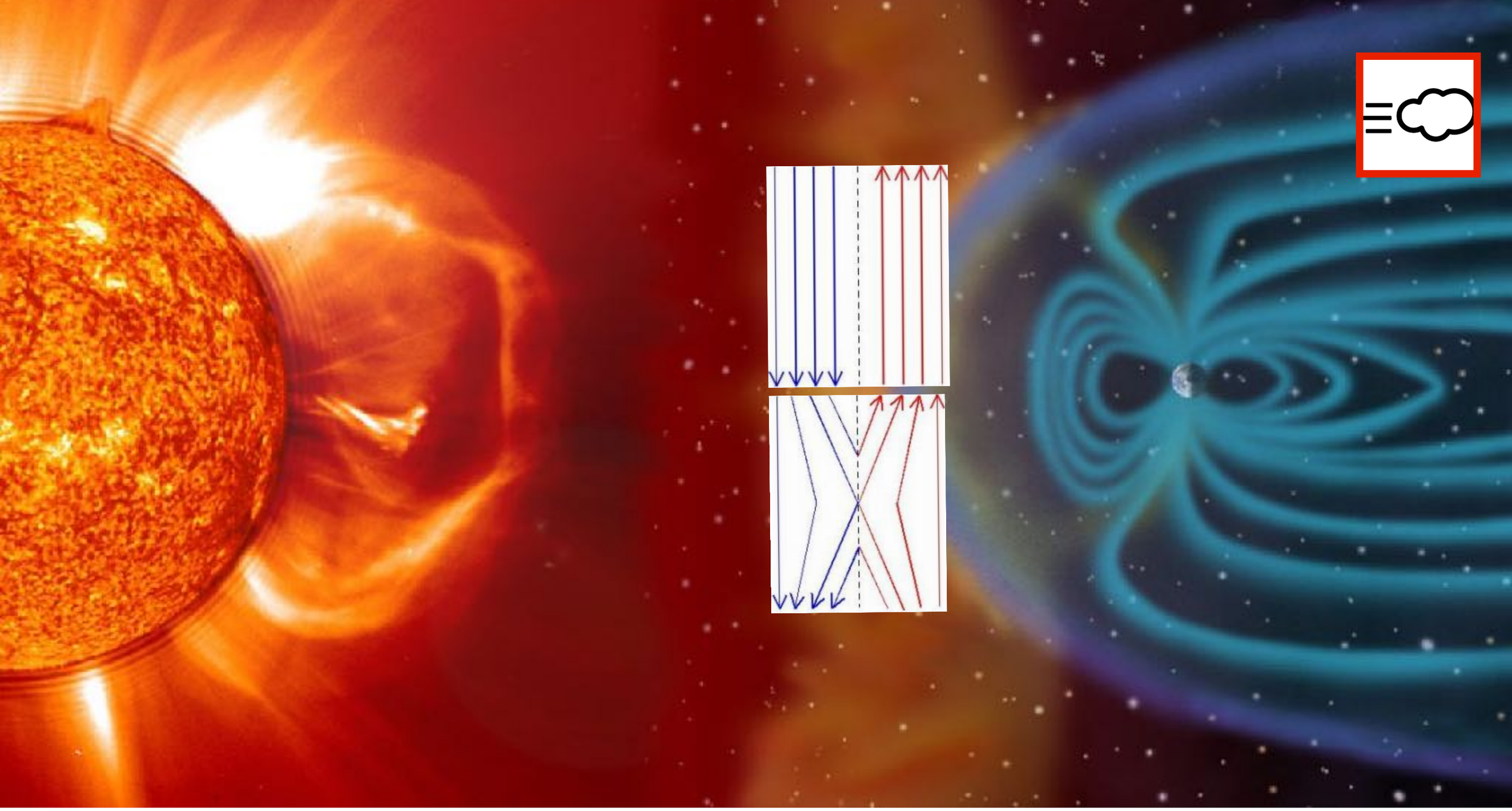
SOLAR WIND

Meets the Earth's magnetic field - geo-effectiveness



RECONNECTION

The magnetic field carried by the solar wind can couple with the magnetic field of Earth. This coupling is stronger when the solar wind magnetic field is opposite to the magnetic field of Earth.



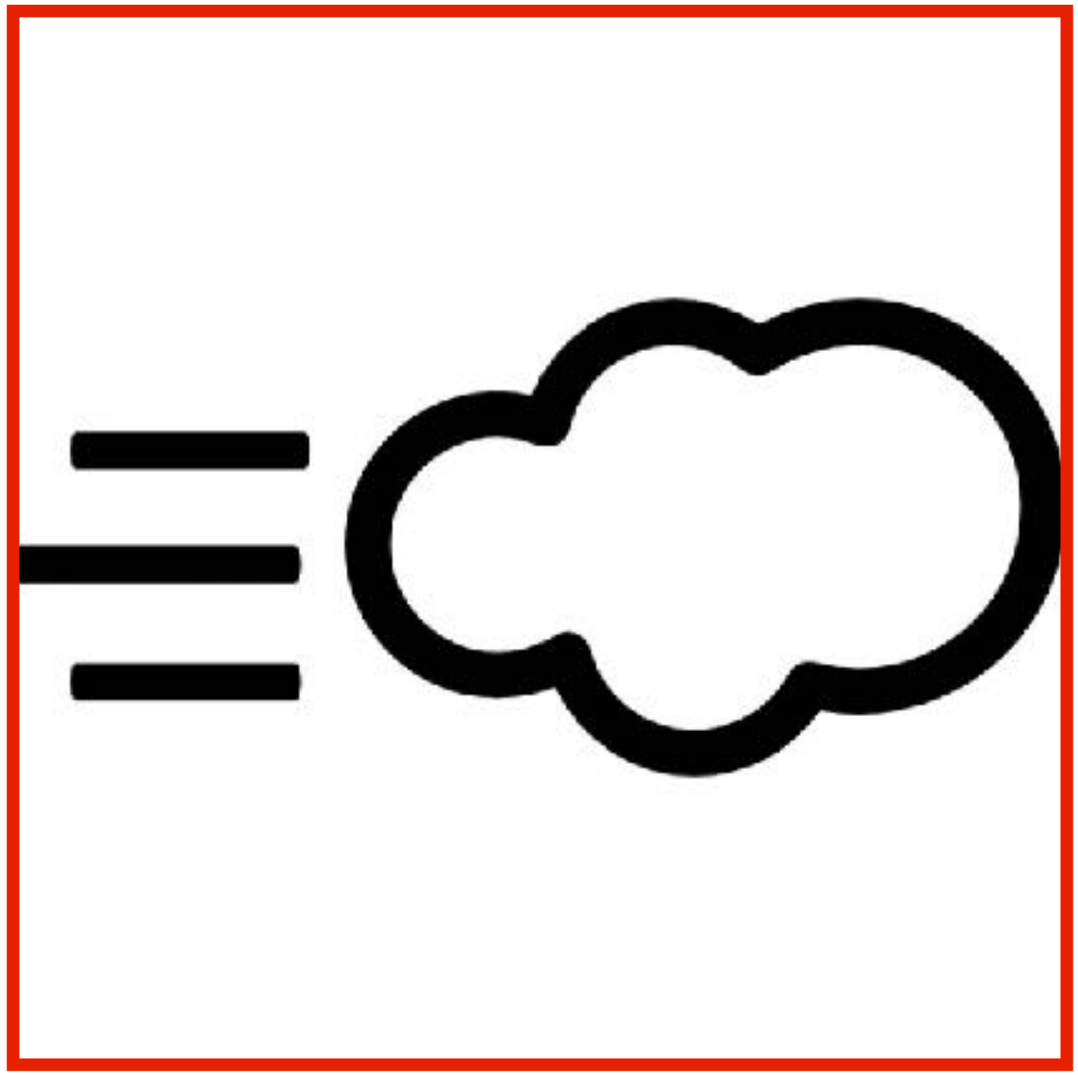
RECONNECTION

The magnetic field carried by the solar wind can couple with the magnetic field of Earth. This coupling is stronger when the solar wind magnetic field is opposite to the magnetic field of Earth.

GEOMAGNETIC CONDITIONS

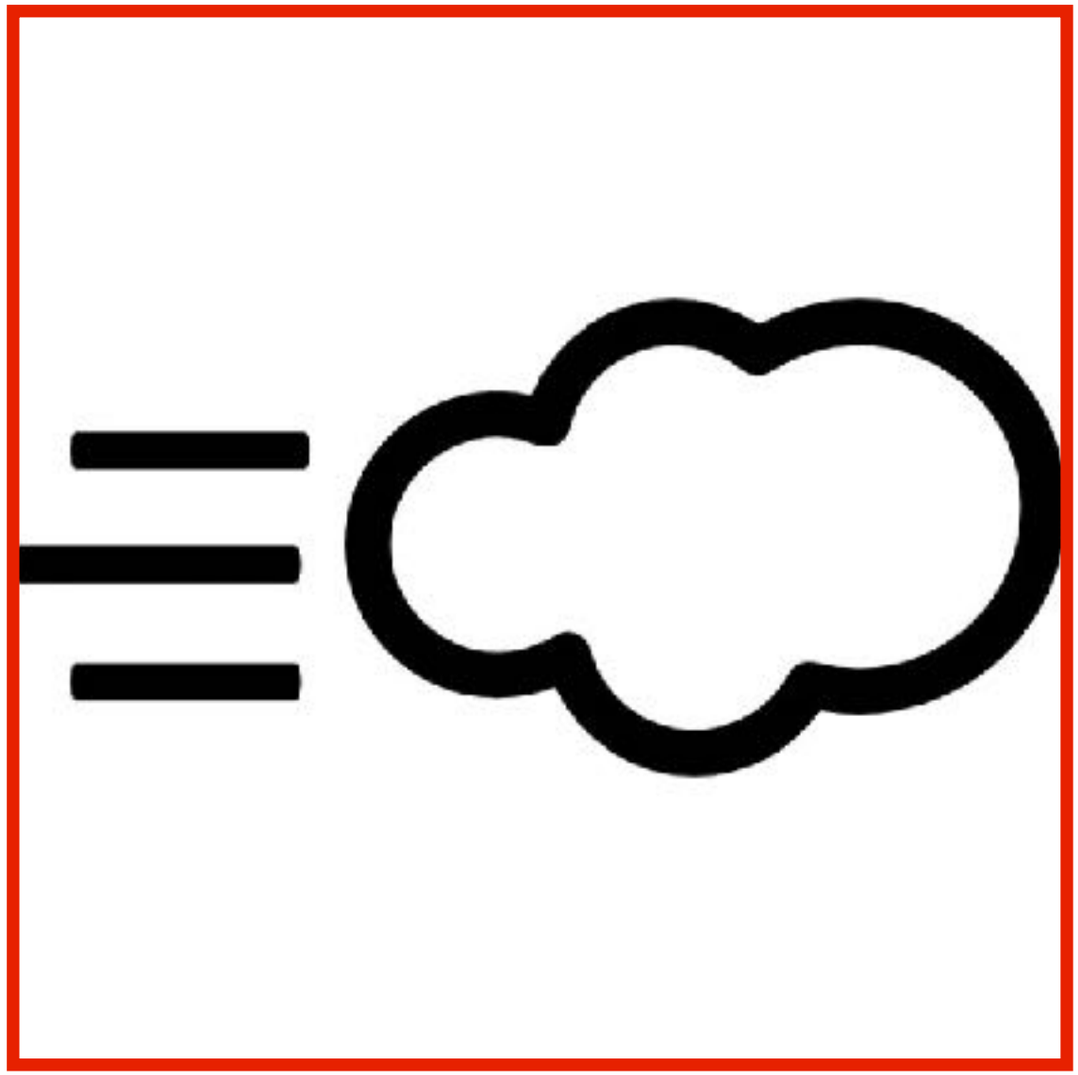
https://www.swpc.noaa.gov/products/planetary-k-index

http://ionosphere.meteo.be/geomagnetism/K_BEL/



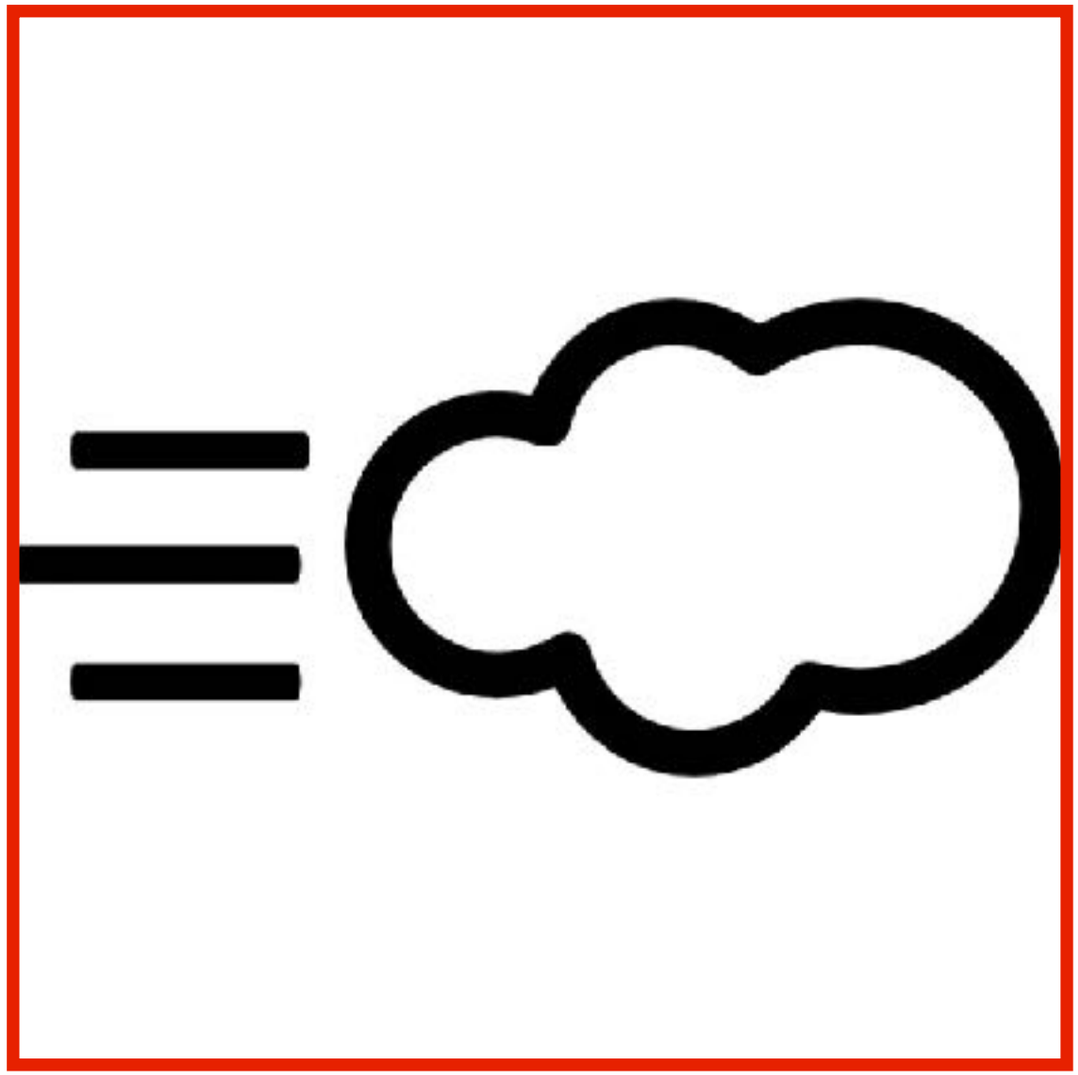
SOLAR WIND

Questions



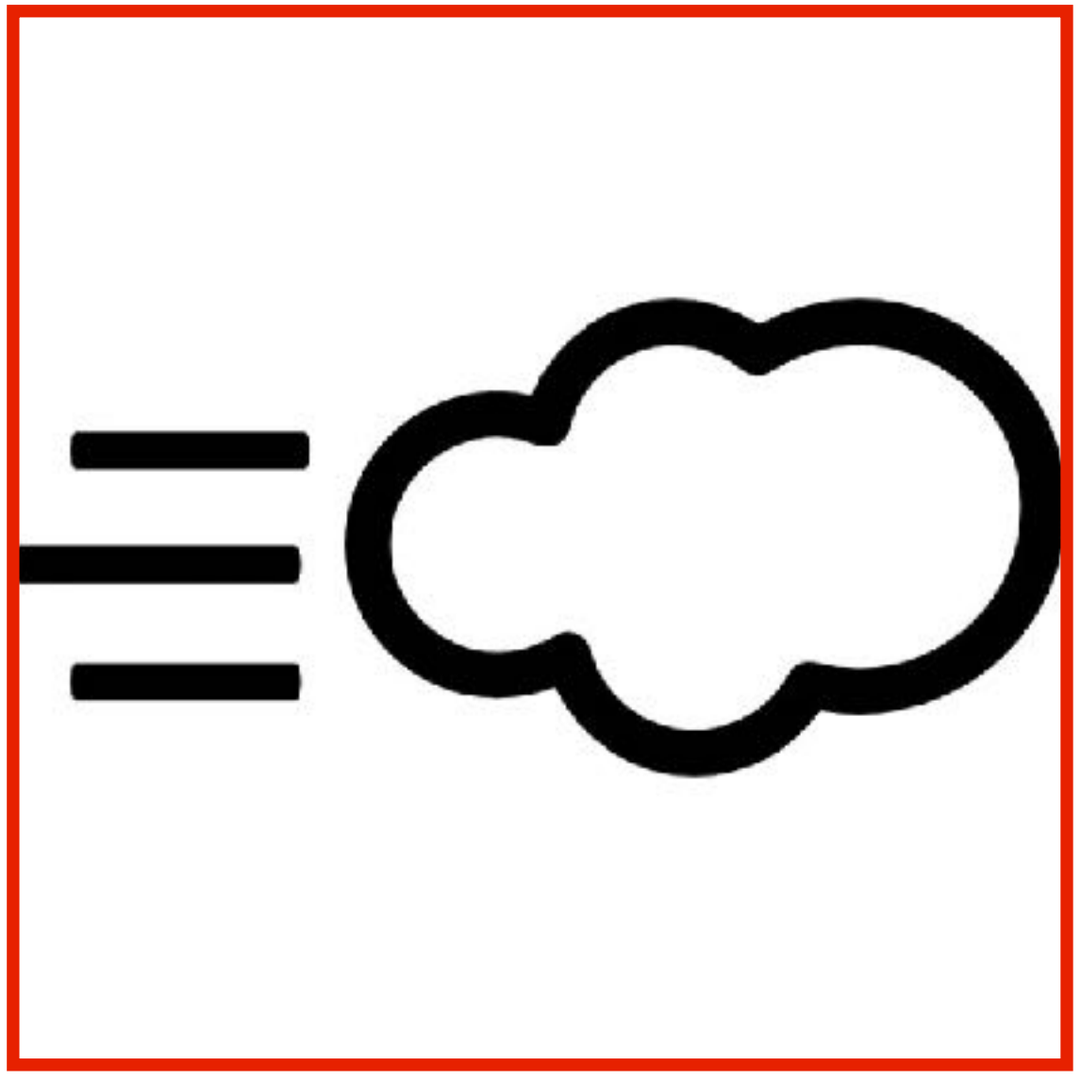
SOLAR WIND

Name 3 transients



SOLAR WIND

Name a satellite that measures the solar wind at L1



SOLAR WIND

Name the 5 panels in ACE or DSCVR graphs.

Solar wind parameters DSCOVR (+ACE), Kp-index (NOAA), K-index (Dourbes)

Bt [0.56, 15.18] nT Bz [-11.34, 11] nT Speed [322.2, 596.8] km/s

Bz (nT)

Bt (nT)

Phi (gsm)

Density (cm^{-3})

Speed (km/s)

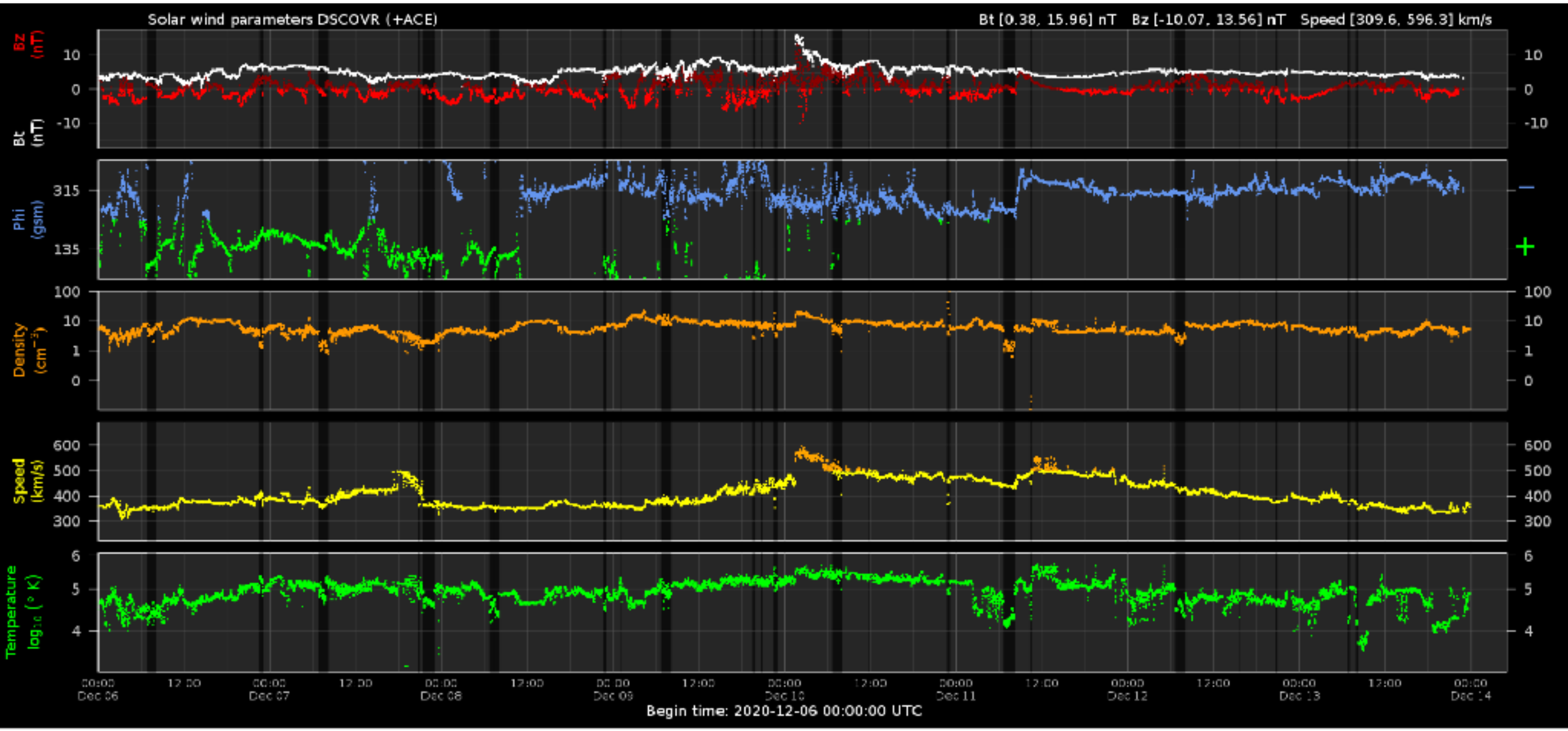
Temperature log$_{10}$ (° K)

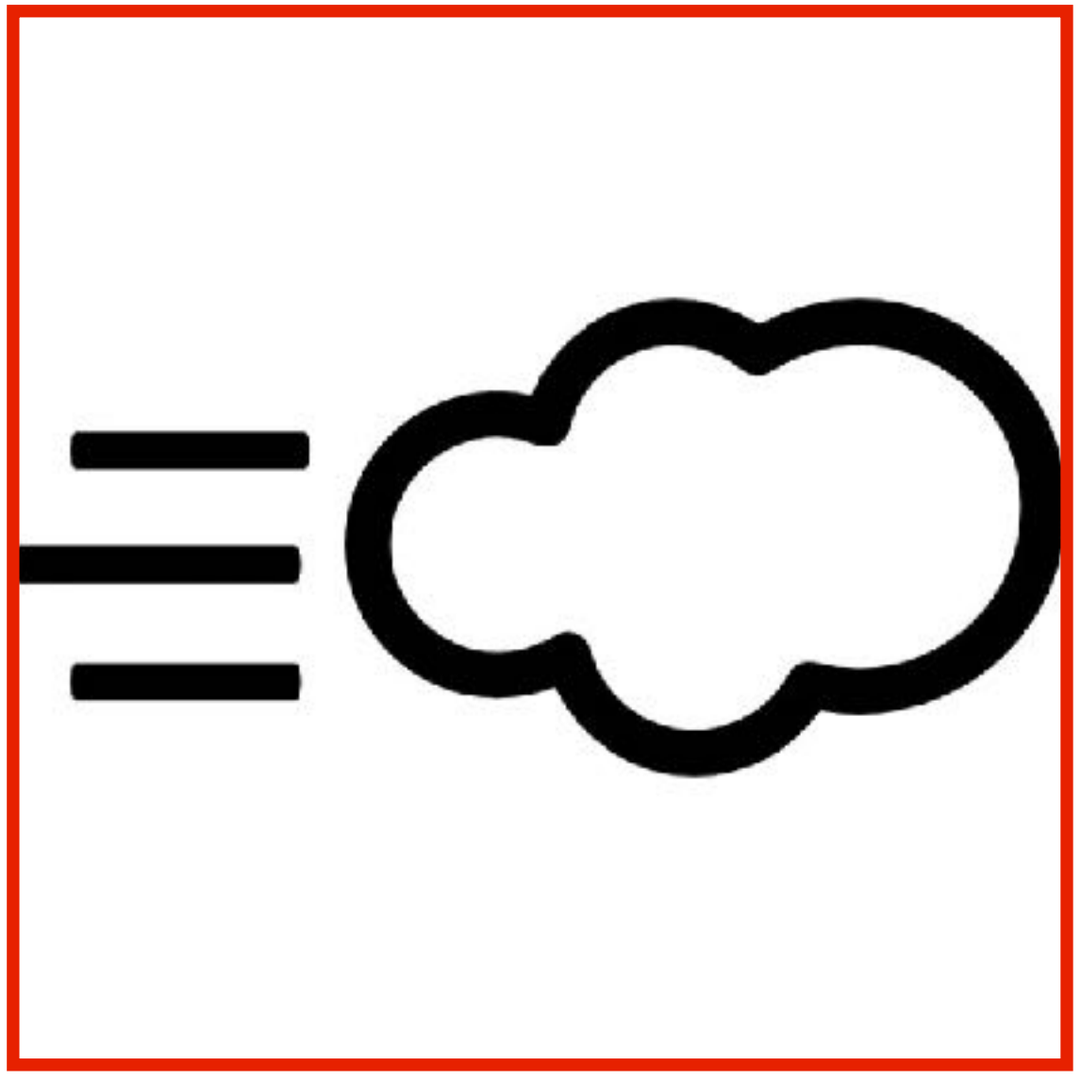
Kp-index NOAA

K-index Dourbes

00:00 Mar 09 · 12:00 · 00:00 Mar 10 · 12:00 · 00:00 Mar 11 · 12:00 · 00:00 Mar 12 · 12:00 · 00:00 Mar 13 · 12:00 · 00:00 Mar 14 · 12:00 · 00:00 Mar 15 · 12:00 · 00:00 Mar 16 · 12:00

Begin time: 2021-03-09 00:00:00 UTC


Solar wind parameters DSCOVR (+ACE)
Bt [0.38, 15.96] nT Bz [-10.07, 13.56] nT Speed [309.6, 596.3] km/s
Bz (nT)
Bt (nT)
10
0
-10
Phi (gsm)
315
135
Density (cm⁻³)
100
10
1
0
Speed (km/s)
600
500
400
300
Temperature log10 (° K)
6
5
4
00:00 Dec 06
12:00
00:00 Dec 07
12:00
00:00 Dec 08
12:00
00:00 Dec 09
12:00
00:00 Dec 10
12:00
00:00 Dec 11
12:00
00:00 Dec 12
12:00
00:00 Dec 13
12:00
00:00 Dec 14
Begin time: 2020-12-06 00:00:00 UTC



SOLAR WIND

Name 3 clearly distinct places where magnetic reconnection takes place.