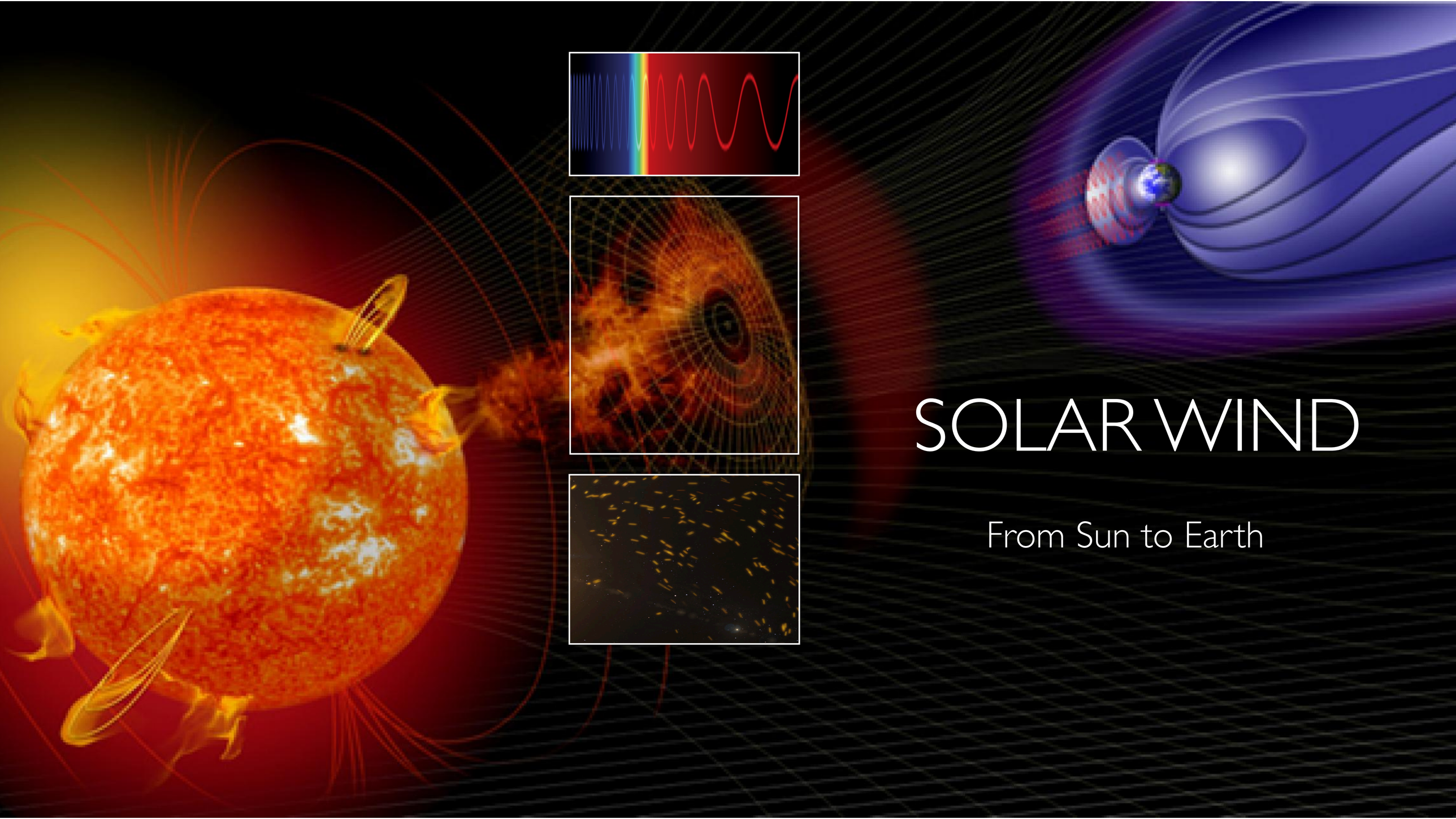
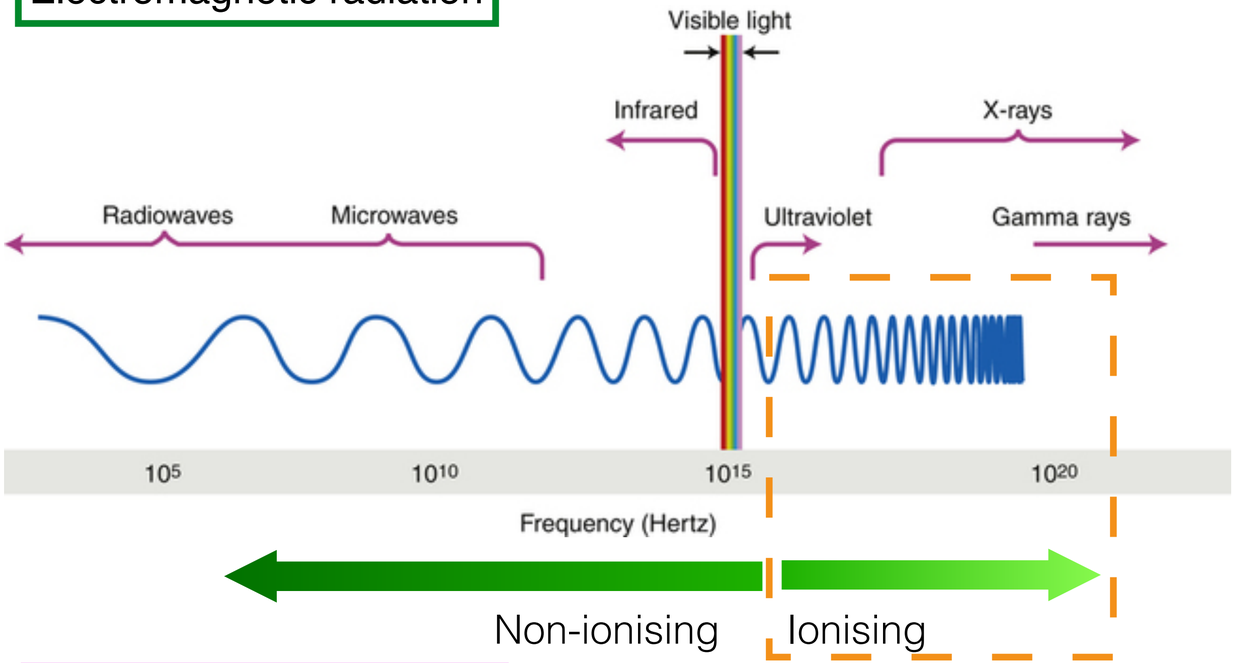


SOLAR WIND

From Sun to Earth

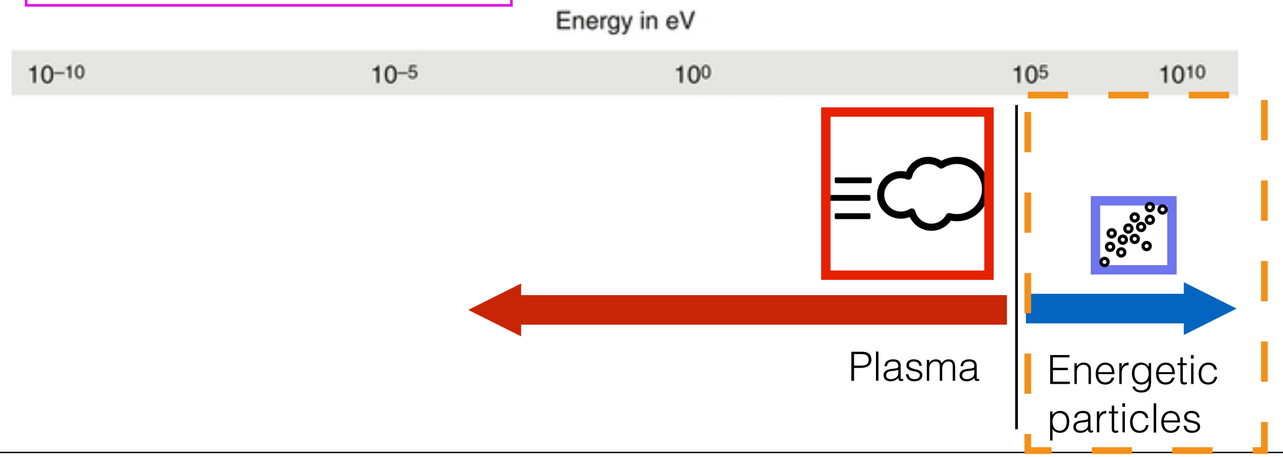
Electromagnetic radiation

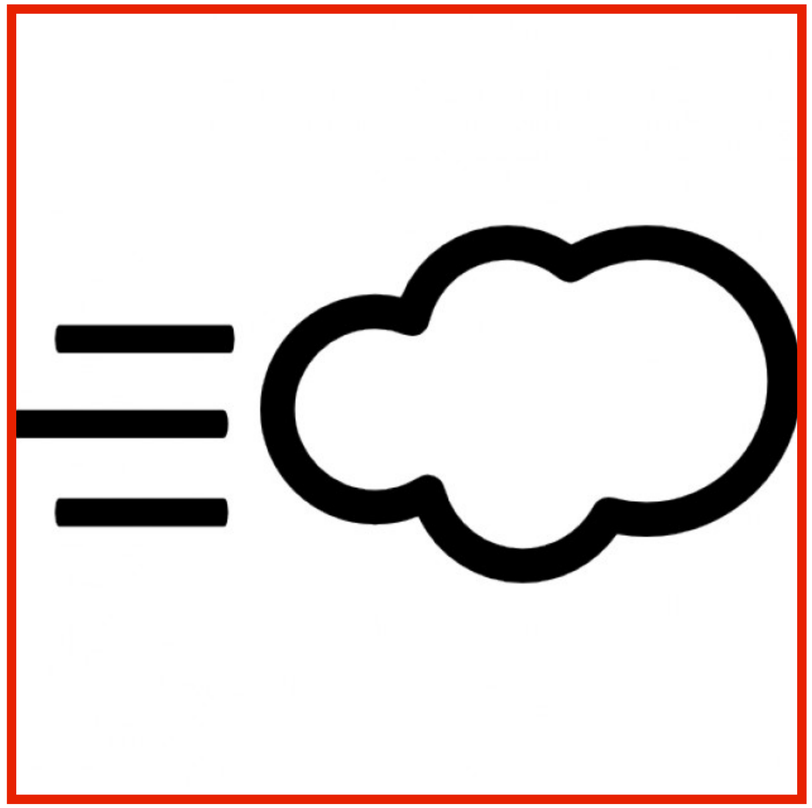
- Photons / electromagnetic waves
- Speed of light



Particles

- Atomic & sub-atomic particles
- km/s to fractions of speed of light
- Magnetic Field

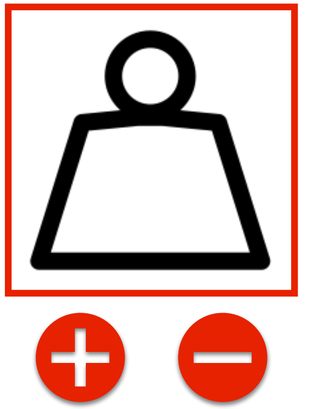




Expanding gas

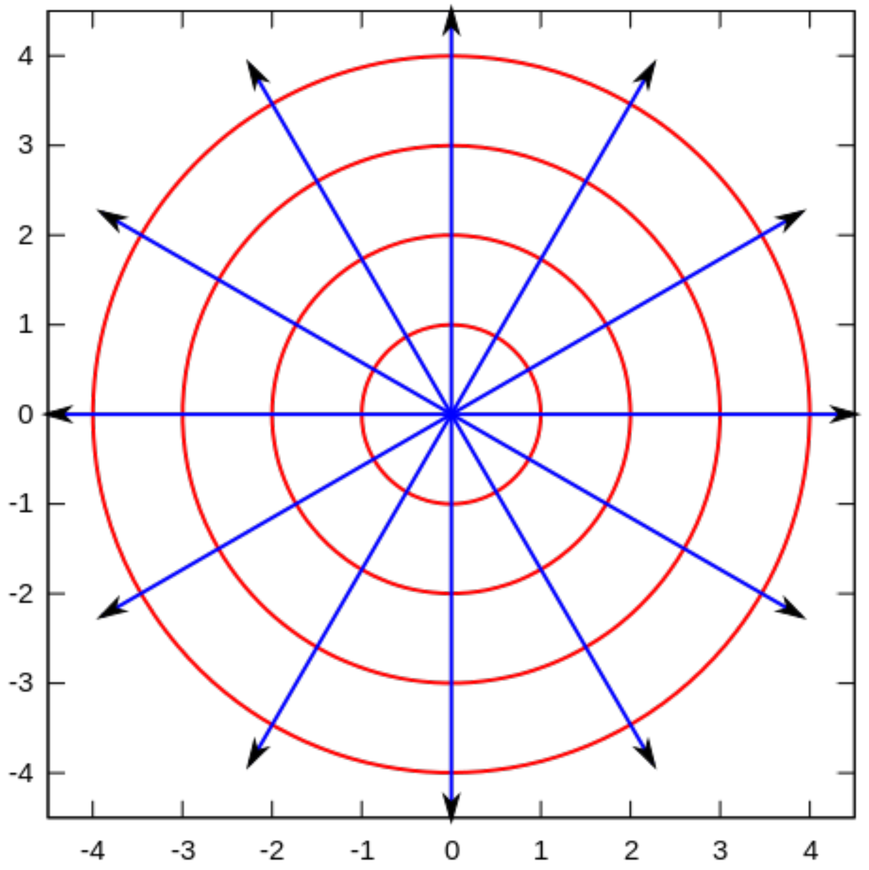
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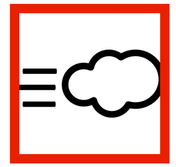
Outward moving plasma

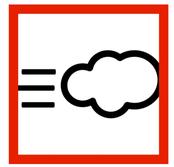


RADIAL SOLAR WIND

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.







To understand the solar wind, we need to understand the Interplanetary Magnetic field, i.e. the solar magnetic field spread in the heliosphere.

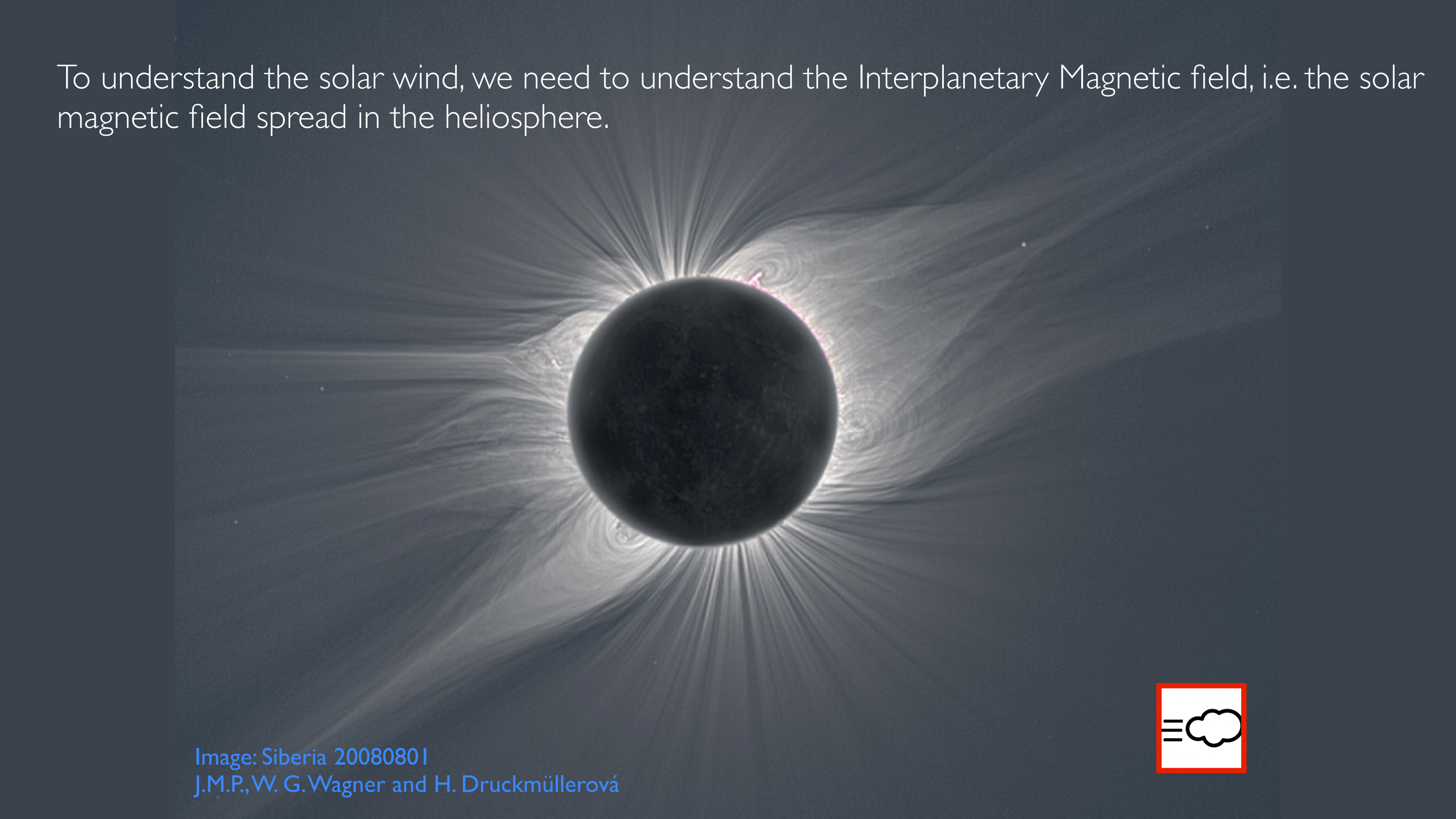
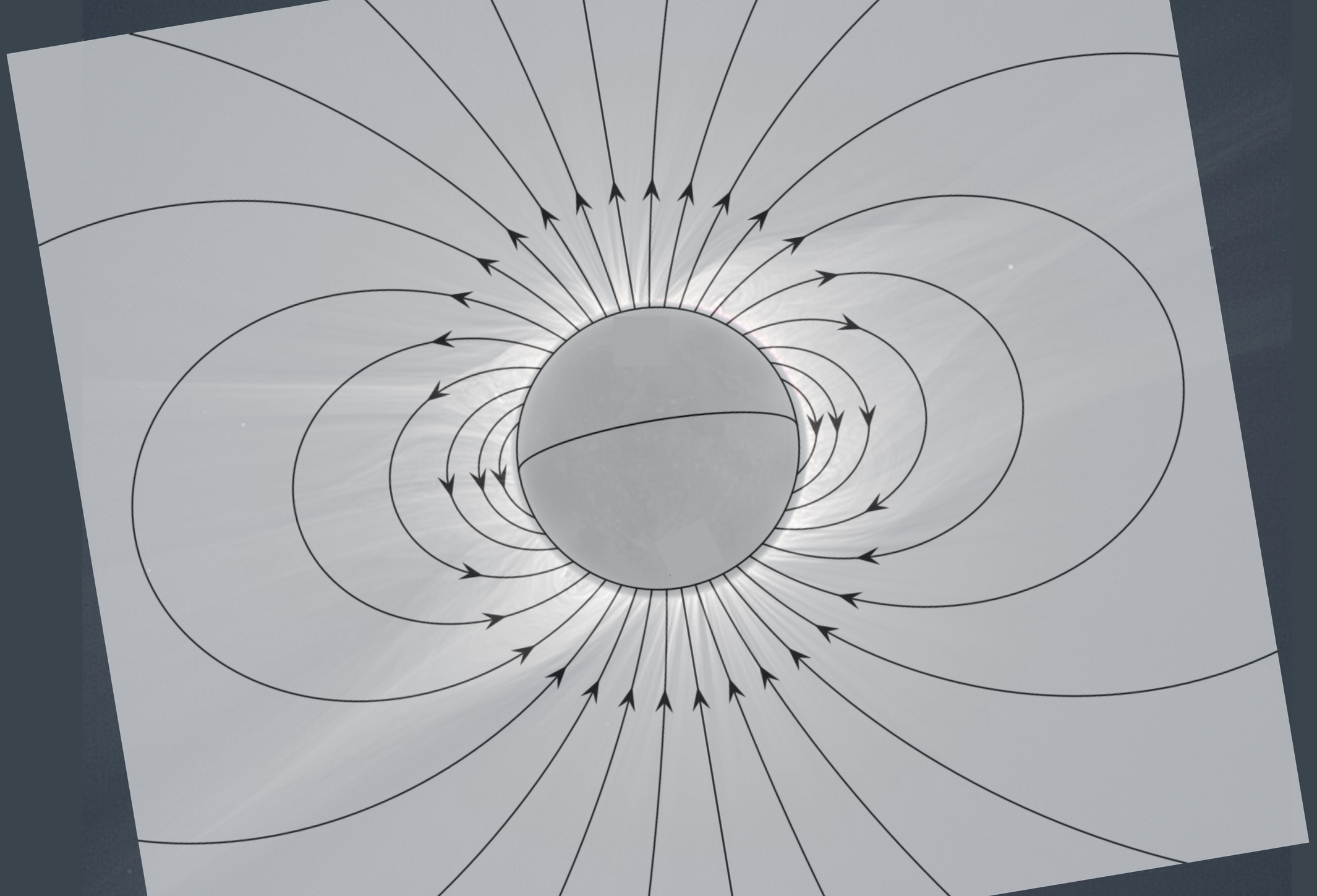
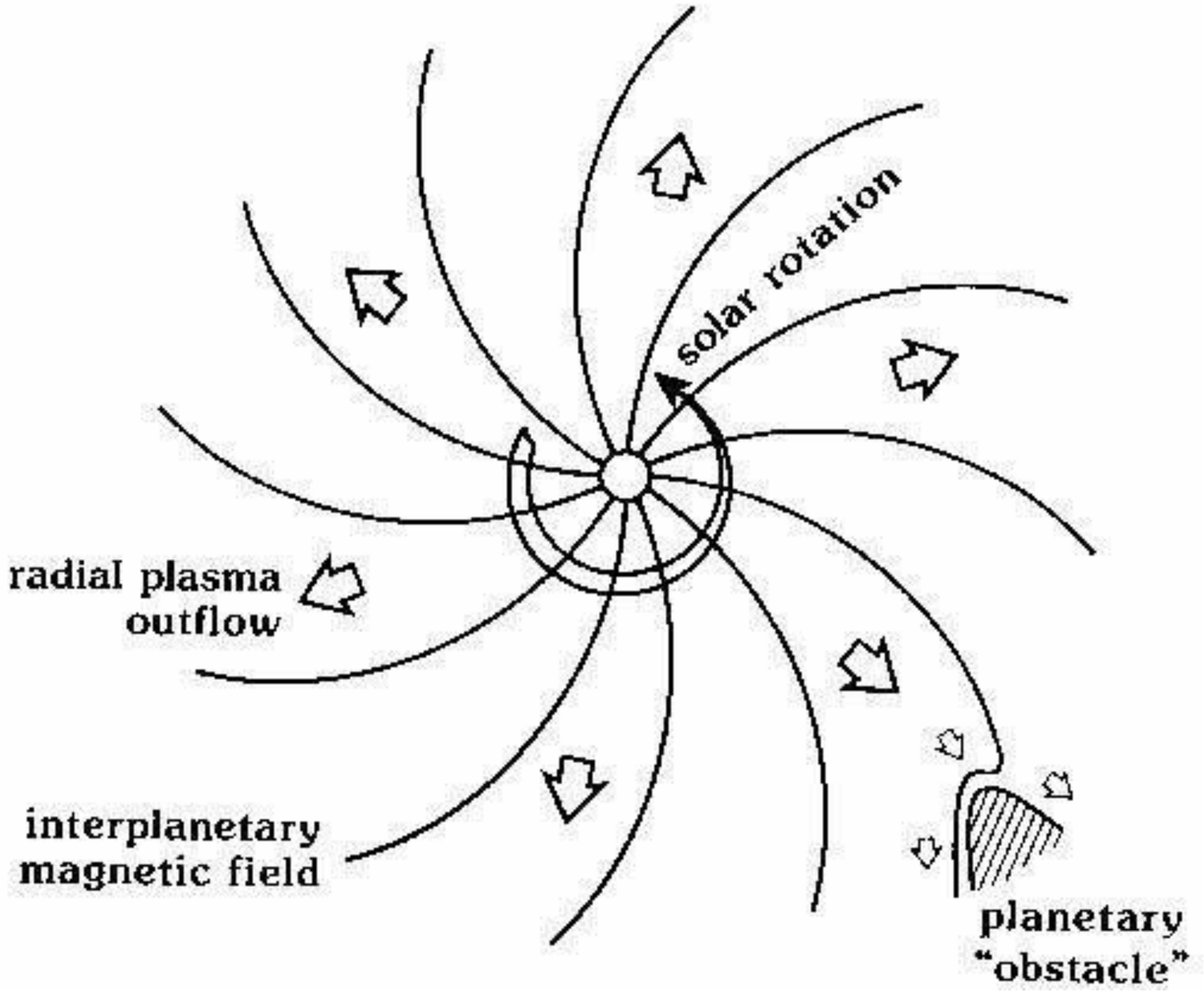


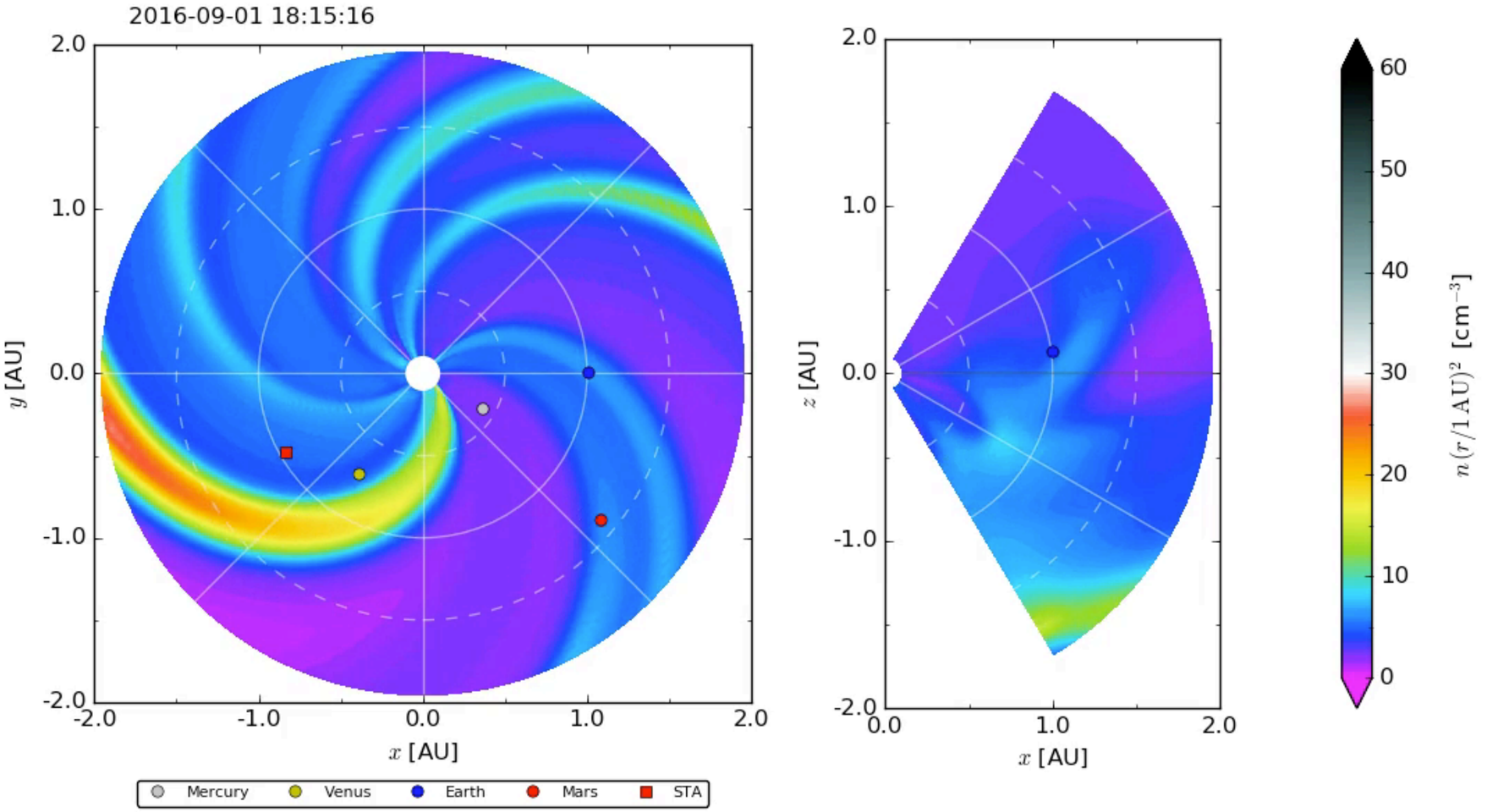
Image: Siberia 20080801
J.M.P., W. G. Wagner and H. Druckmüllerová



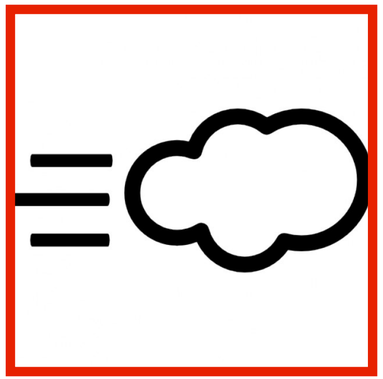
PARKER SPIRAL

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





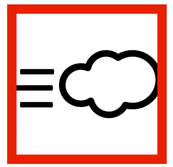
EUHFORIA, realtime simulations of the inner heliosphere



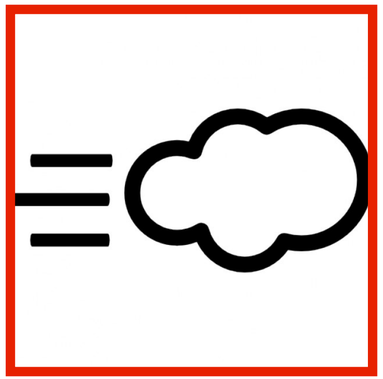
The moving plasma and the IMF together form the solar wind.

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

SLOW versus FAST

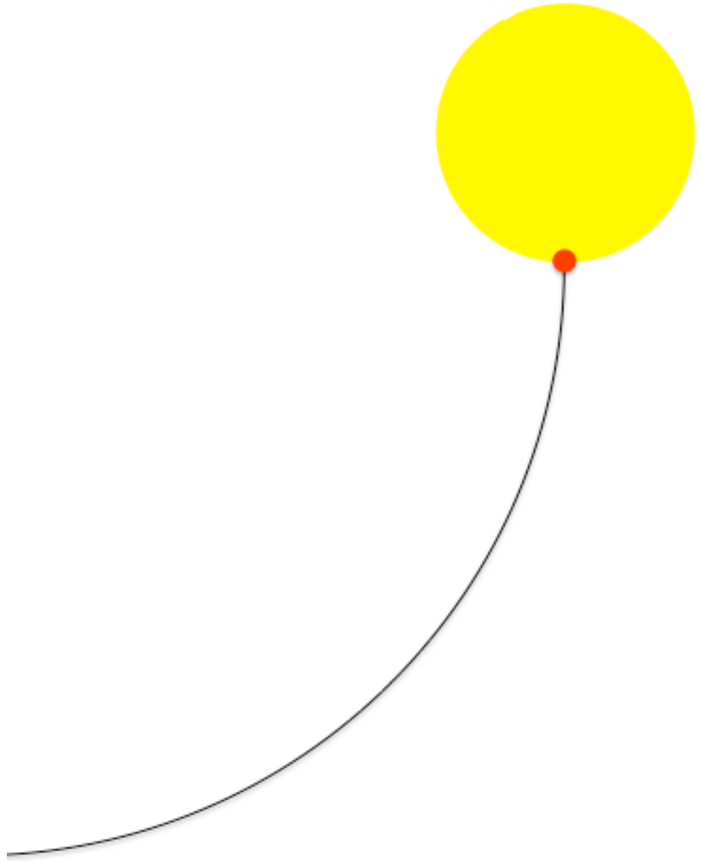


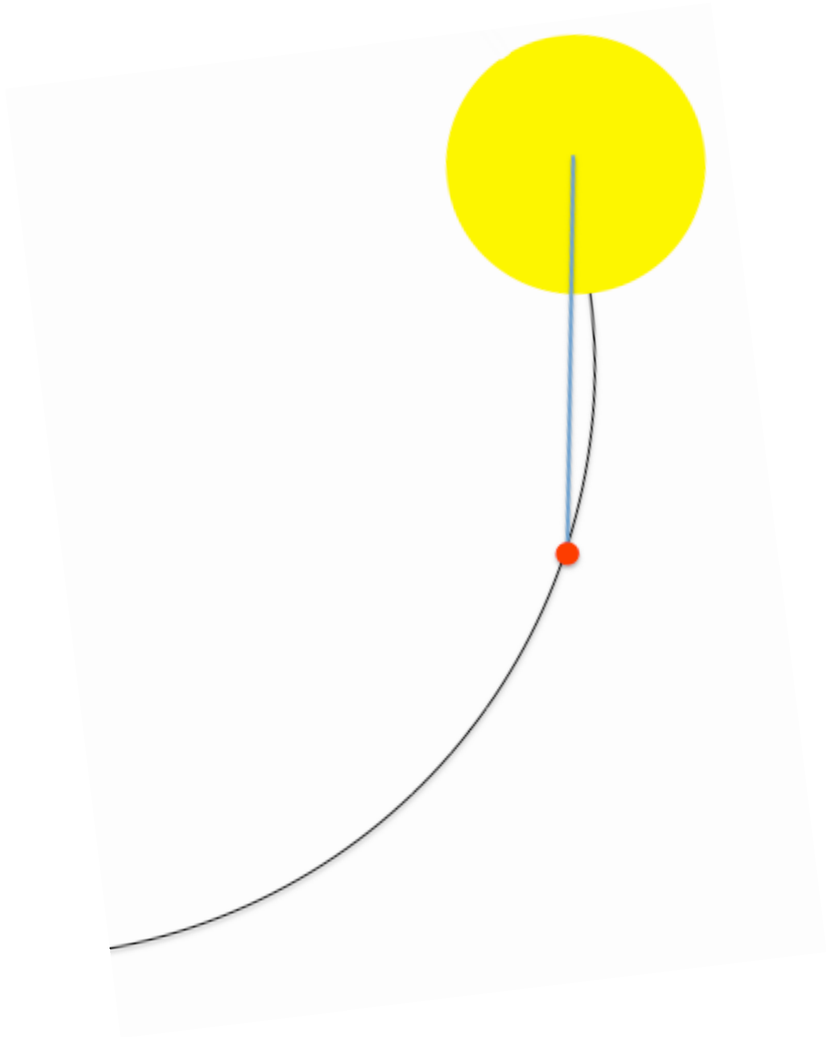
250-400	km/s	400-800
High: ~10	Density, cm^{-3}	Low: ~3
Low: ~10^{4}K, ~1eV	Temperature	High: ~10^{5}K, ~10eV
Variable	Behaviour	Stationary

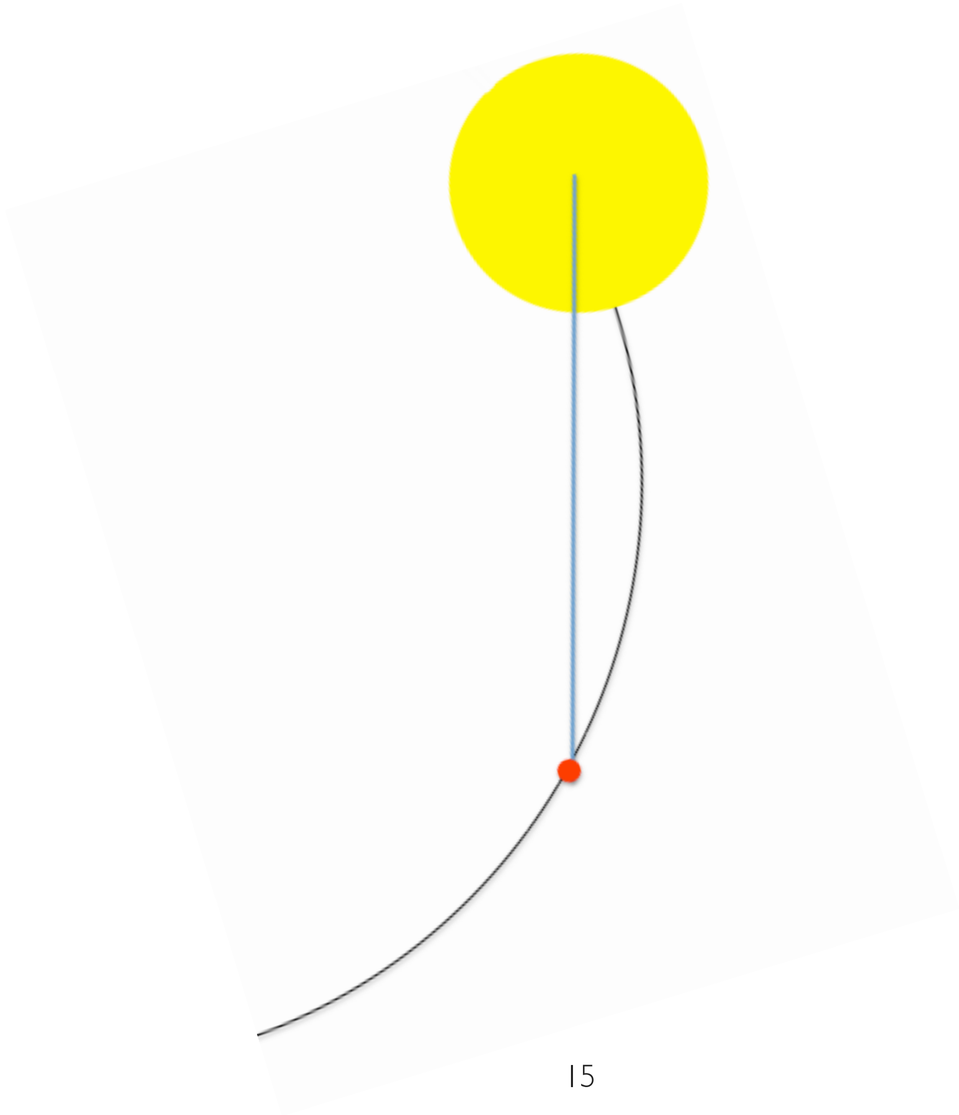


IMF is bent and the plasma flow is radial. Euh?

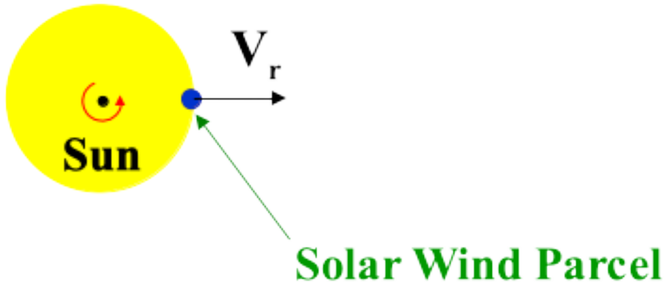
SOLAR WIND IS RADIAL & IMF BENDS?





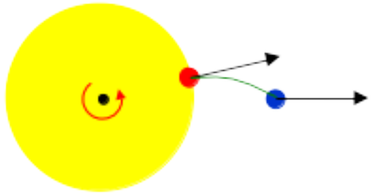


The Solar Wind and the Interplanetary Magnetic Field
(Formation of the Parker Spiral)



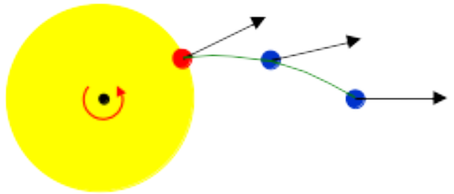
Arge, 2018

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



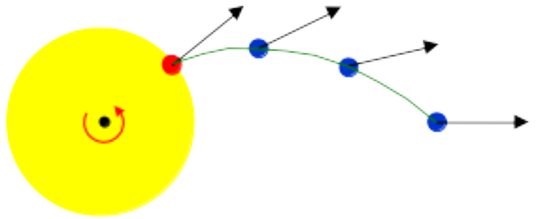
Arge, 2018

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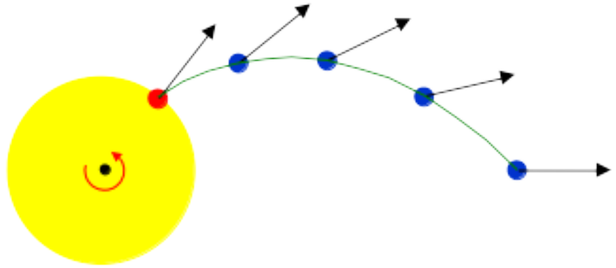
Arge, 2018

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



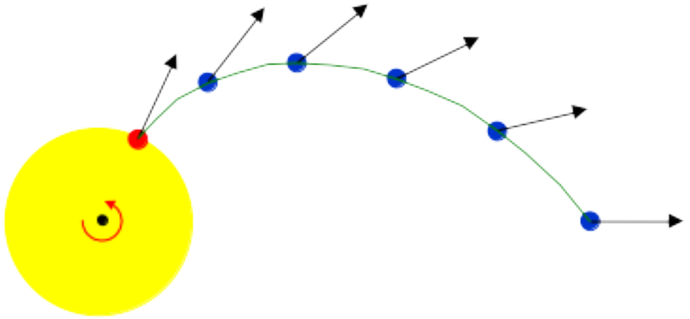
Arge, 2018

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



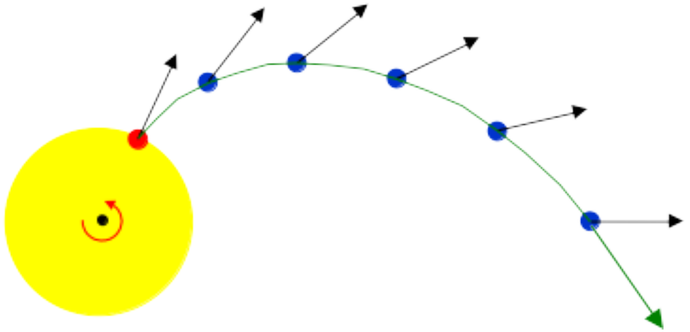
Arge, 2018

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



Arge, 2018

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



Arge, 2018



Continuous radial outflow of gas - Consists of charged particles

Shapes the IMF - Can carry magnetic structures.

The IMF is straight/bent.

IMF are open/closed magnetic field lines.

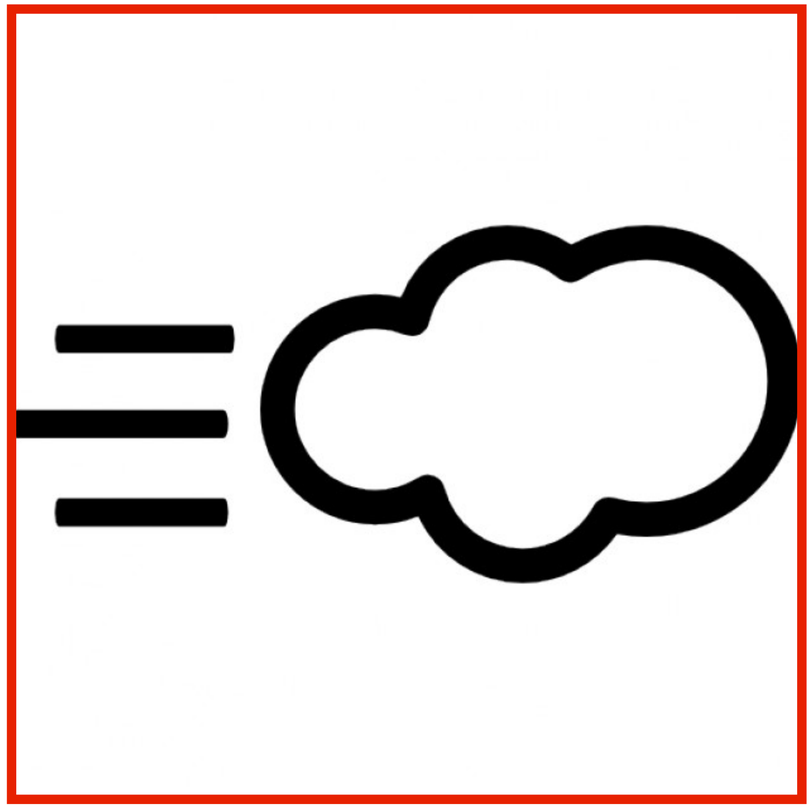


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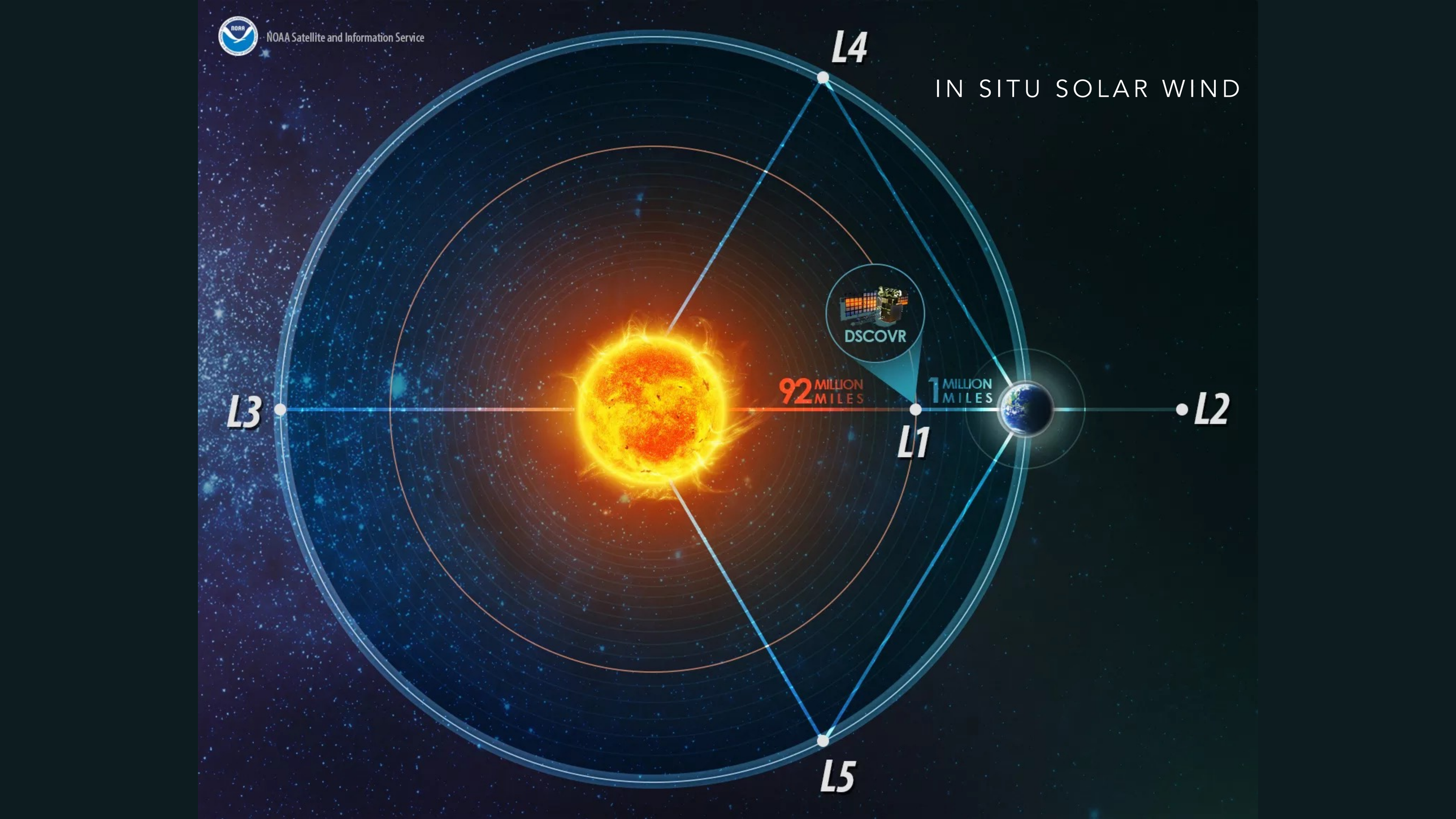
The IMF is bent.

IMF are open magnetic field lines.

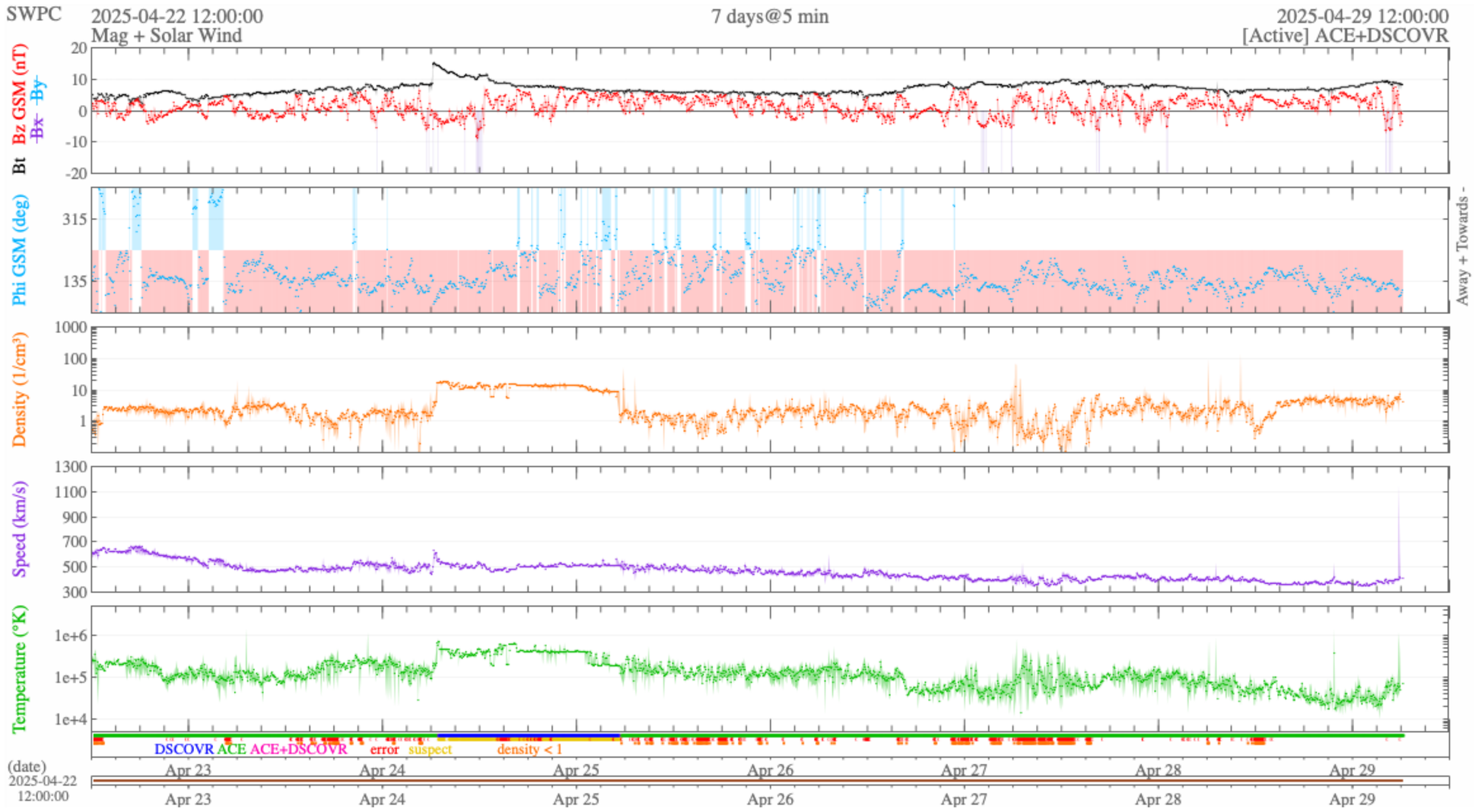


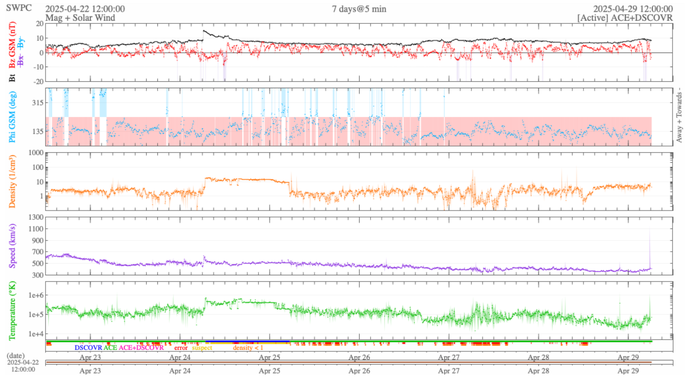
SOLAR WIND

Near Earth

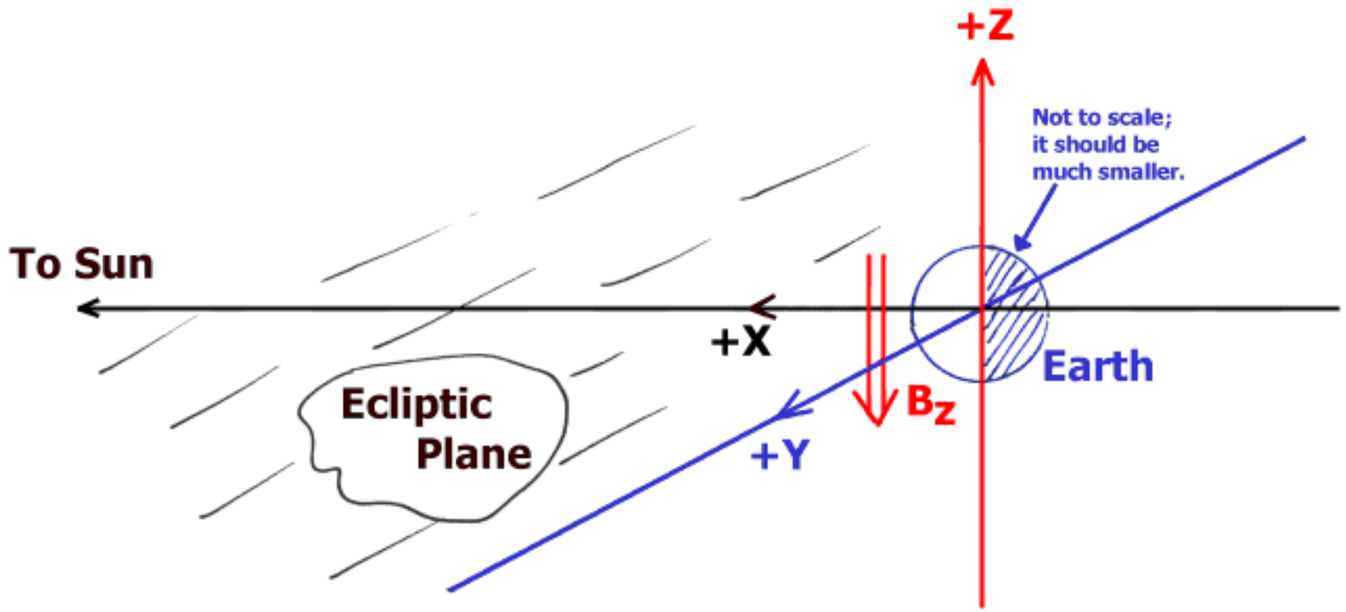

NOAA Satellite and Information Service
L4
IN SITU SOLAR WIND
DSCOVR
92 MILLION MILES
1 MILLION MILES
L3
L1
L2
L5

https://www.swpc.noaa.gov/products/real-time-solar-wind

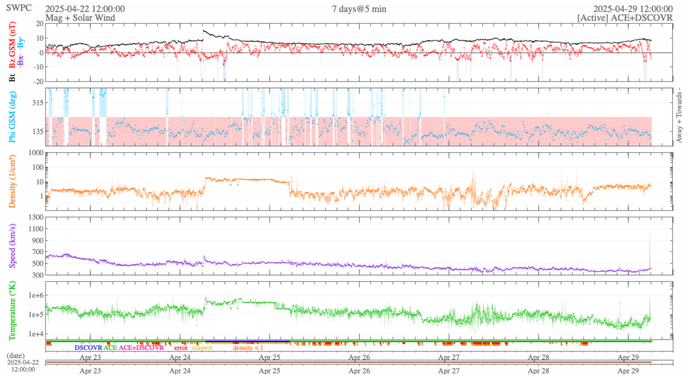




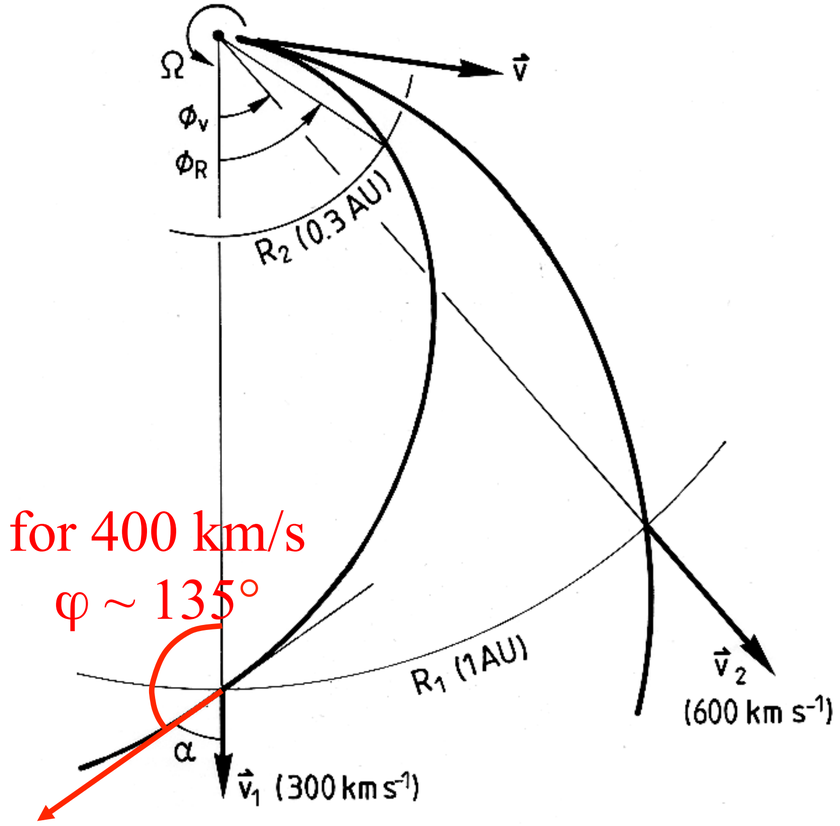
COORDINATE SYSTEM



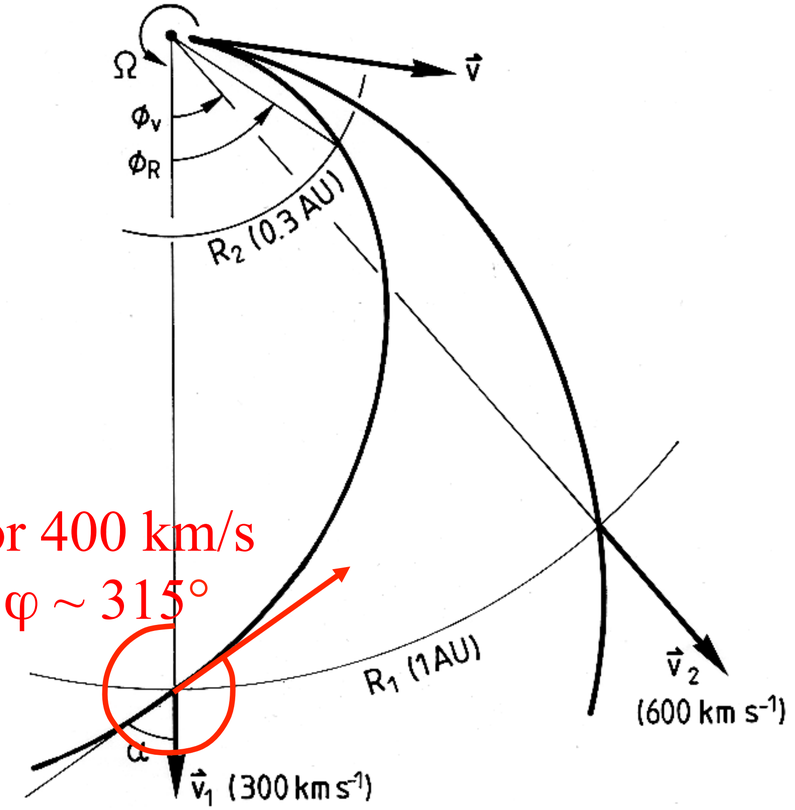
+Z is perpendicular to the Ecliptic Plane.



IMF POLARITY

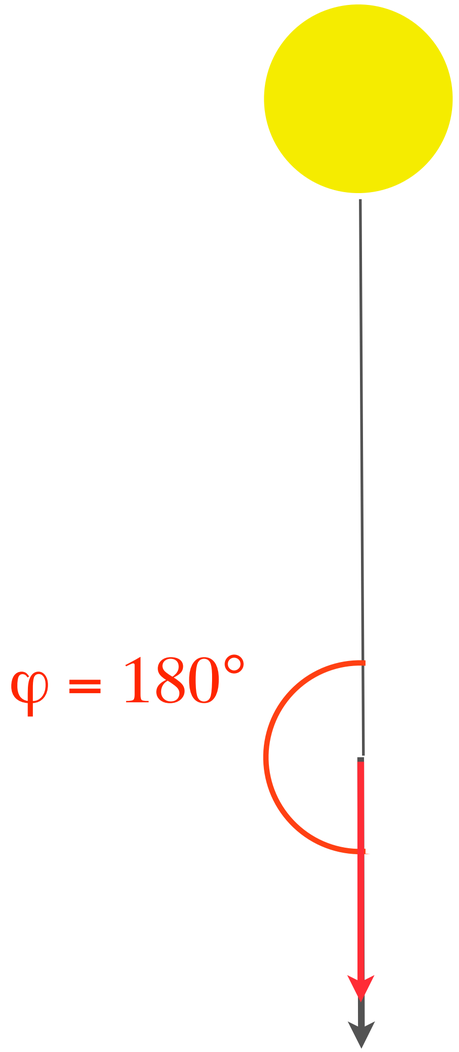


for 400 km/s
φ ~ 135°

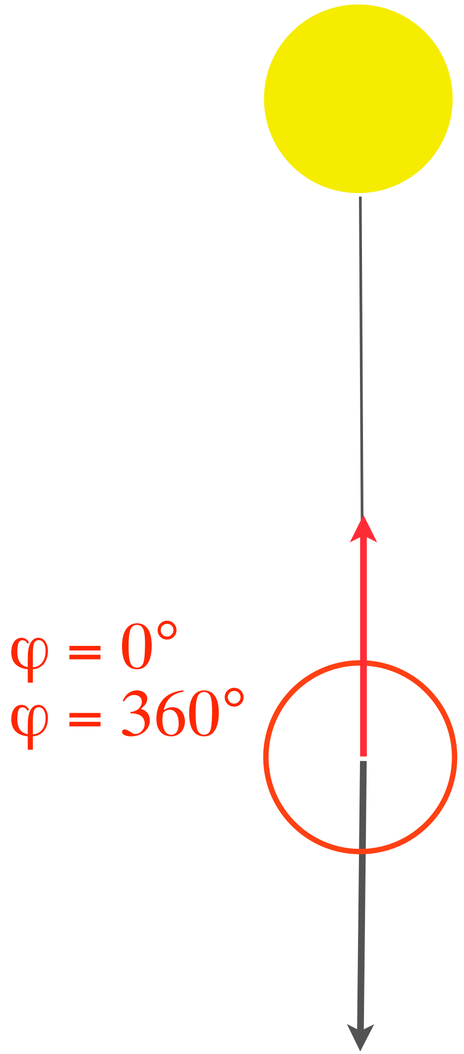


for 400 km/s
φ ~ 315°

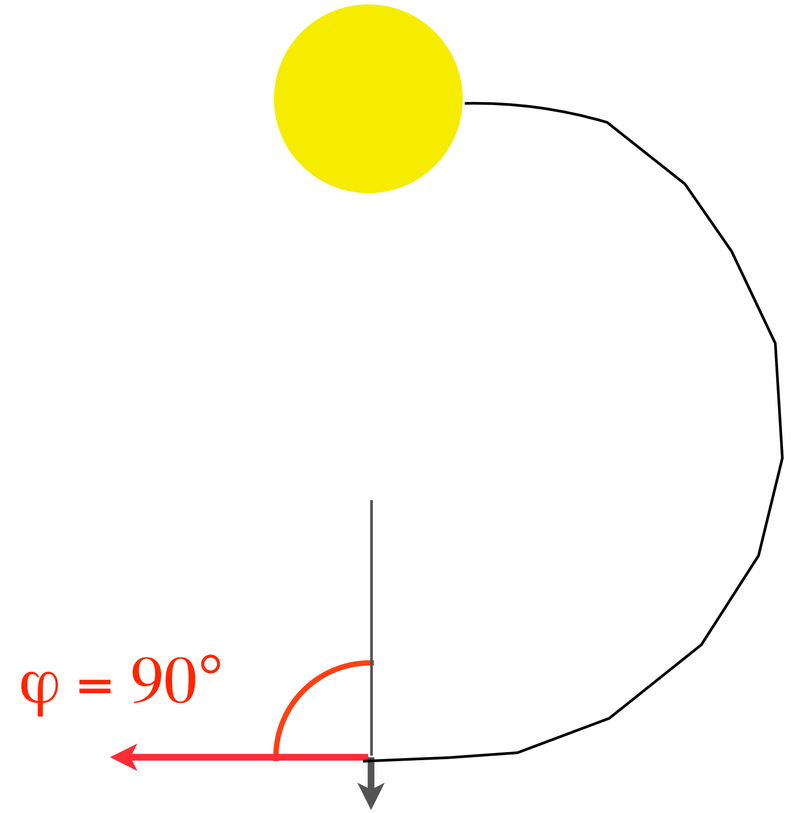
EXTREME FAST

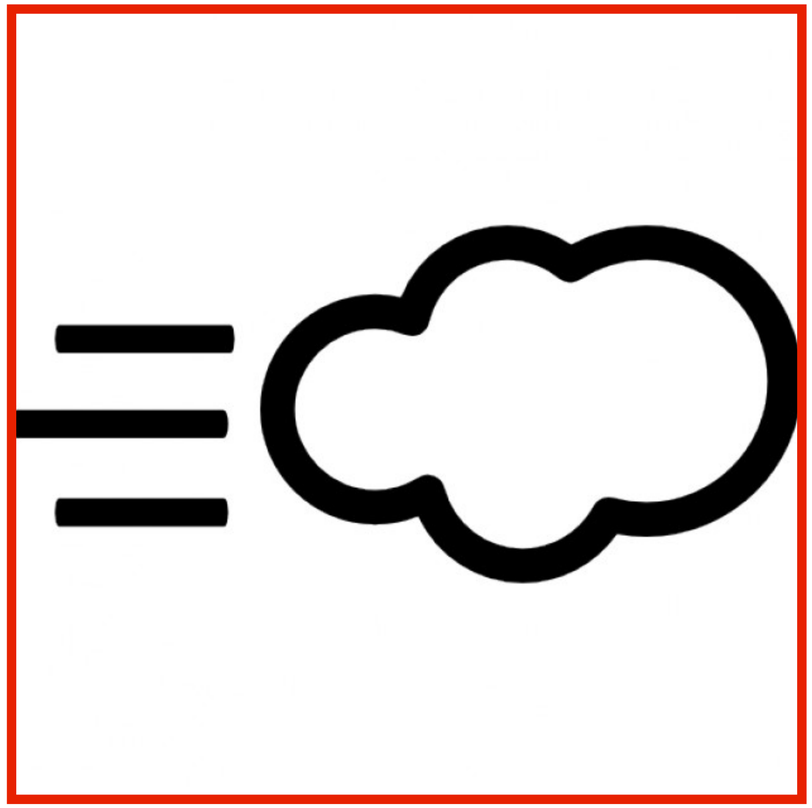


EXTREME FAST



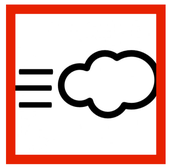
EXTREME SLOW





SOLAR WIND

Transients



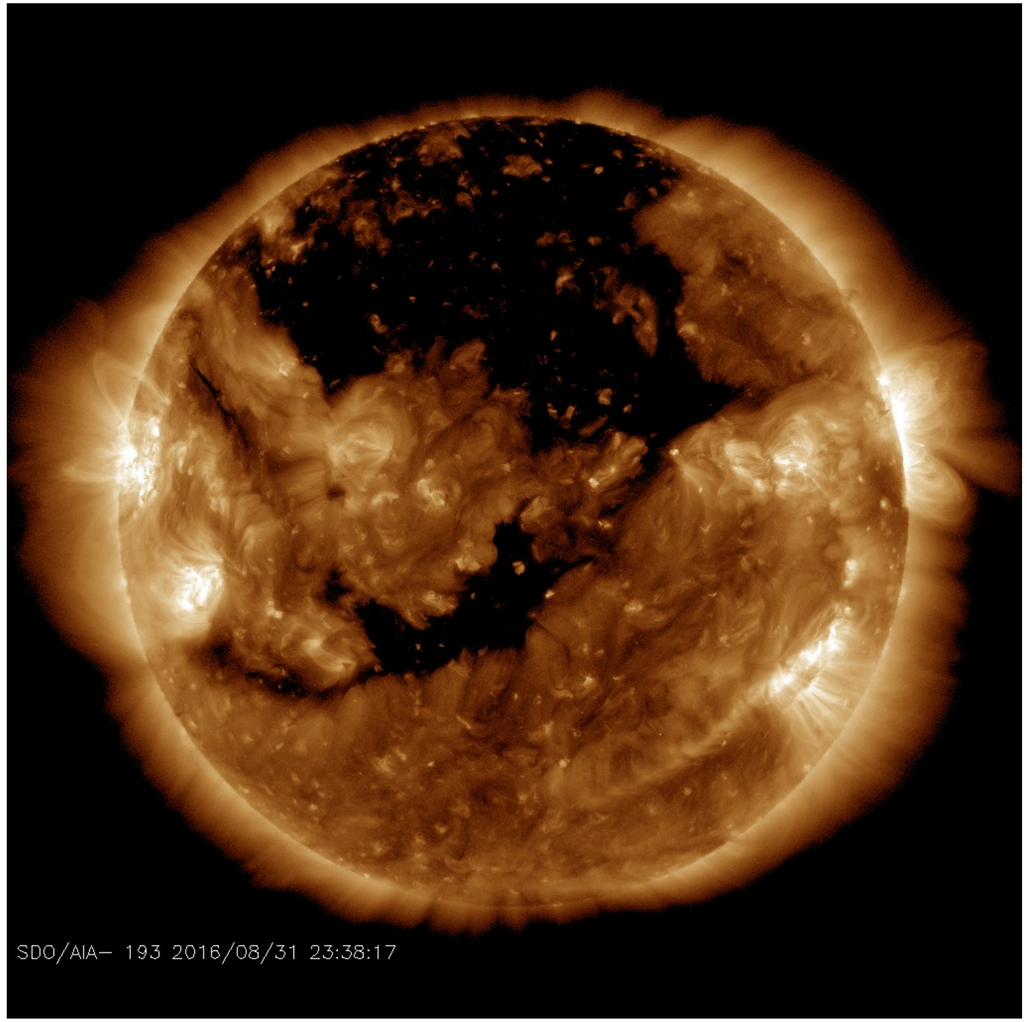
Transients

High Speed Streams (HSSs)

And

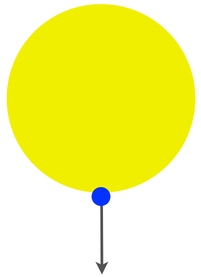
Co-rotating Interaction Regions (CIRs)

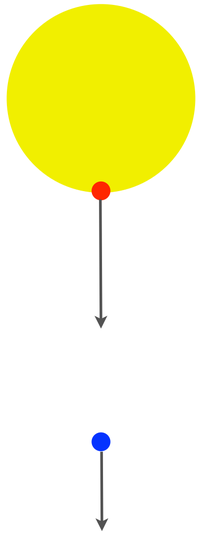
Coronal Hole



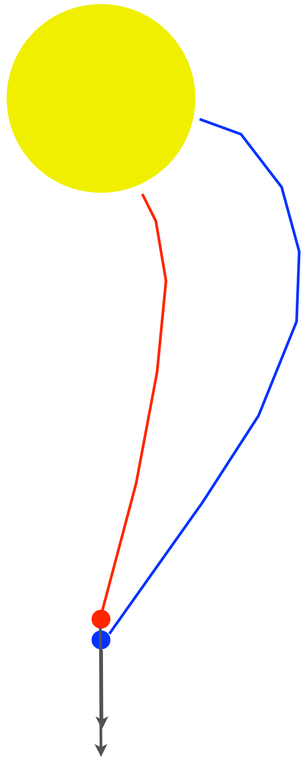
WHAT HAPPENS WHEN FAST CATCHES SLOW?

Top View



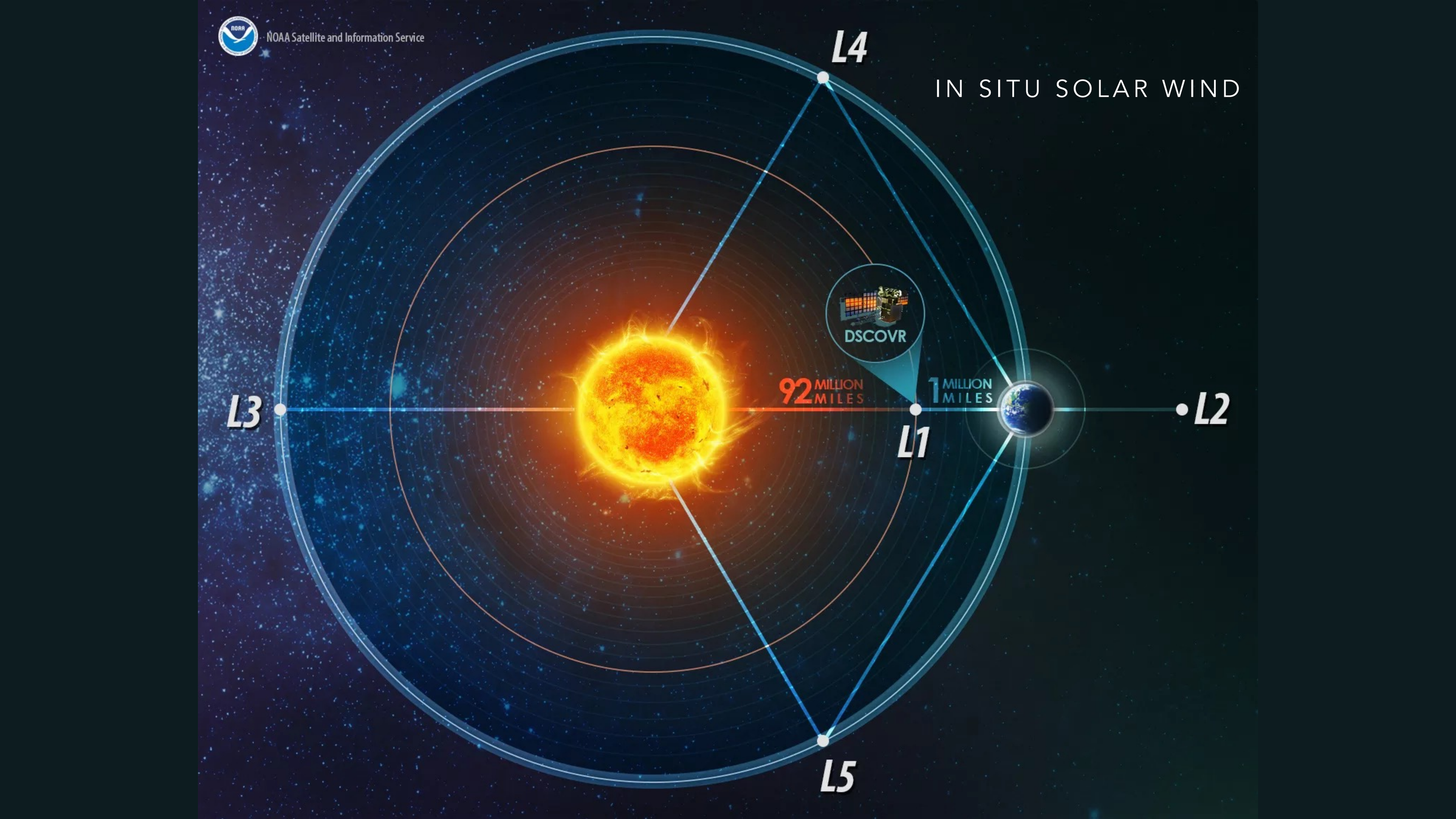






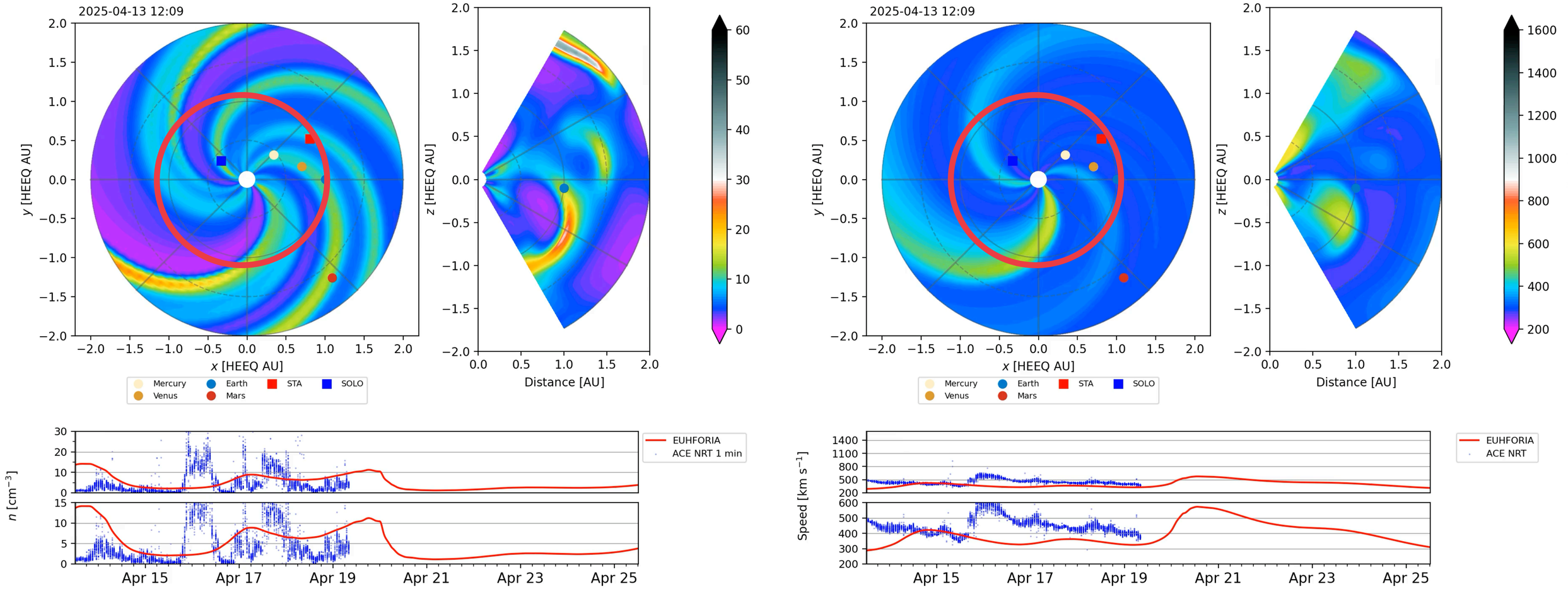
Interaction Region
Rotates together with the Sun

Co-rotating Interaction Region


NOAA Satellite and Information Service
L4
IN SITU SOLAR WIND
DSCOVR
92 MILLION MILES
1 MILLION MILES
L3
L1
L2
L5


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 log10 (° 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

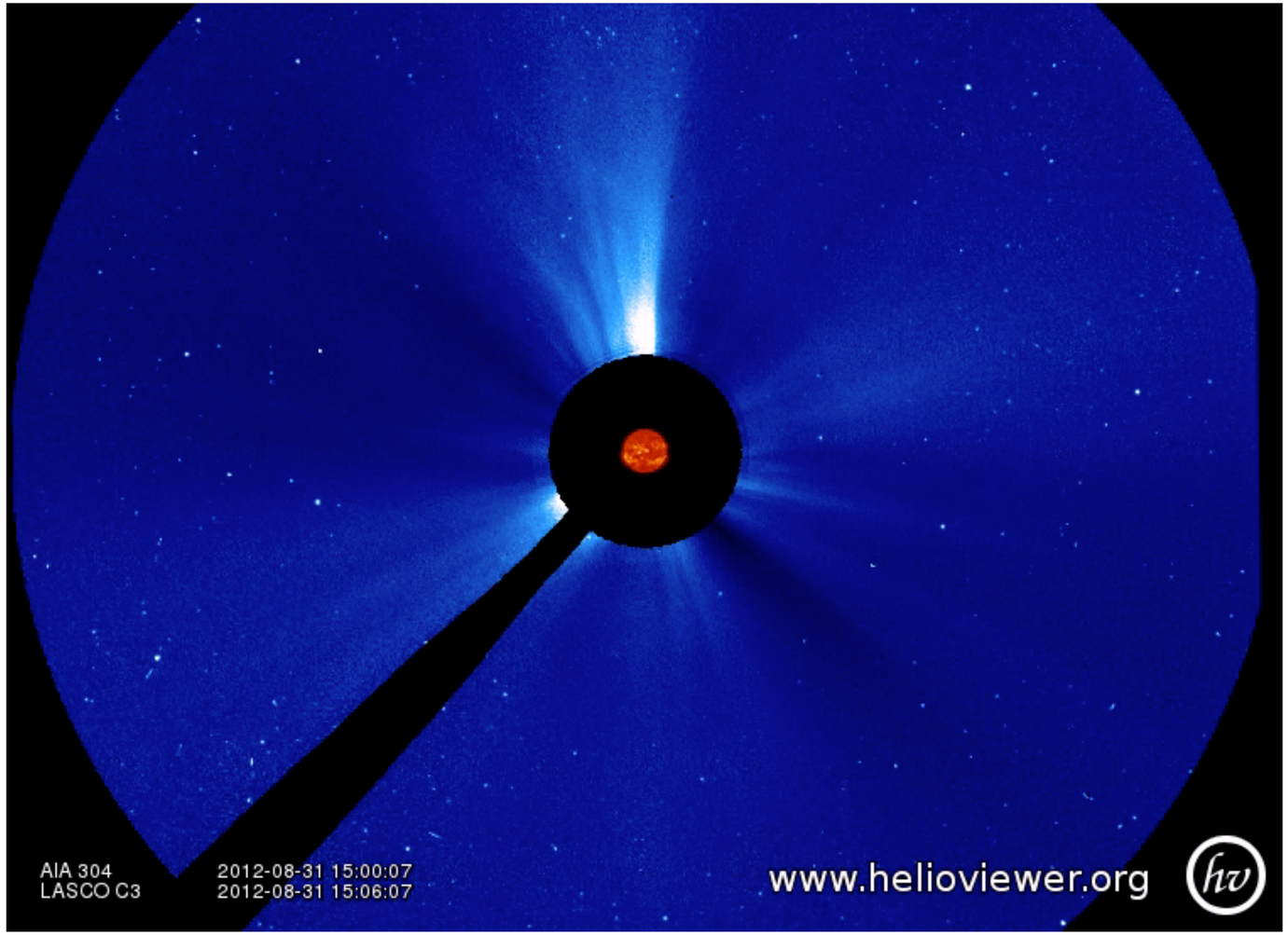
Co-rotating Interaction Region

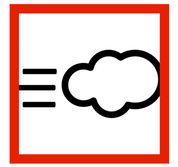


EUHFORIA, realtime simulations of the inner heliosphere

Transients

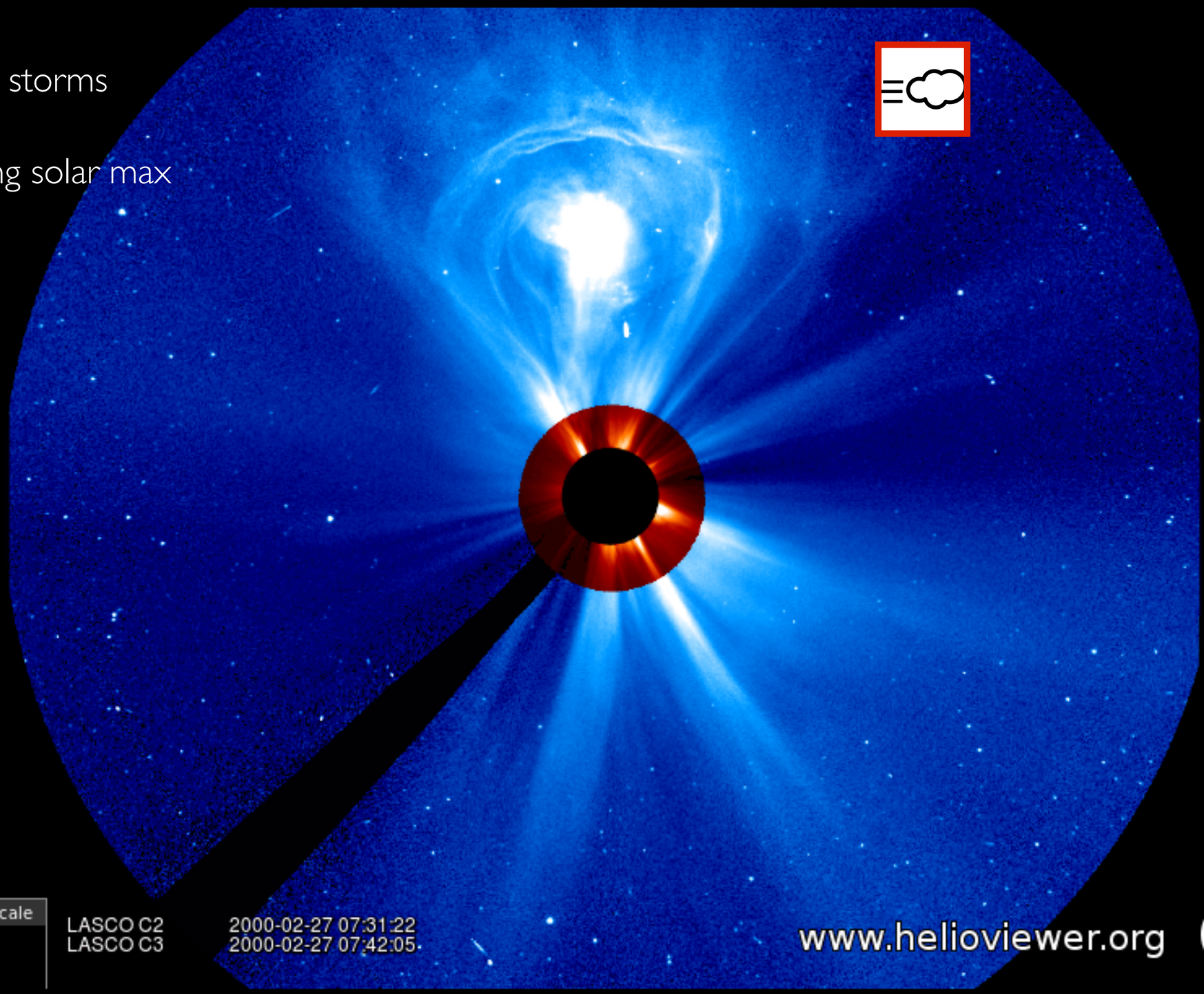
Coronal Mass Ejections

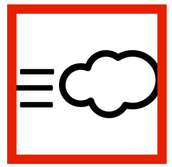




A new, discrete, bright white light feature in the coronograph field-of-view with a predominantly, radial outward velocity.

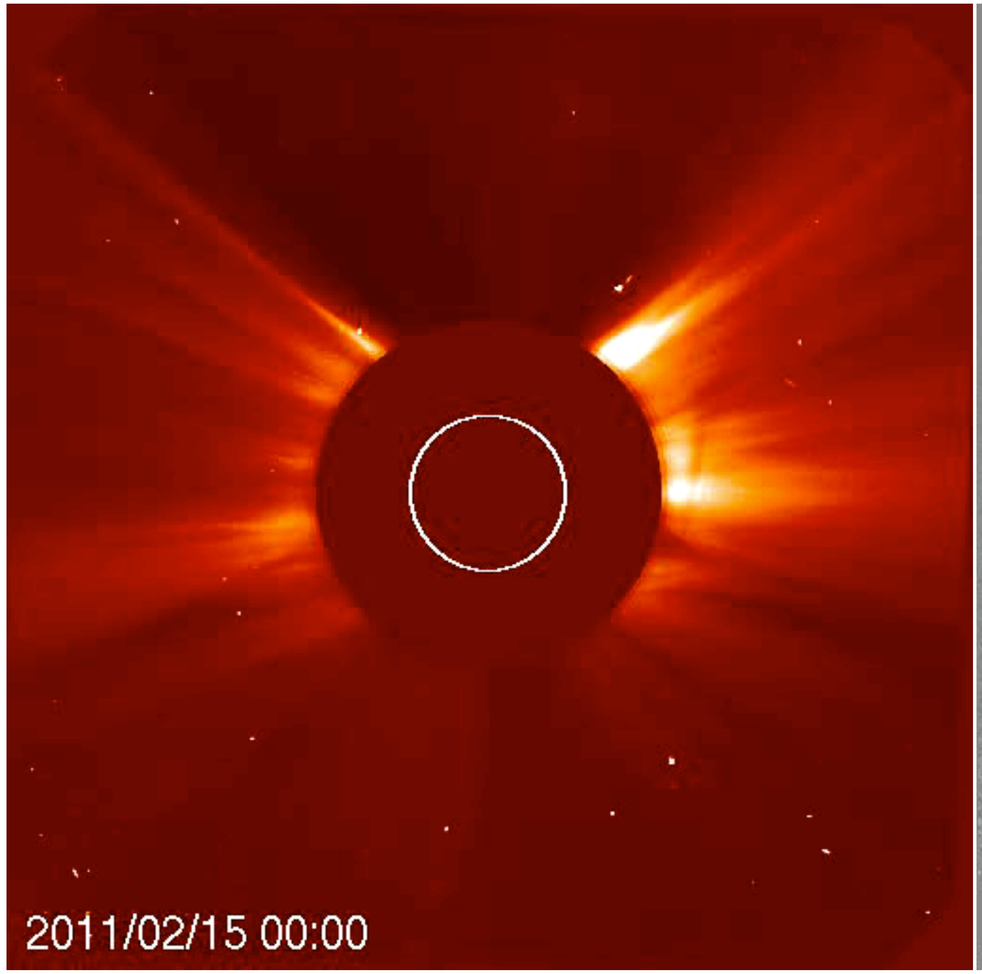
- Trigger the strongest geomagnetic storms
- <1/day during solar min, ~ 3 during solar max
- V between 400 and 2000 km/s
- Travel time typically 2-4 days

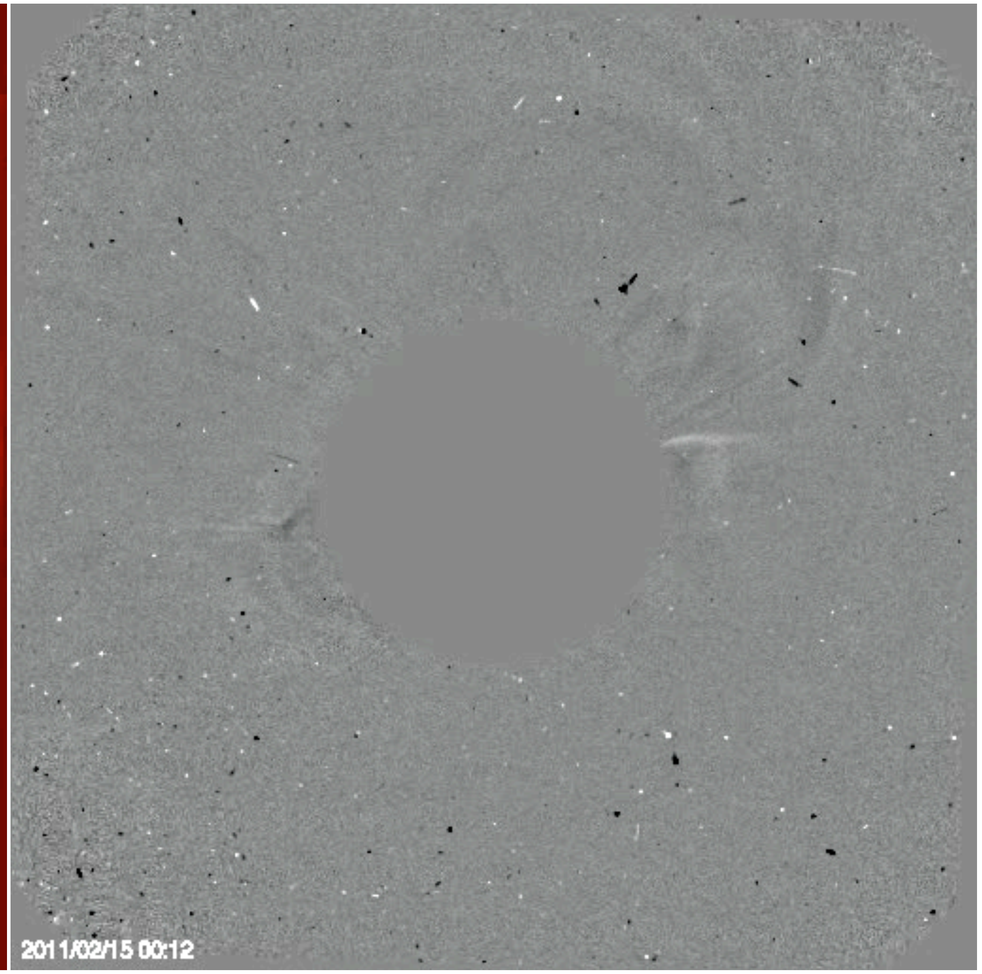




How do you know there is a CME?

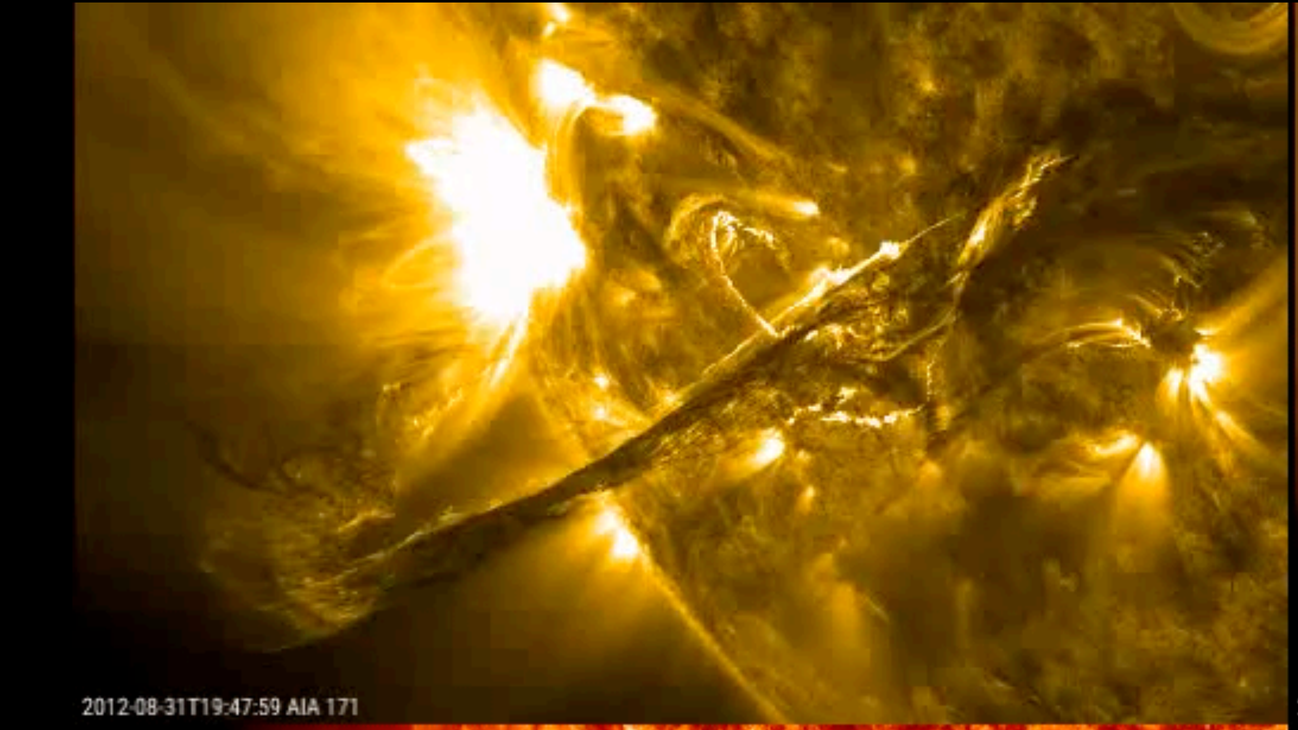
IN CORONAGRAPHS





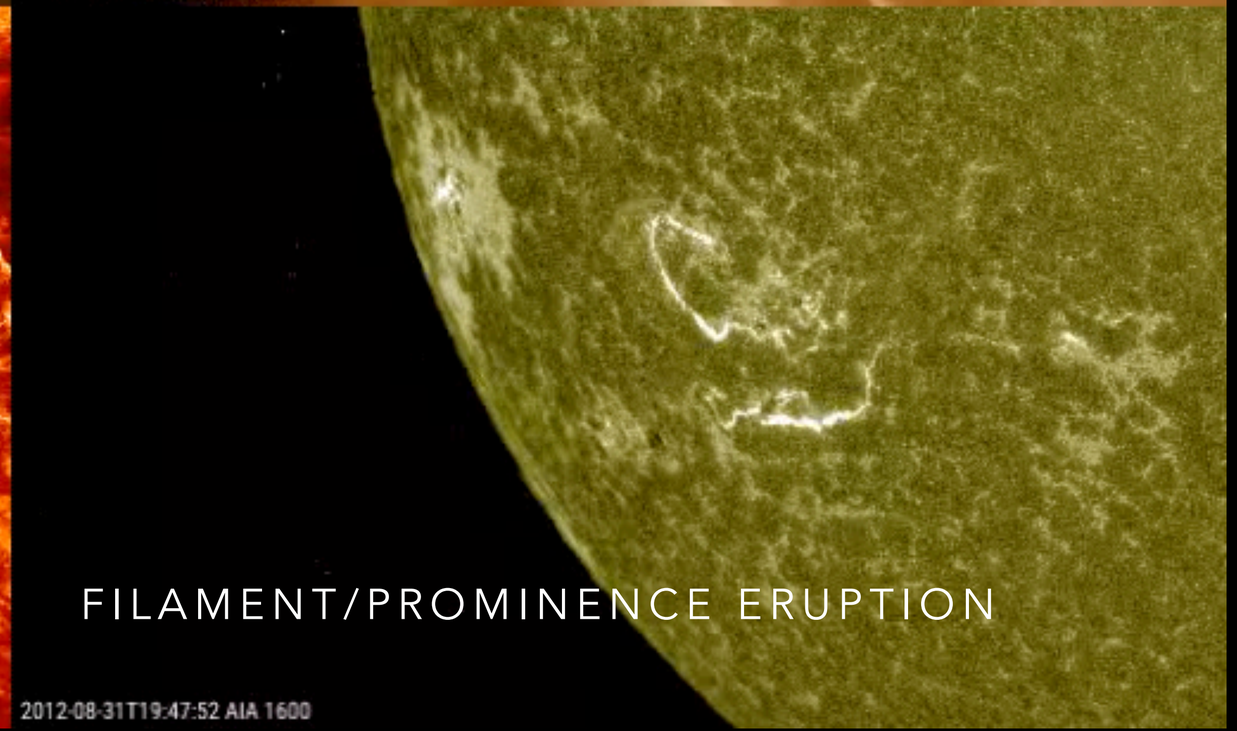
SOHO / LASCO c2

running difference

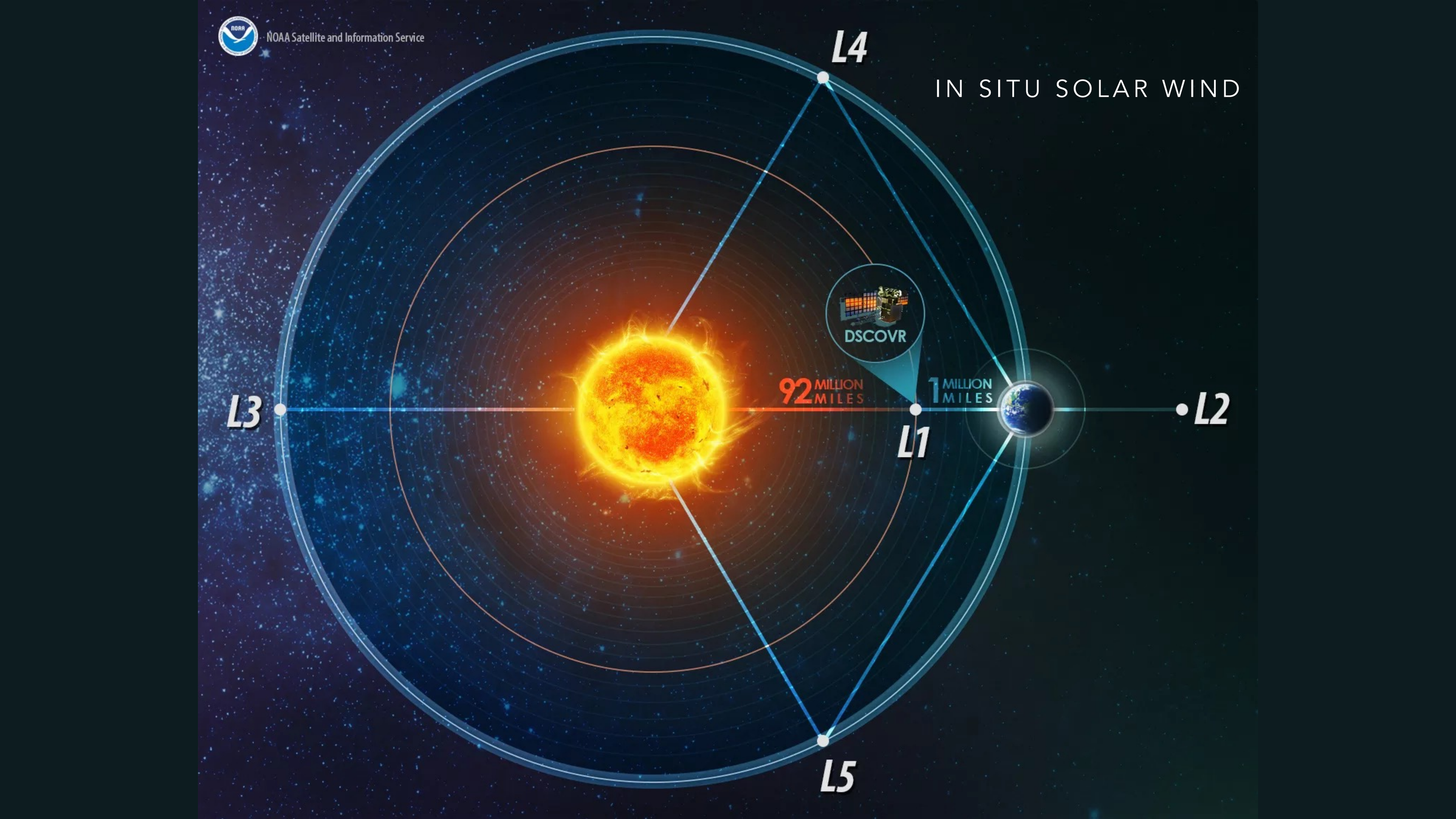


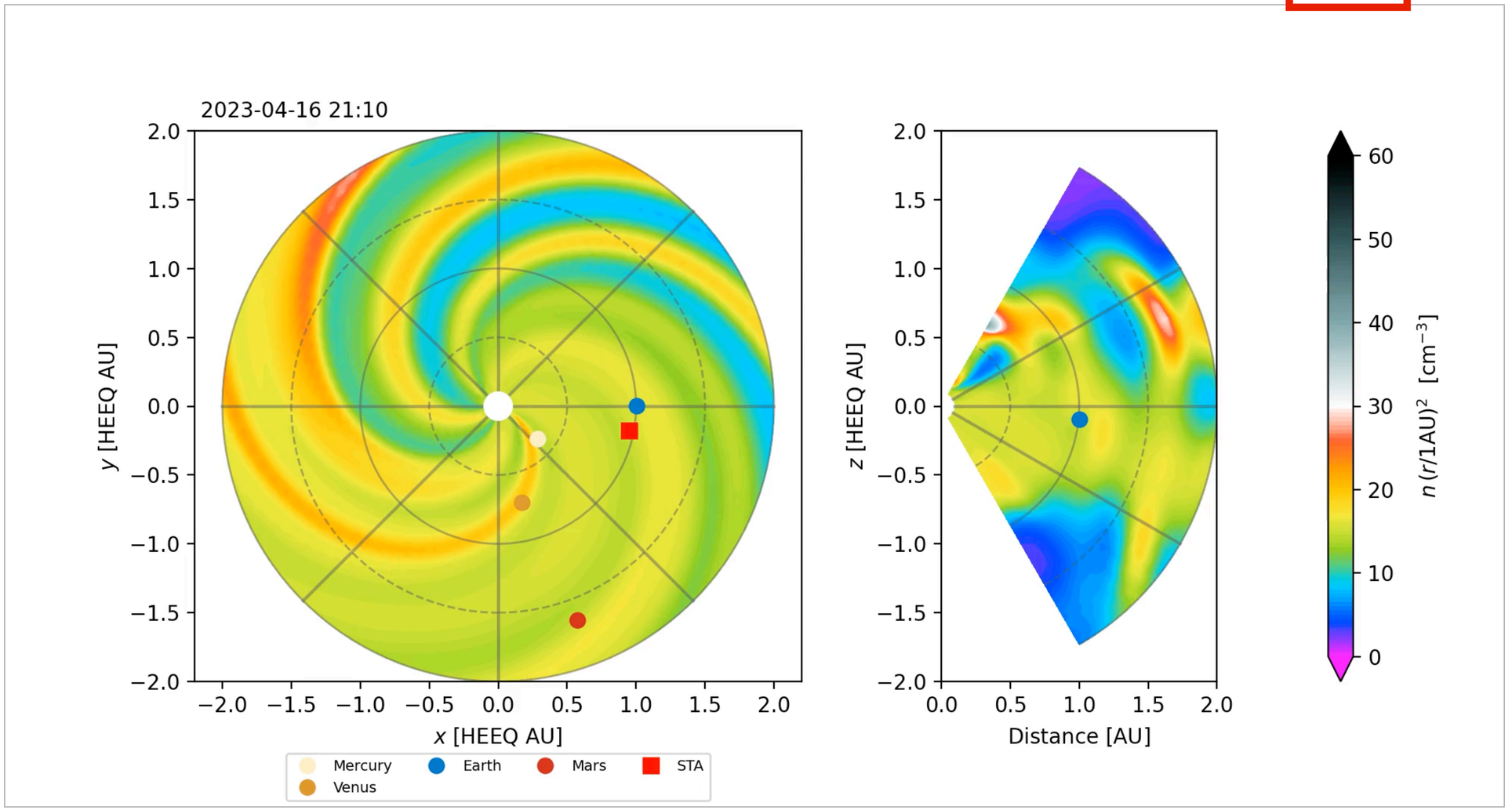


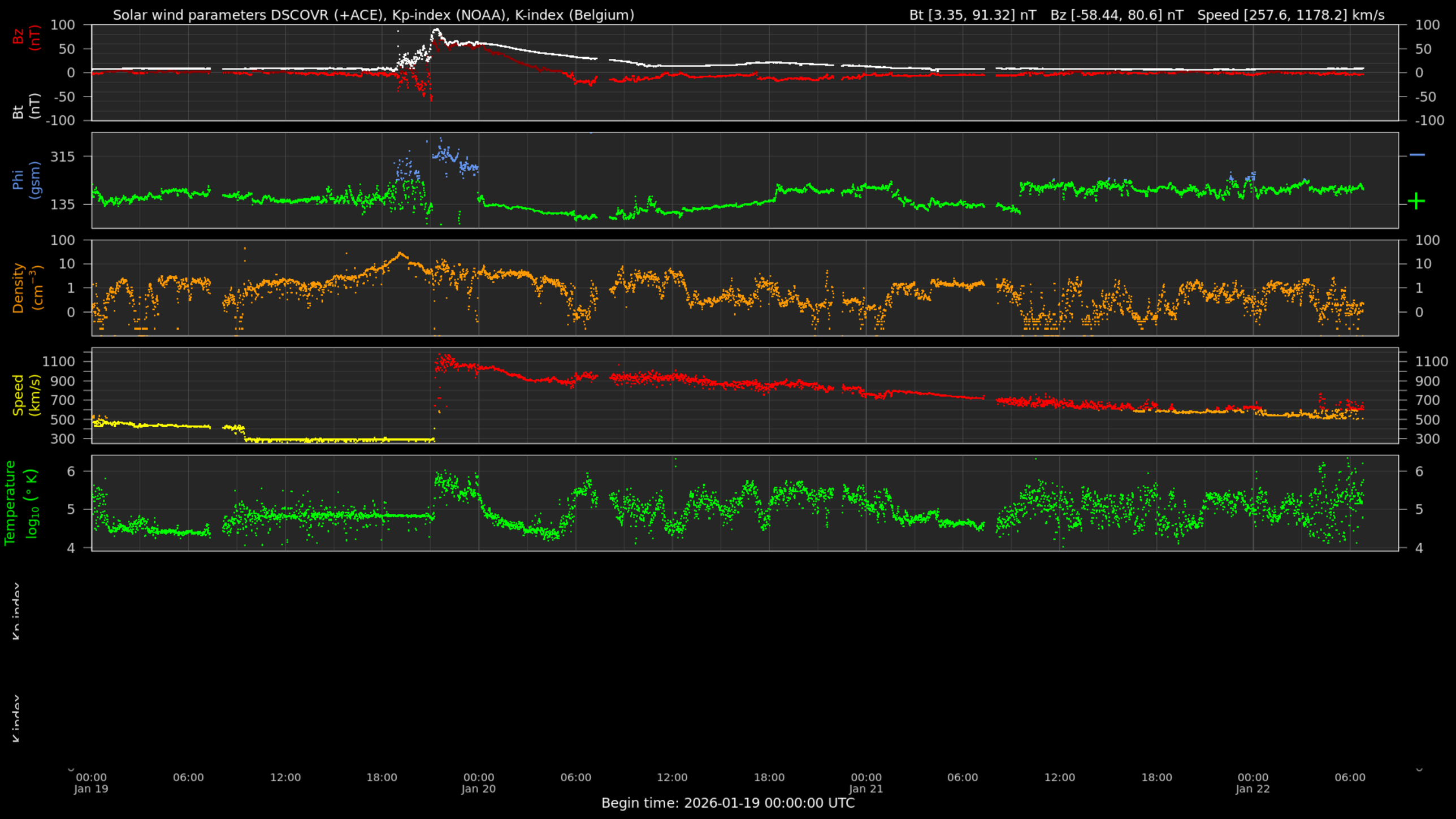




FILAMENT/PROMINENCE ERUPTION


NOAA Satellite and Information Service
L4
IN SITU SOLAR WIND
DSCOVR
92 MILLION MILES
1 MILLION MILES
L3
L1
L2
L5

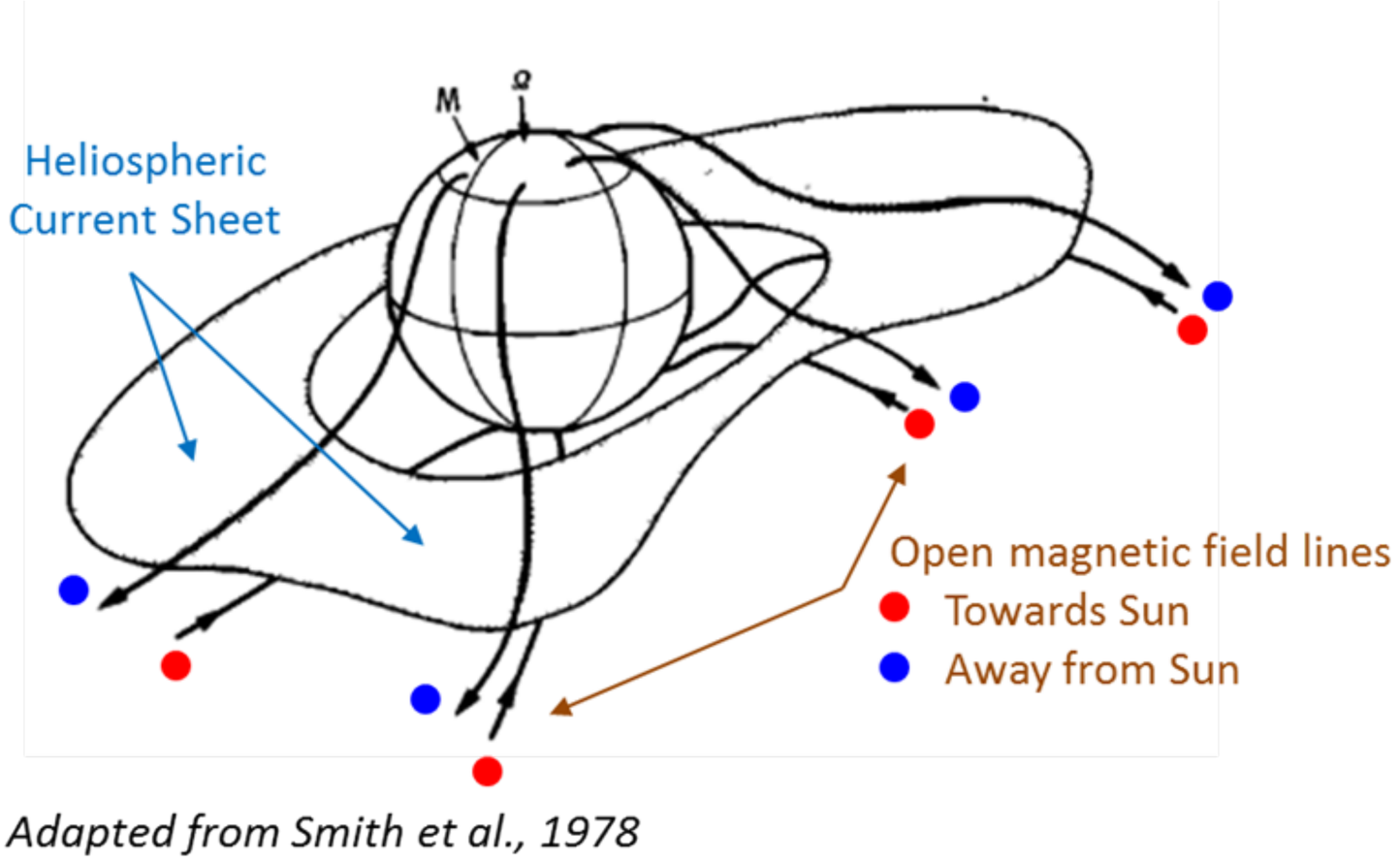

2023-04-16 21:10
y [HEEQ AU]
x [HEEQ AU]
z [HEEQ AU]
Distance [AU]
n (r/1AU)² [cm⁻³]
Mercury
Venus
Earth
Mars
STA


Solar wind parameters DSCOVR (+ACE), Kp-index (NOAA), K-index (Belgium)
Bt [3.35, 91.32] nT Bz [-58.44, 80.6] nT Speed [257.6, 1178.2] km/s
Bz (nT)
Bt (nT)
Phi (gsm)
Density (cm⁻³)
Speed (km/s)
Temperature log10 (° K)
Kp index
K index
00:00 Jan 19
06:00
12:00
18:00
00:00 Jan 20
06:00
12:00
18:00
00:00 Jan 21
06:00
12:00
18:00
00:00 Jan 22
06:00
Begin time: 2026-01-19 00:00:00 UTC

Transients

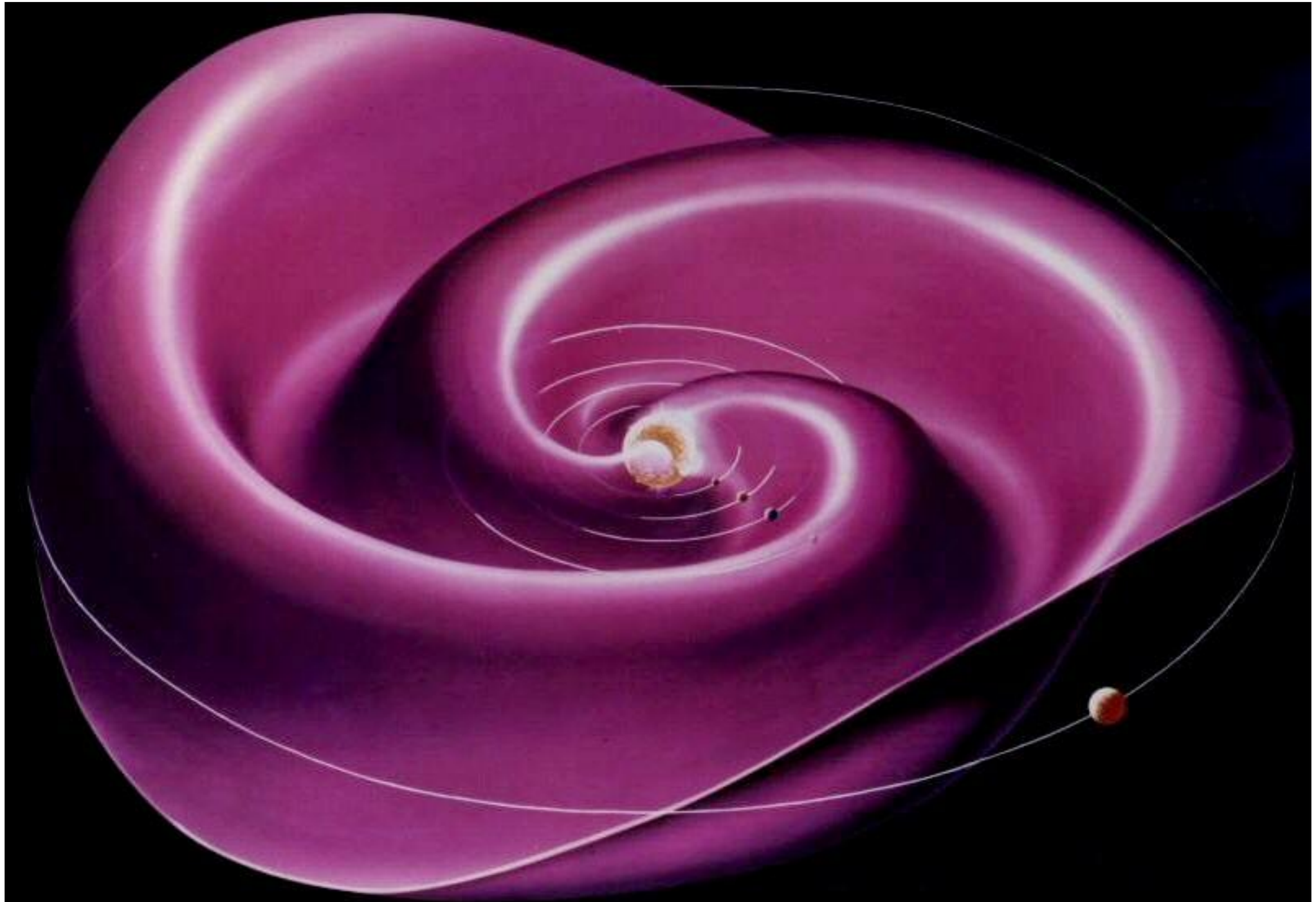
Sector Boundary Crossing

HELIOSPHERIC CURRENT SHEET

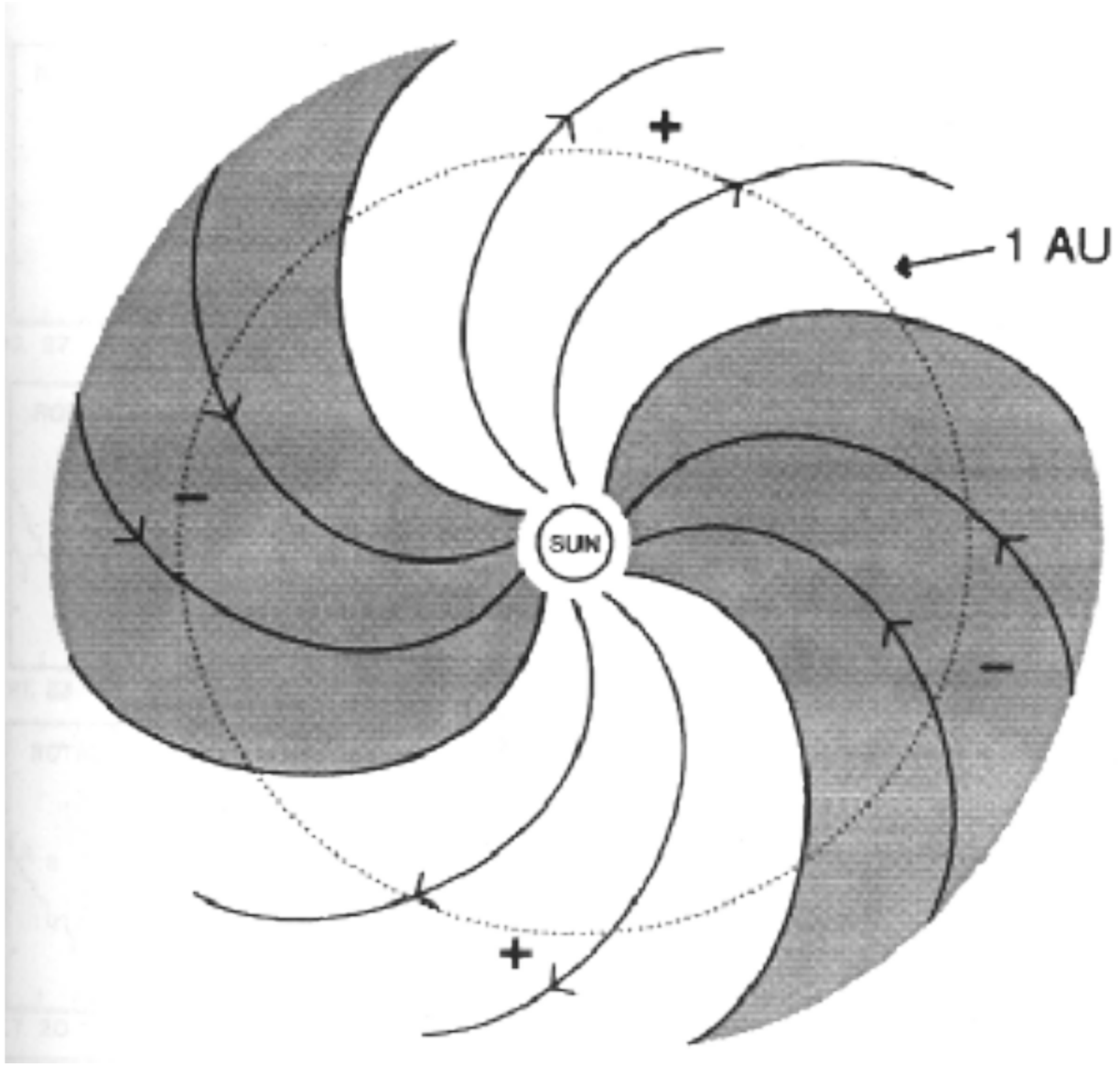


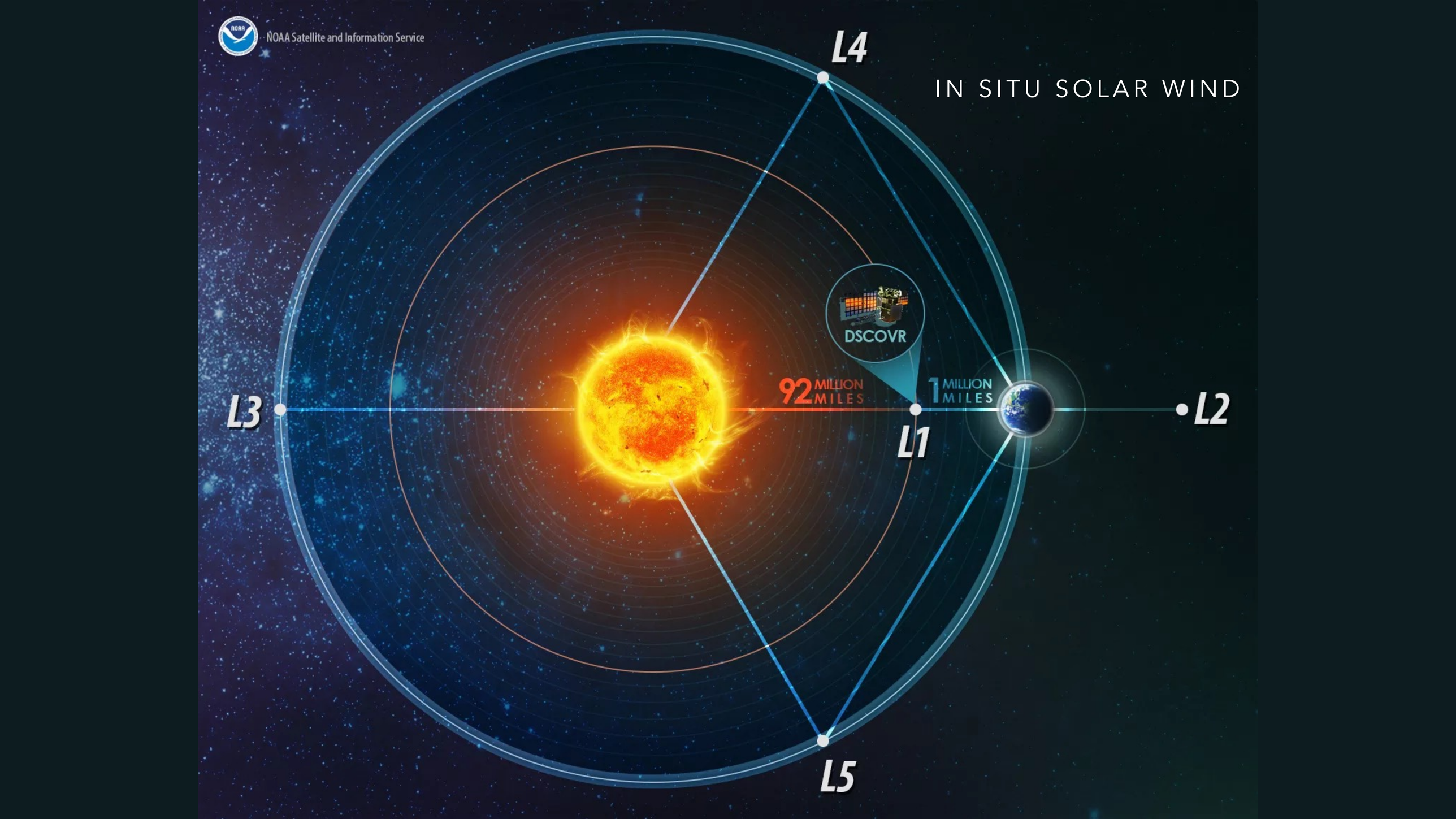
Adapted from Smith et al., 1978

BALLERINA SKIRT

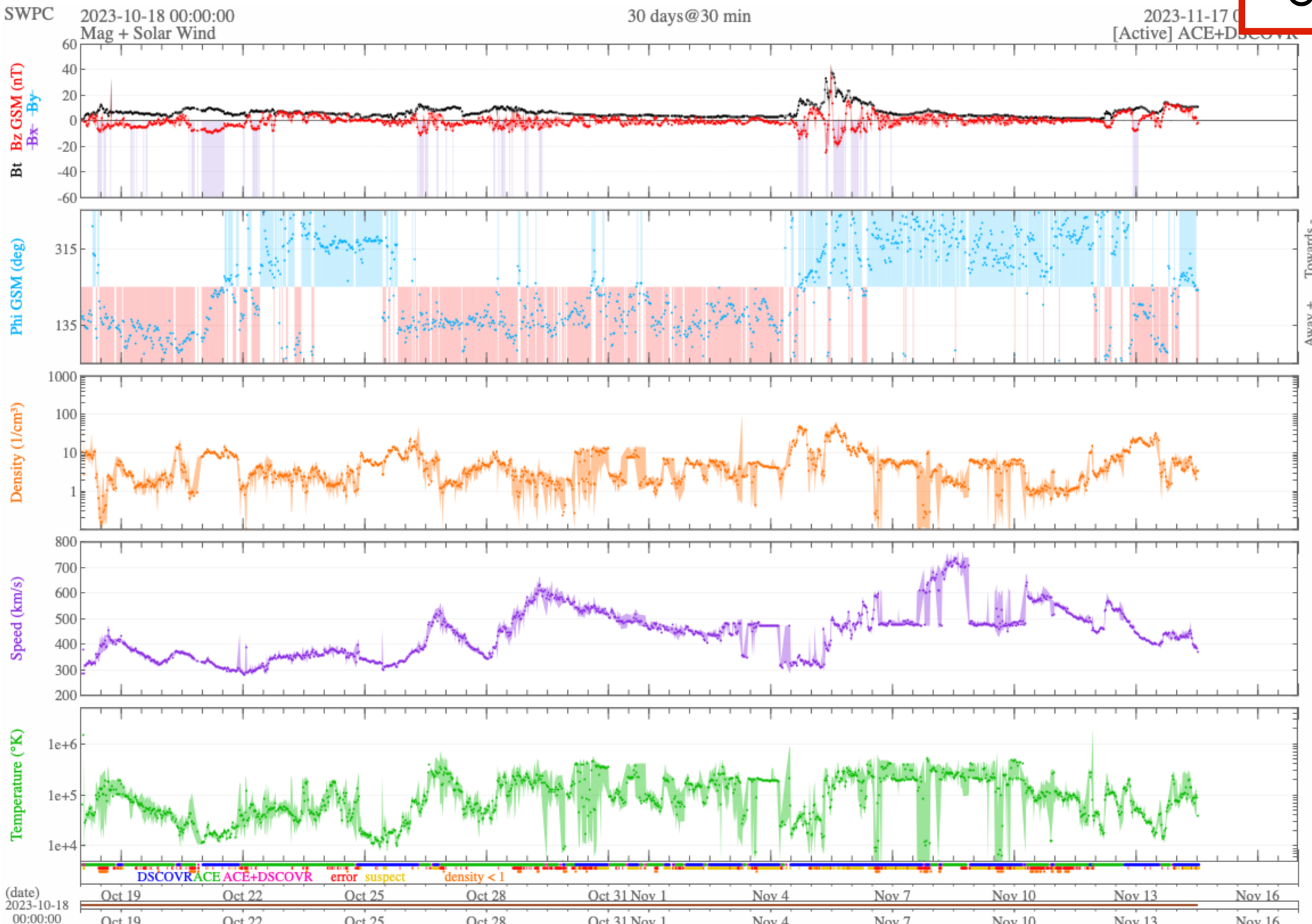


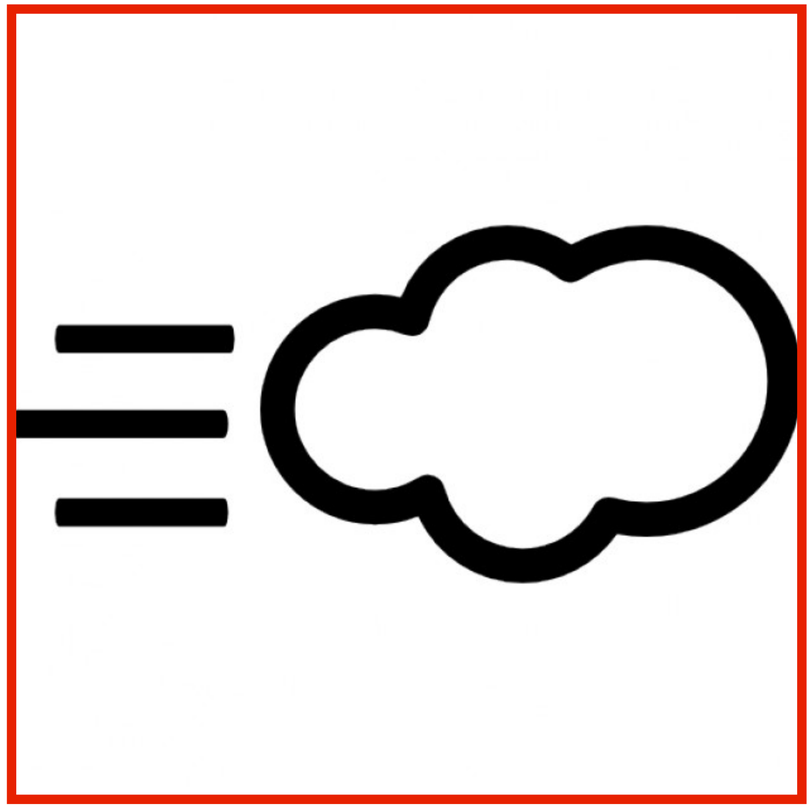
AWAY/TOWARDS SECTORS




NOAA Satellite and Information Service
L4
IN SITU SOLAR WIND
DSCOVR
92 MILLION MILES
1 MILLION MILES
L3
L1
L2
L5

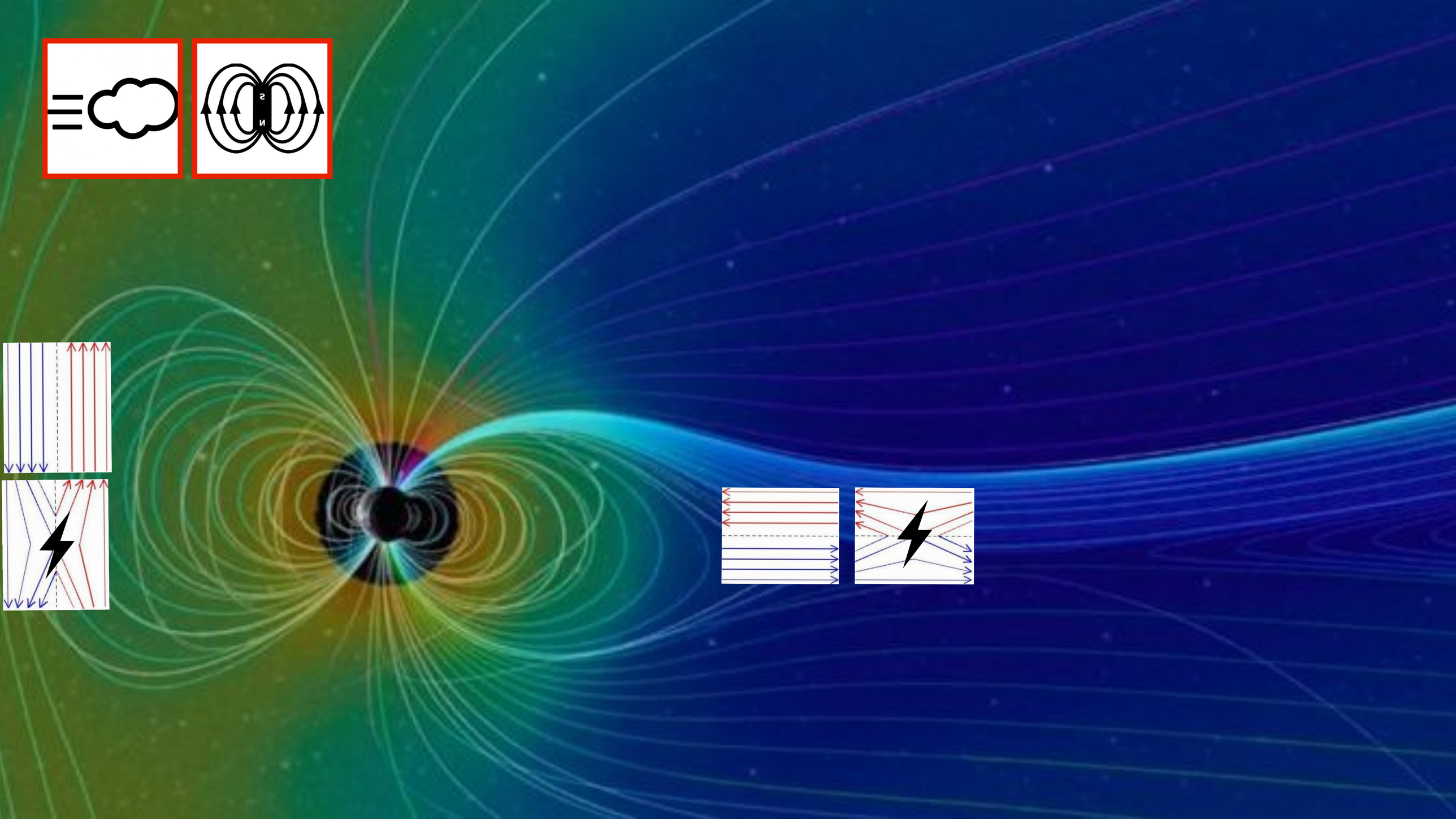
IN SITU


SWPC
2023-10-18 00:00:00
Mag + Solar Wind
30 days@30 min
2023-11-17 0
[Active] ACE+DSCOVR
Bt Bz GSM (nT)
Bx By
Phi GSM (deg)
Towards -
Away +
Density (1/cm³)
Speed (km/s)
Temperature (°K)
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

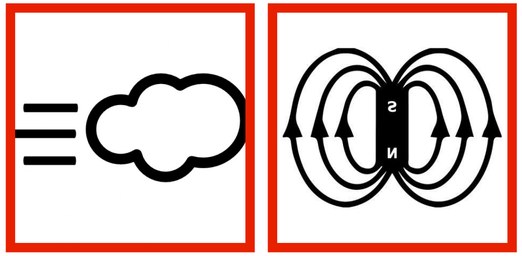


GEOMAGNETIC STORM

Solar wind meets the Earth
Geoeffectivity


S
N

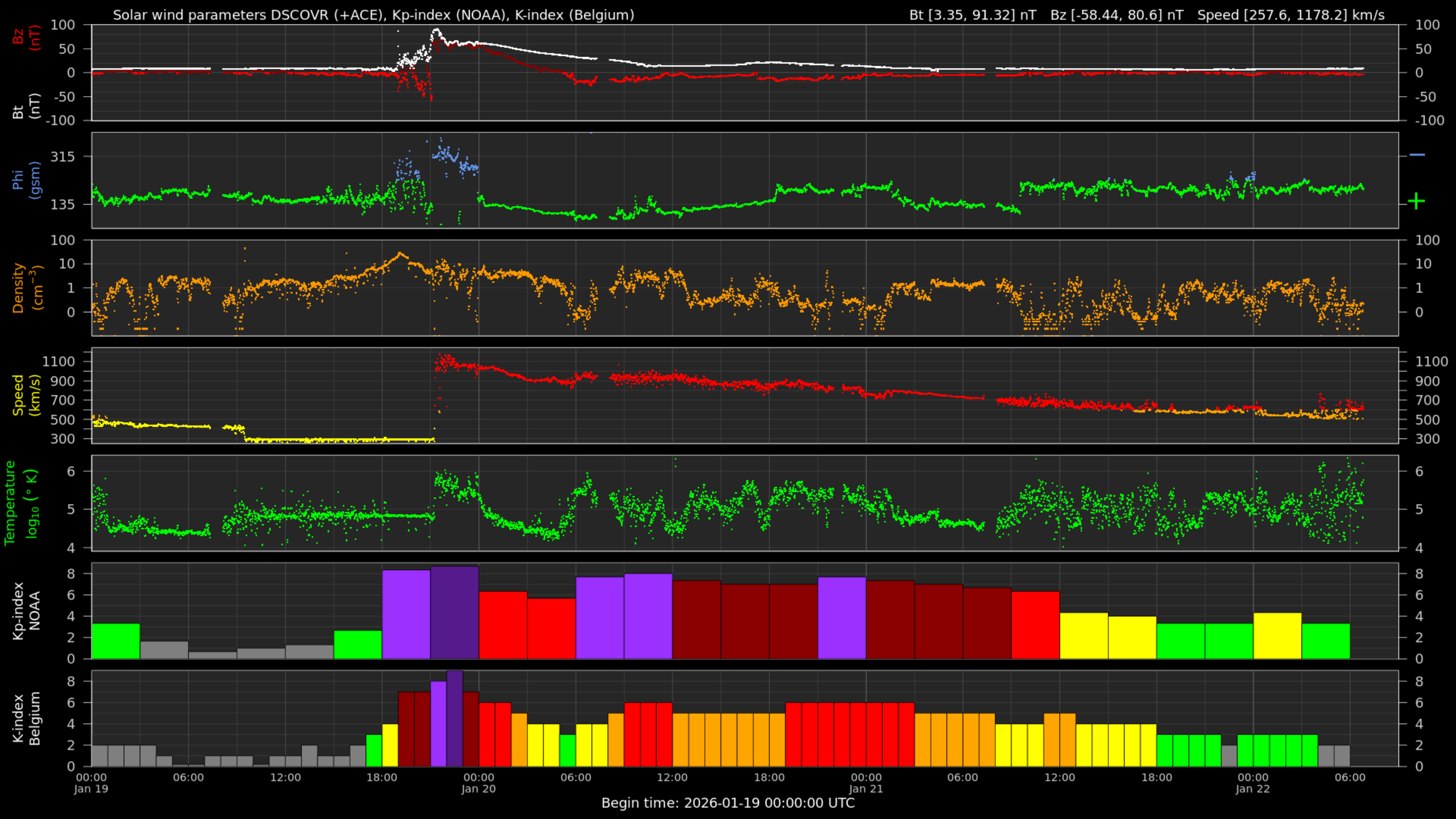
GEOMAGNETIC CONDITIONS



https://kp.gfz.de/en/



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


Solar wind parameters DSCOVR (+ACE), Kp-index (NOAA), K-index (Belgium)
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Bt (nT)
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Density (cm⁻³)
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Temperature log10 (° K)
Kp-index NOAA
K-index Belgium
00:00 Jan 19
06:00
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Begin time: 2026-01-19 00:00:00 UTC





