SOLAR WIND

Solar wind =

Plasma

+

Interplanetary Magnetic field

Continuous radial outflow of gas - Consists of charged particles

Shapes the IMF - Can carry magnetic structures.

Is the IMF Straight/Bended?

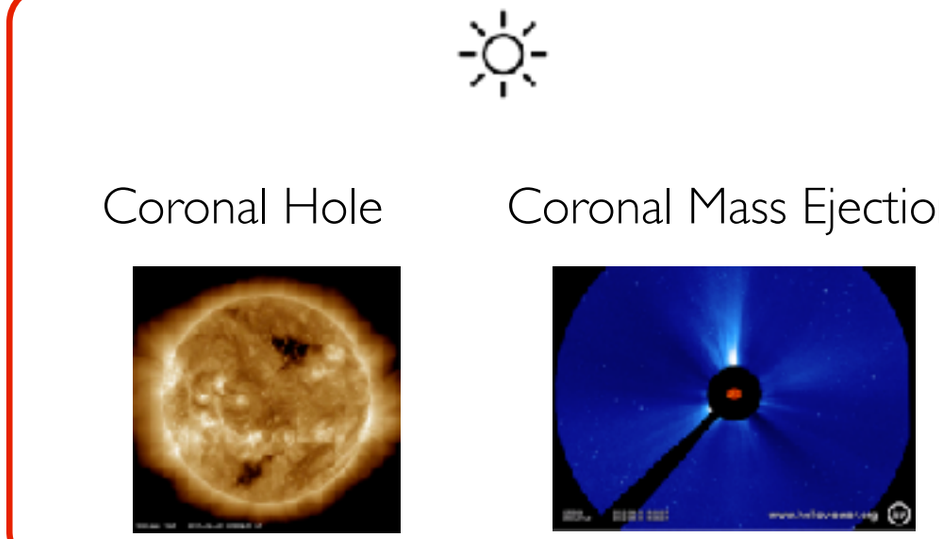
IMF are open/closed magnetic field lines?

Radial outflow: linked to open magnetic field lines
Example of a Magnetic structure: a CME

The solar wind plasma is glued to the IMF - or the IMF is glued to the plasma.

The solar wind is a continuous radial stream of solar plasma that leaves the sun and moves away from it. It fils the space between the planets with solar mass. The solar wind reaches the boundaries of the heliosphere, a magnetic shield around the Sun. In the heliosphere, the Sun sets the rules and you have solar weather. Outside the heliosphere, you have the rest of the galaxy. Earth is in the heliosphere.

SOLAR WIND VARIATIONS



Non-eruptive
Eruptive

Magnetic reconnection
No magnetic reconnection

B reconnection on the SUN

The variations in the solar wind introduce space weather events.

CME - suddenly, a mass is ejected into space. A CME is an eruptive event.
—> magnetic reconnection is involved

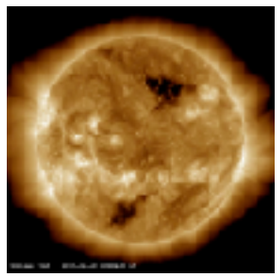
A CH is not eruptive. A CH is present, it doesn't pop up suddenly. A CH can of course slowly appear or disappear, become bigger, become smaller but not on time scale of a few minutes. It is also not the case that a CH ejects material and a little bit later, not any more. The solar wind continuously emanate from a CH.
—> no magnetic reconnection is involved

SOLAR WIND VARIATIONS

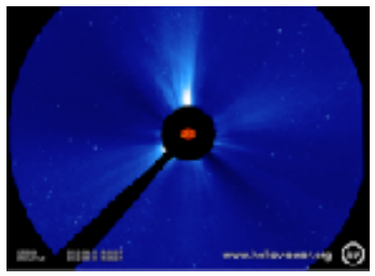
Non-eruptive
No B reconnection

Eruptive
B reconnection

Coronal Hole



Coronal Mass Ejection



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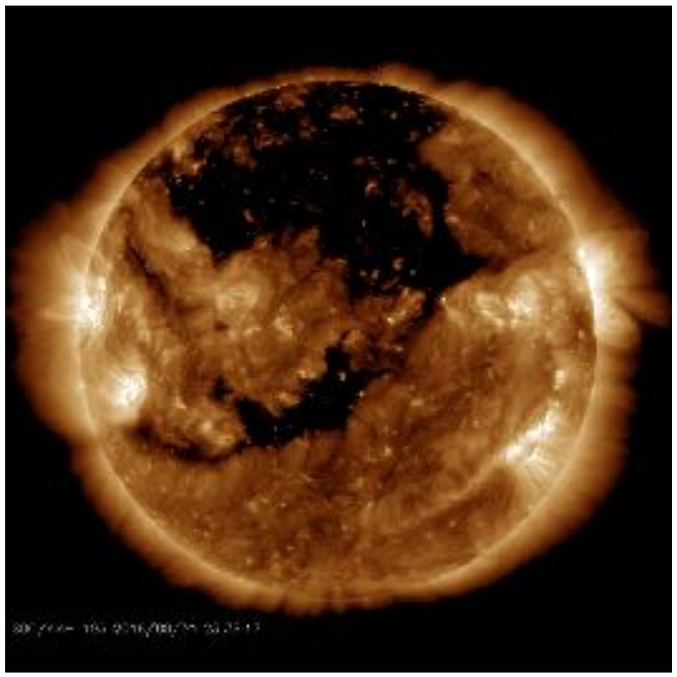
CORONAL HOLE

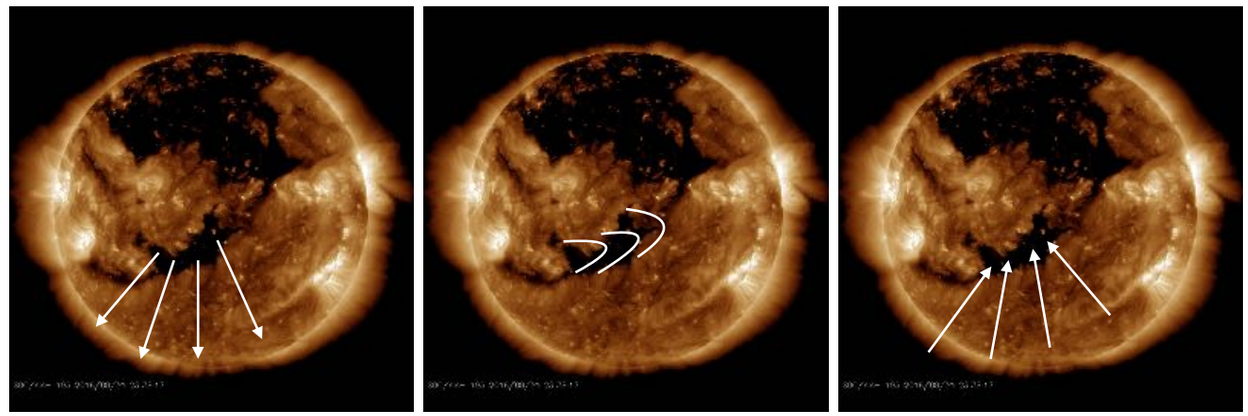


open field structure, source of fast solar wind
non eruptive
radial - plasma leaving when it is at the central meridian, reaches Earth

What is important determining when and how strong the impact of a CH will be:
- The heliographic latitude of earth
- The latitude of the CH on the solar disk: the part of a CH with a low latitude is important. Polar coronal holes have only an impact when they extent to lower latitudes.
- It is the material that leave at the central meridian that will reach earth. You have to guess how fast the solar wind is. Calculate the time the material needs to cross the distance 1AU and you have an estimate of the arrival time of the CH wind near Earth.

at the central meridian

B OF CORONAL HOLE



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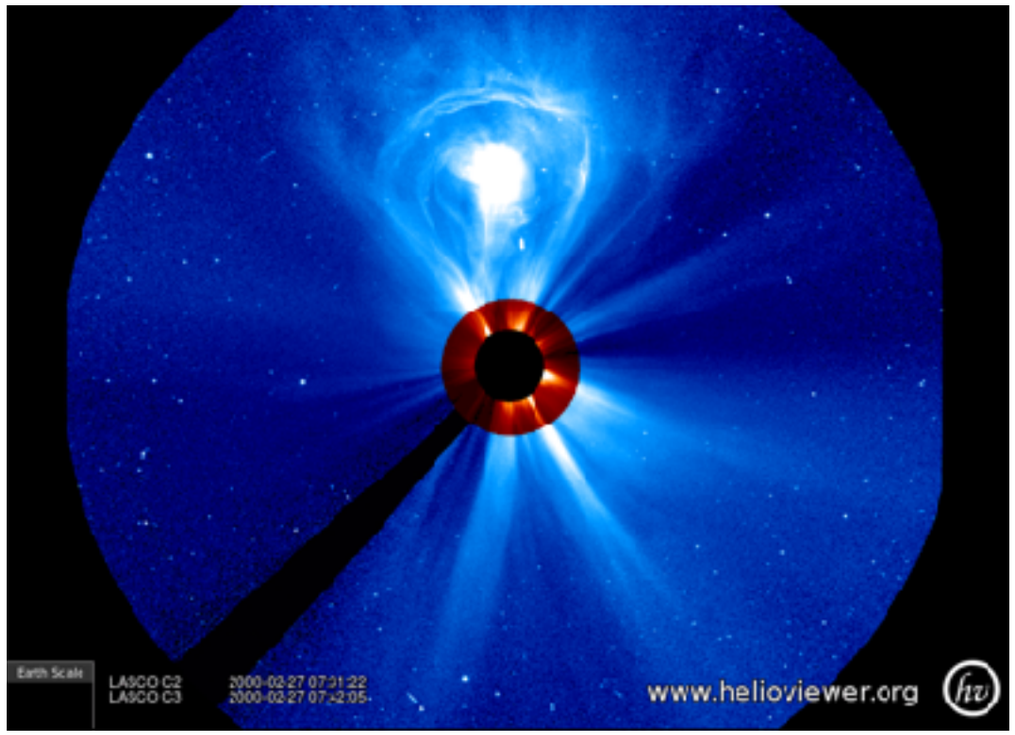
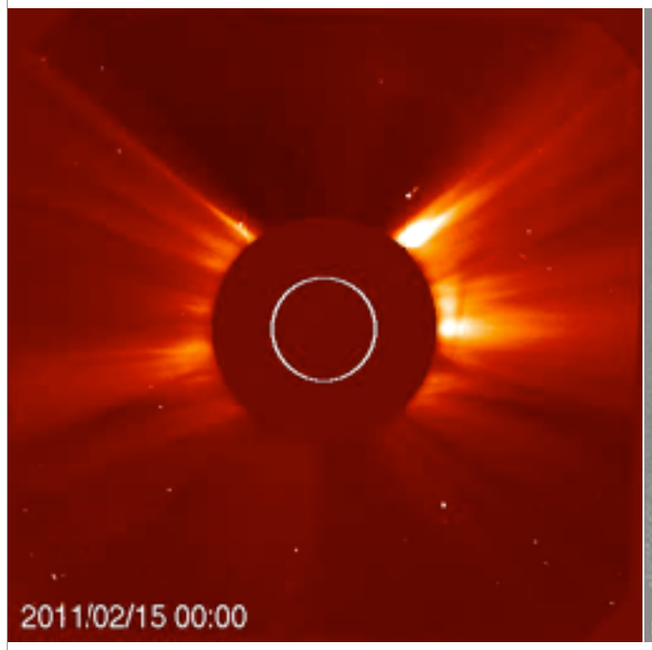
CORONAL MASS EJECTION

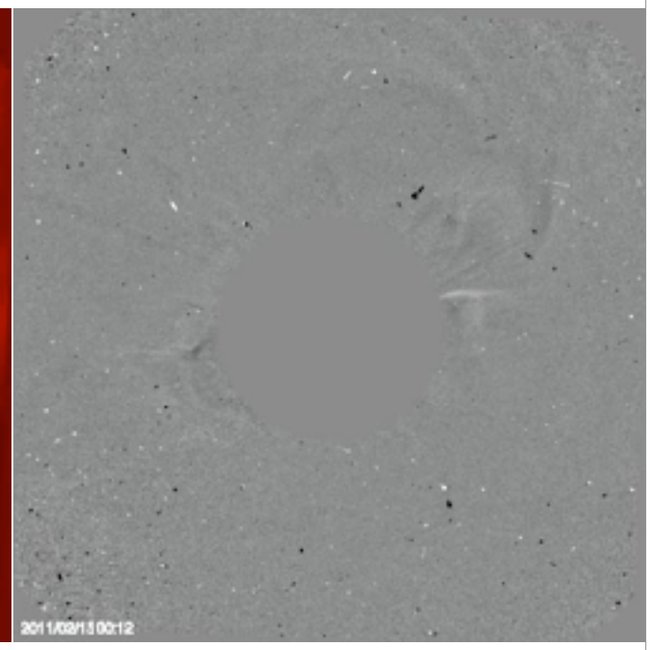


Transient: only lasting for a short time

Low density, but enormous and therefore massive.

CME is large: compare its size with the size of the sun.





SOHO / LASCO c2

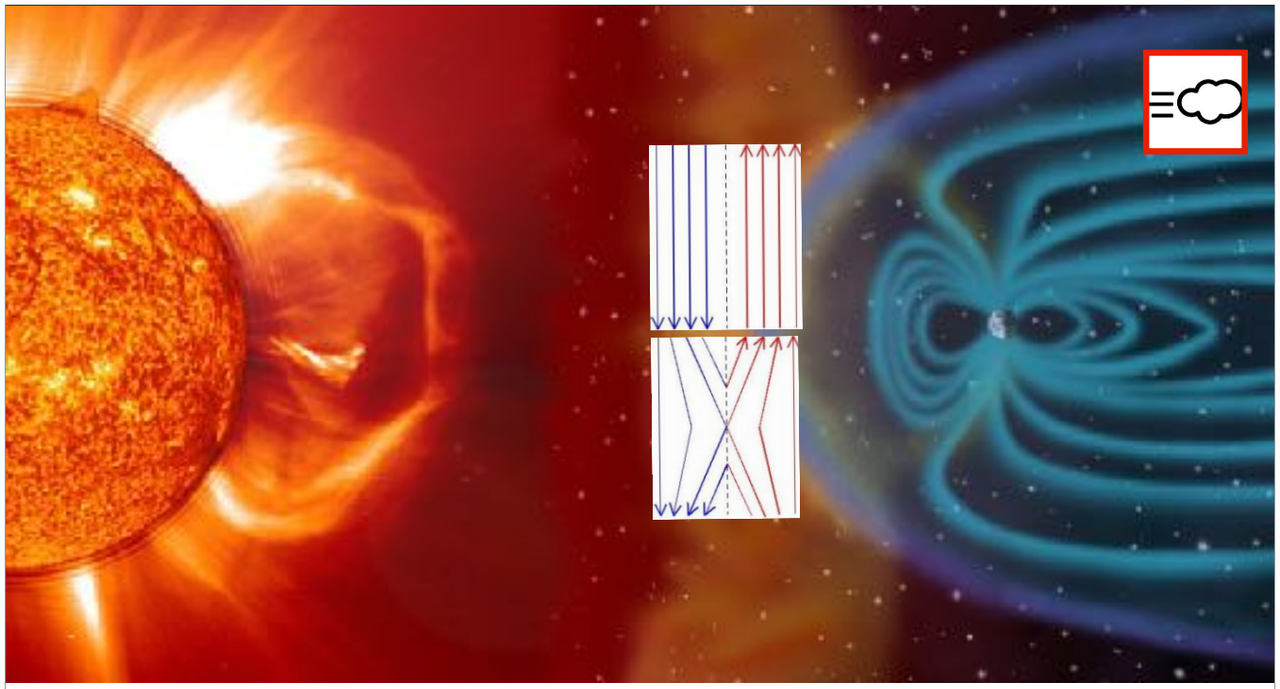
running difference

CMEs cause the most extreme geomagnetic storms. Therefore, there is great interest in understanding the properties of CMEs, especially when they have a halo signature around the solar disk that indicates the CME is aimed at Earth.
Furthermore, if the CME results in a magnetic cloud with a strong and out of ecliptic magnetic field,forecasts are likely for strong to extreme storms.

NEAR EARTH

This are in situ solar wind measurements done by the
NOAA DSCOVR satellite
http://www.swpc.noaa.gov/products/real-time-solar-wind

This satellite is located at the Lagrangian point L1: in between the earth and the sun. When the earth moves around the sun, L1 follows. We call L1 one hour upstream of earth. This refers to the solar wind. It takes the solar wind from that point roughly 1 hour to reach the magnetosphere of the 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.

Magnetic reconnection at the magnetosphere of Earth.
Doesn't matter if the wind is linked with a CH or CME.

This is the earths magnetosphere. The sun is somewhere far away in the right top corner.
The earth is a giant dipole - similar as the sun. Except, the solar magnetic dipole field reverses every 11 year. The Earths magnetic poles don't. They are already for ages like this.
The part of the earths dipole facing the sun/solar wind is pushed more together, while the part behind the earth is stretched and forms a tail. In front of the magnetic structure, you have a shock.

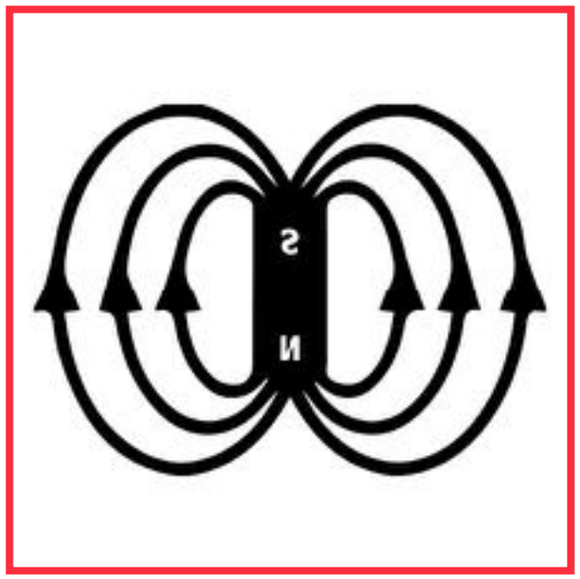
This is a structure similar like a shock in front of a speed boat that moves very fast over water: the water waves that the moving boat initiate are slower compared to the speed of the boat. The boat is super-water wave.
When a plane is super-sonic, there is also a shock in front of it. The pressure waves that the moving plane creates move much slower than the plane.

In the case of a speed boat, the boat moves through the water.
In our case, it is the solar wind that blows over the earth. It is just a matter of reference, but the result is the same: a shock.

A magnetic field is imbedded in the solar wind. This magnetic field can interact with the magnetic field of the earth at the boundaries of the earth magnetosphere. This interaction is called reconnection. It happens when 2 magnetic regions are confronted with each other.

The blue magnetic field lines are imbedded in the solar wind.
The red magnetic field lines represent the earth magnetosphere.
The blue and the red magnetic region have to face each other. Opposite magnetic field lines can reconnect easily and 'open'. This causes geomagnetic storms. Magnetic field lines in the same direction interact less.
Therefore, it is very important to know how strong the

0.3 T – solar sunspot
5mT – strength of a typical refrigerator magnet
31.869 μT (3.1×10^{-5} T) – strength of Earth's magnetic field at 0° latitude (North/South), 0° longitude (west/east)
1 to 5 nT – IMF at L1



GEOMAGNETIC STORM

Ap Kp Dst

Can you give a few ‘markers’/geomagnetic indices for the strength of a geomagnetic storm

How does the Solar Wind looks like at L1?

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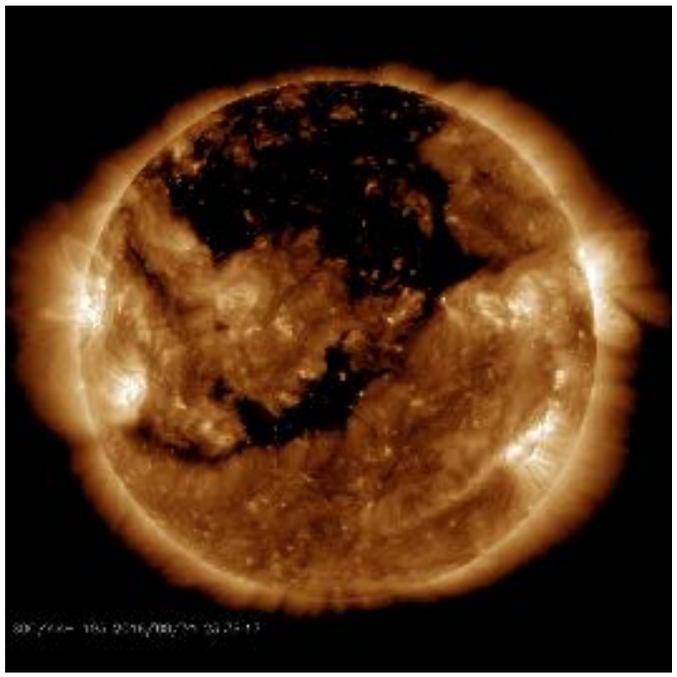

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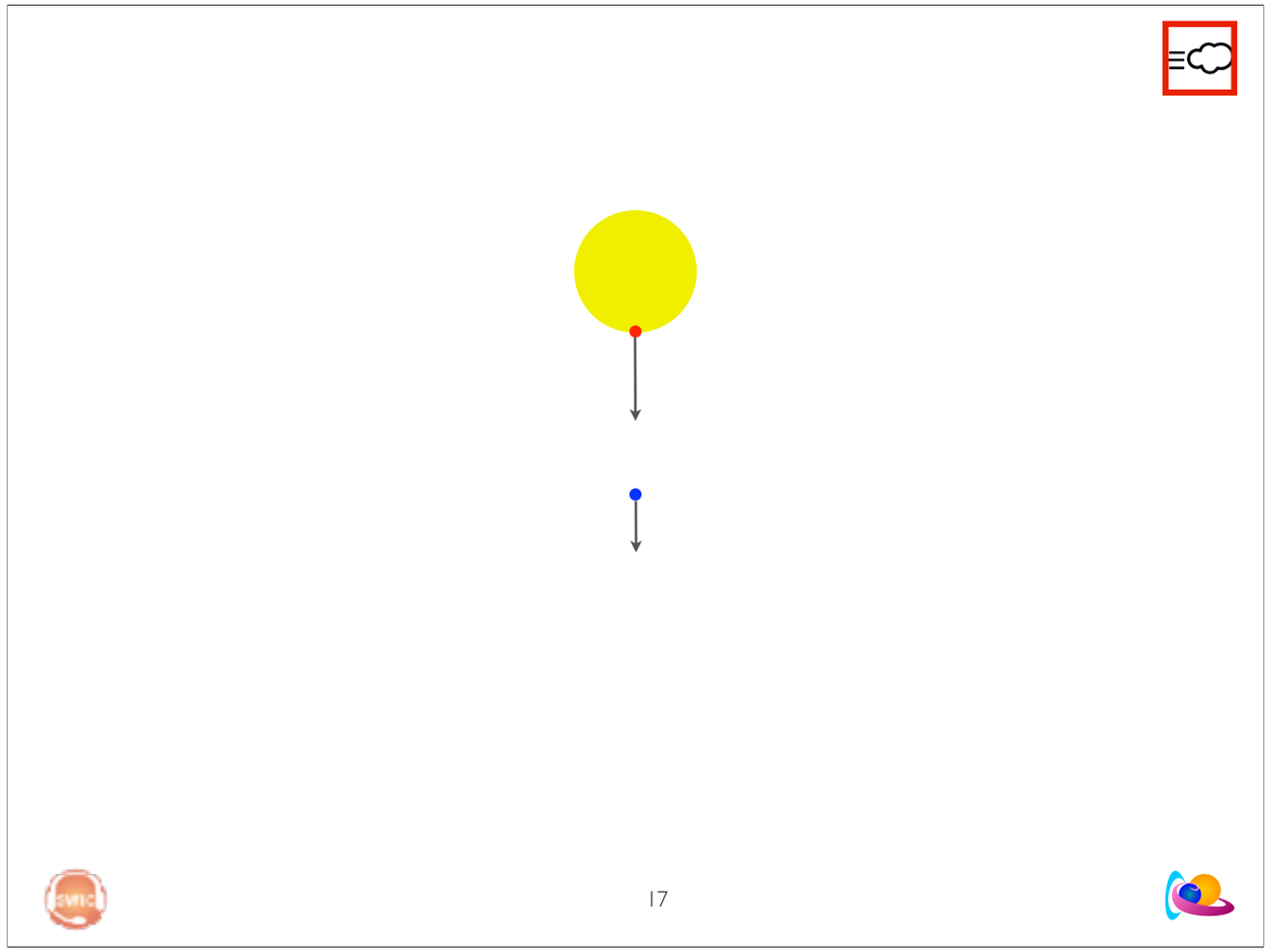
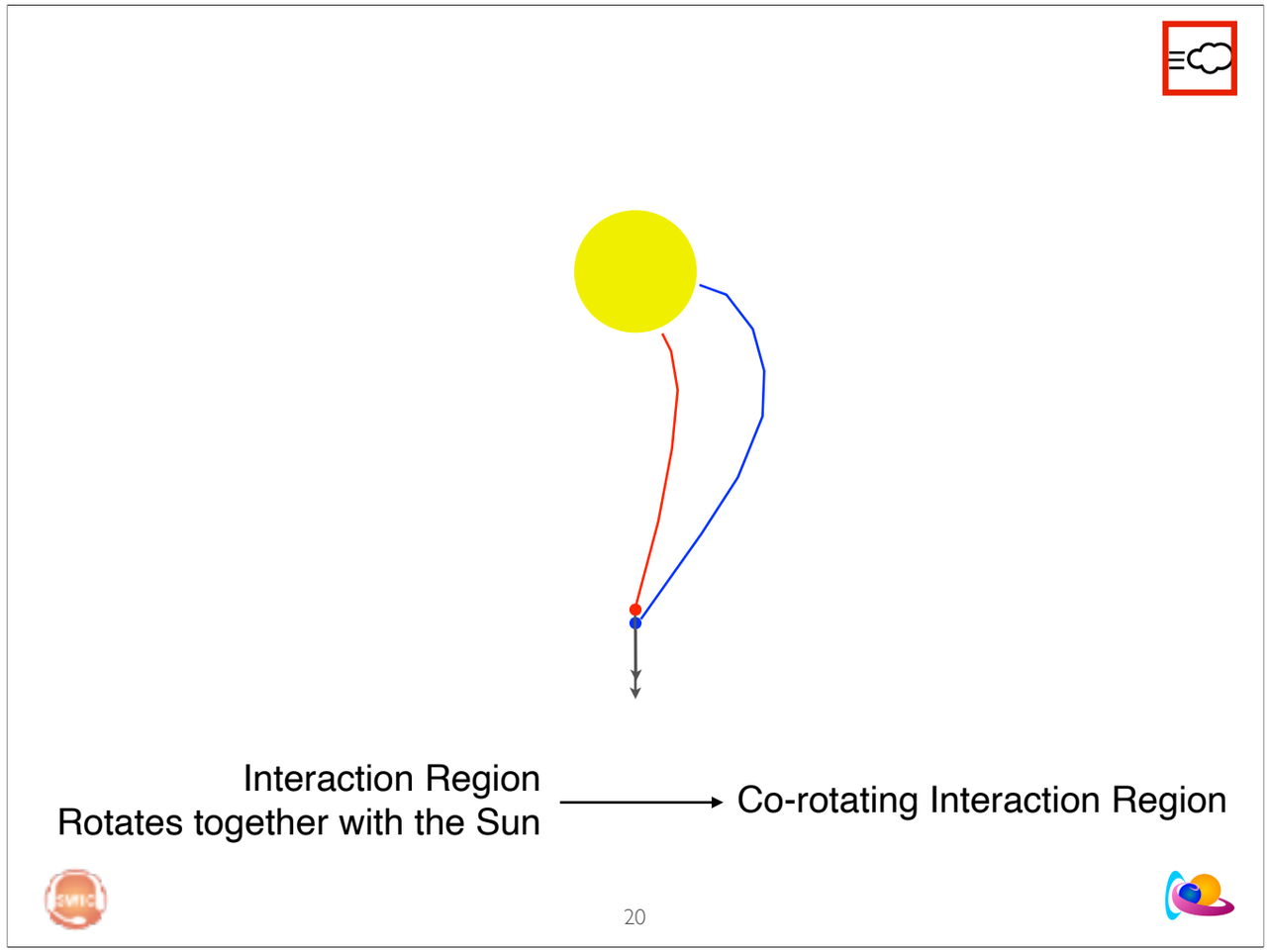
WHAT HAPPENS WHEN FAST CATCHES SLOW?

Top View

What happens when fast catches slow solar wind material?



The Sun has turned such that another part of the solar disk is now at the point where previously the blue dot left.
Now, the red can chase the blue.



Continuous process - the source of the fast particles, i.e. stays present.

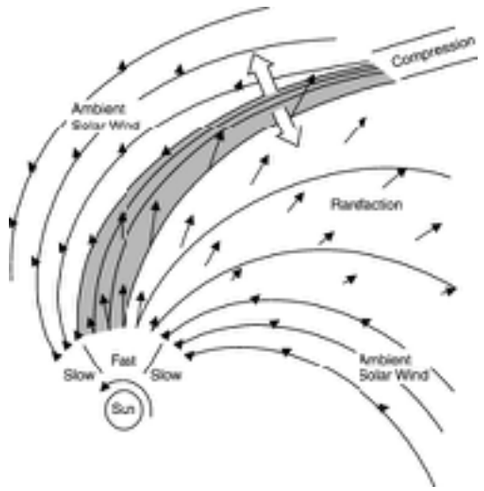
When fast solar-wind streams, emanating from coronal holes, interact with slow streams, they can produce Co-rotating Interaction Regions in interplanetary space. The magnetic fields of the slow streams in the solar wind are more curved due to the lower speeds, and the fields of the fast streams are more radial because of their higher speeds. Intense magnetic fields can be produced at the interface (IF) between the fast and slow streams in the solar wind. The Co-rotating Interaction Regions are bounded by a forward shock (FS) and a reverse shock (RS).

One reason why two shocks are eventually formed at a CIR is due to symmetry about the pressure enhancement caused by compression and entraining of the slow wind ahead of the fast stream (Figure 10.9 [Gosling, 1996]): shocks are driven away from the pressure increase in both directions, resulting in a so-called \Forward-Reverse shock pair" in which the forward shock propagates away from the Sun while the reverse shock propagates towards the Sun but is carried out with the solar wind flow.

http://www.boulder.swri.edu/~deforest/Movies.html

CORONAL HOLE

- Co-rotating structure
- Radial!



als zon niet ronddraait, haalt de snelle zonnewind de trage niet in want die zit er niet achter.

doordat de zon roteert, creëer je dit profiel.

Cartoon showing the interaction of a fast and a slow stream. The fast stream runs into the slow wind, forming a compression region between the two, which results eventually in the formation of a forward-reverse shock pair.

continue toevoer, oorzaak blijft aanwezig

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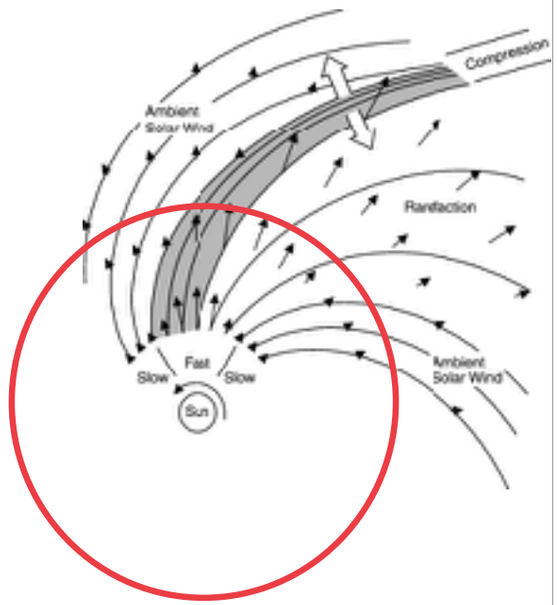
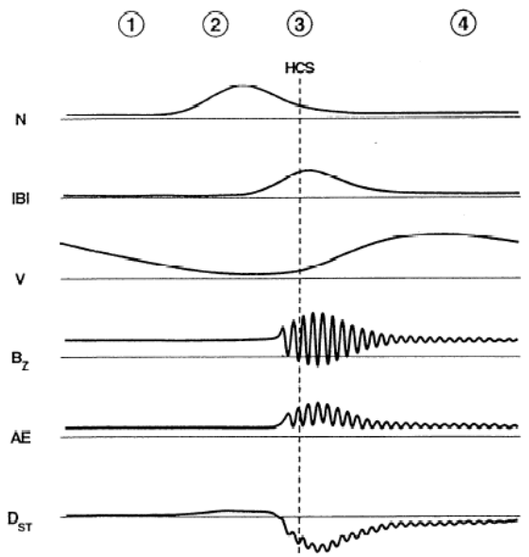


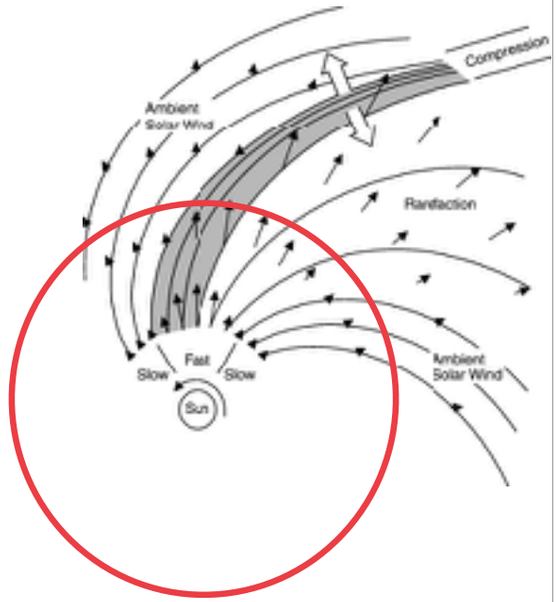
Earth

At a point in space: the total flux of mass is the same
—> v high, density low
—> v low, density high

When your plasma is more dense, the closer the magnetic field lines.

Coronal Hole



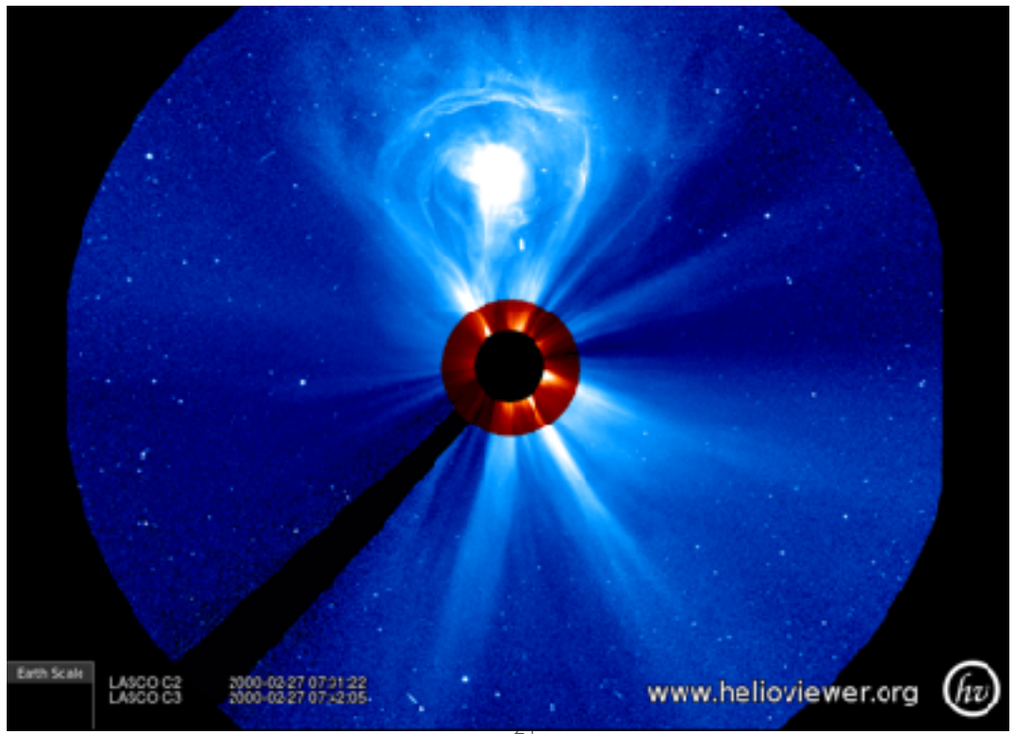


X-axis= where you are on the red circle, Arc length, time
At a point in space, e.g. : the total flux of mass is the same
—> v high, density low
—> v low, density high

When your plasma is more dense, the closer the magnetic field lines.

High temperature

CORONAL MASS EJECTION



Transient: only lasting for a short time

Low density, but enormous and therefore massive.

CME is large: compare its size with the size of the sun.

Temperature of CH and CME

SOLAR WIND IN L1

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

ACE
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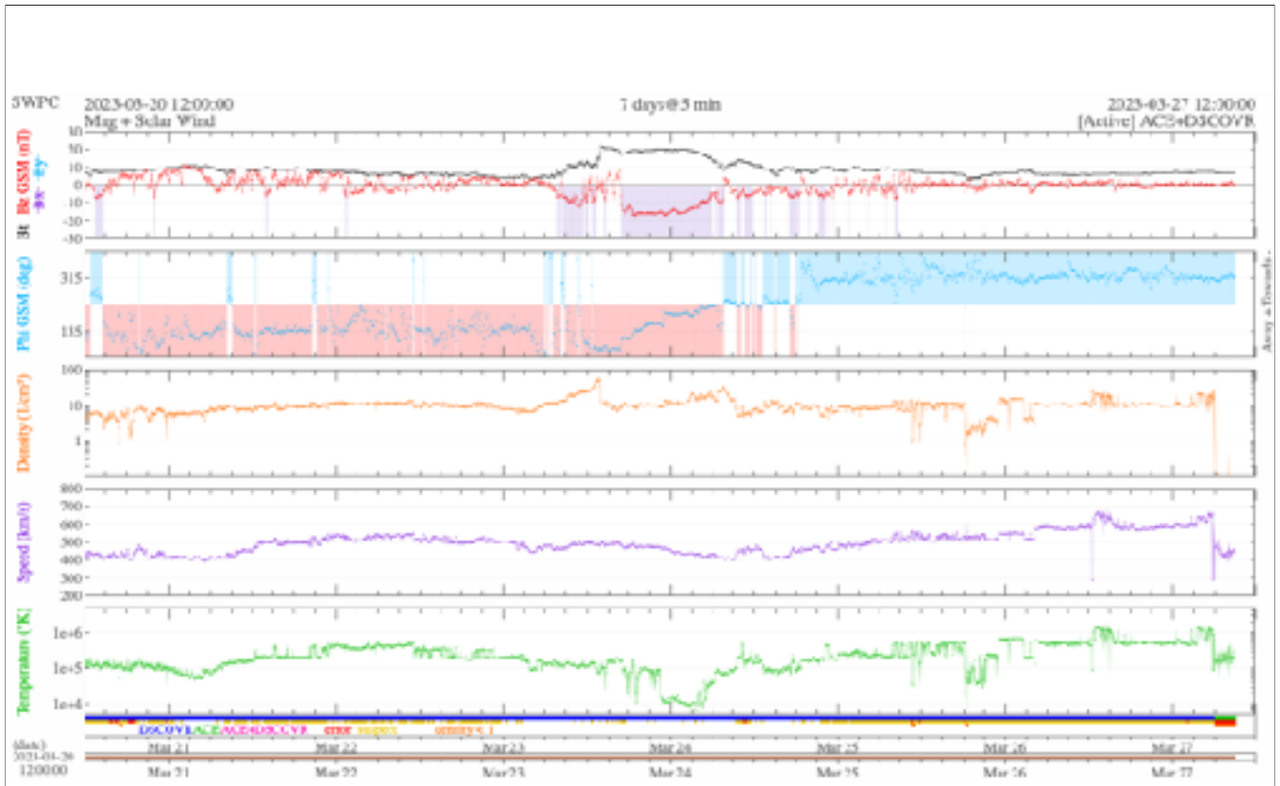
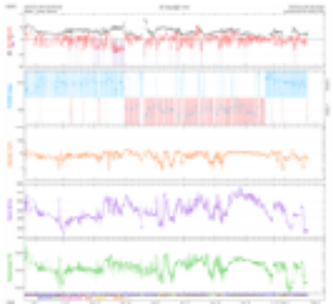
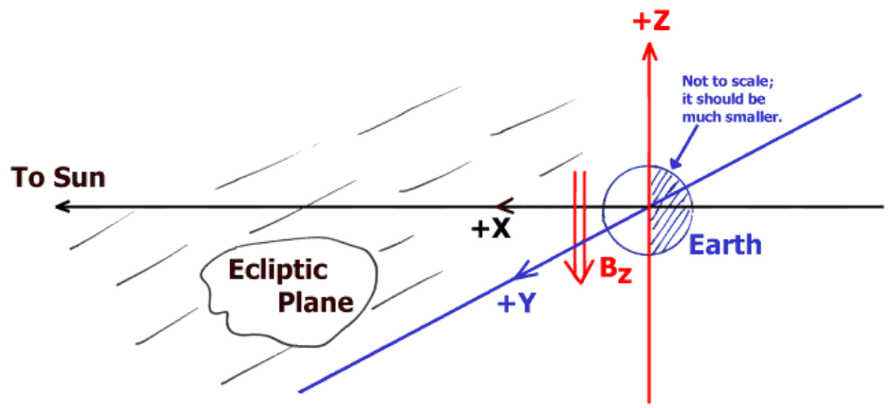


what is shown in the solar wind graphs?



COORDINATE SYSTEM



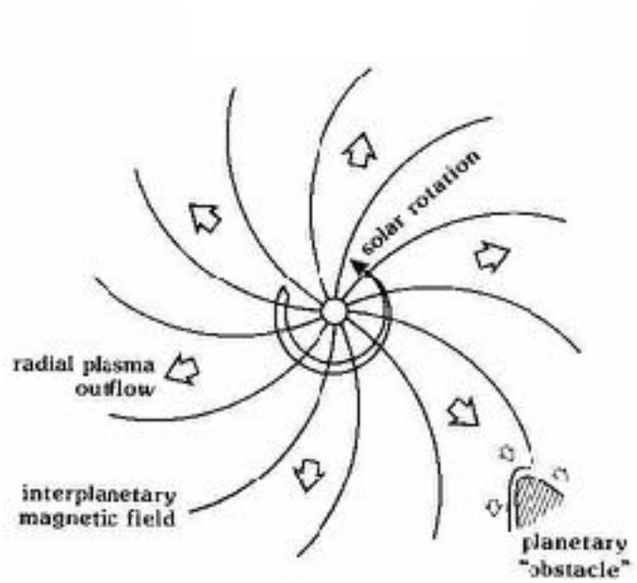
+Z is perpendicular to the Ecliptic Plane.

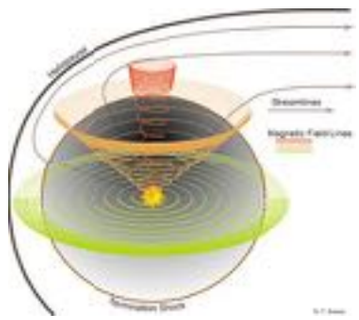
GSM: Geocentric Solar Magnetospheric System. This has its X-axis pointing from the Earth toward the Sun and its Y-axis is chosen to be in the ecliptic plane pointing towards dusk (thus opposing planetary motion). Its Z-axis is parallel to the ecliptic pole. Relative to an inertial system this system has a yearly rotation.

GSM: Geocentric Solar Magnetospheric coordinate system.
The x-axis of the GSM coordinate system is defined along the line connecting the center of the Sun to the center of the Earth. The origin is defined at the center of the Earth, and is positive towards the Sun. The y-axis is defined as the cross product of the GSM x-axis and the magnetic dipole axis; directed positive towards dusk. The z-axis is defined as the cross product of the x- and y-axes. The magnetic dipole axis lies within the xz plane.

PARKER SPIRAL

The magnetic field stays connected to the Sun. As the Sun rotates, the magnetic field gets bended. Nevertheless, the plasma goes radial.

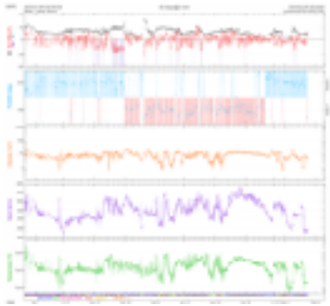




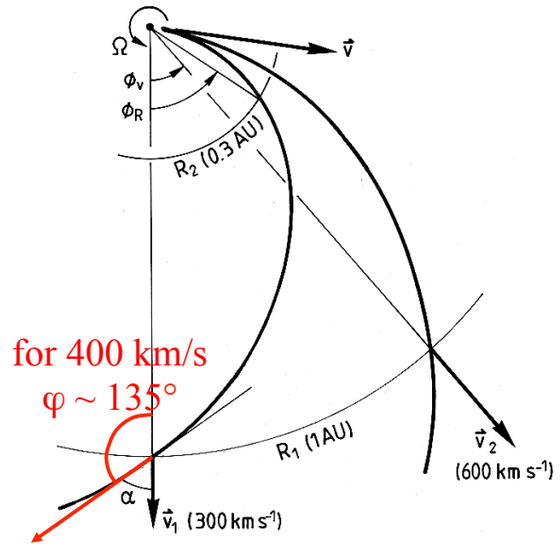
Left: This is a view of the global IMF in the solar equatorial plane.
Right: The IMF and our space is 3D. You have at a particular latitude also IMF lines coming out. Also these lines bend because of the solar rotation. All IMF lines at a particular latitude form a magnetic coin. The solar equatorial plane is a flat cone, a plane.

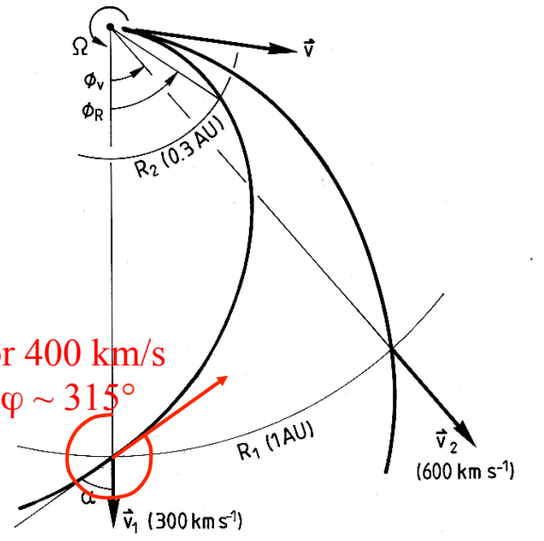
This is the ideal IMF.
left: It has no component perpendicular on the solar equatorial plane.
right: it has no component perpendicular to the surface of the magnetic cone.

The frozen-flux theorem: IMF and plasma are glued.
The food points of the magnetic field lines are attached to the sun. At the same time, the plasma of the solar wind on the further distance is glued to that same magnetic field line. When the sun rotates, the IMF is forced to bend.



IMF POLARITY

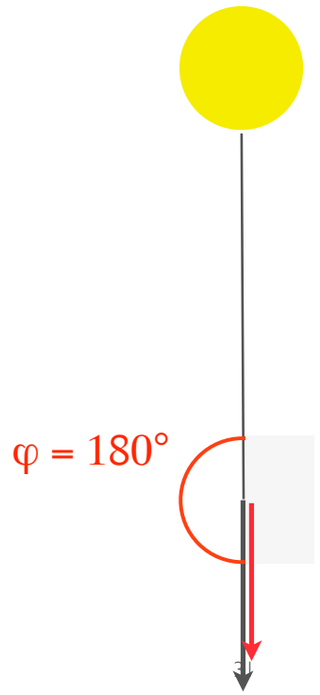




This is the IMF

Phi is a value between
90° and 180°
270° and 360°

EXTREME FAST



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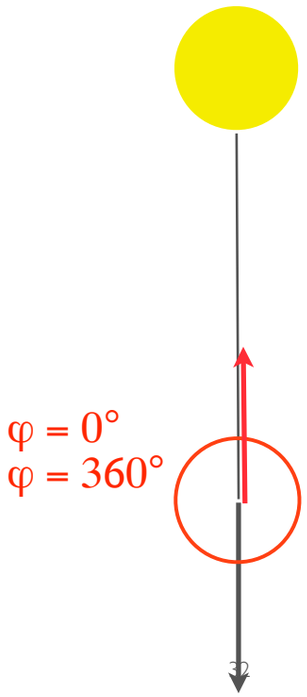
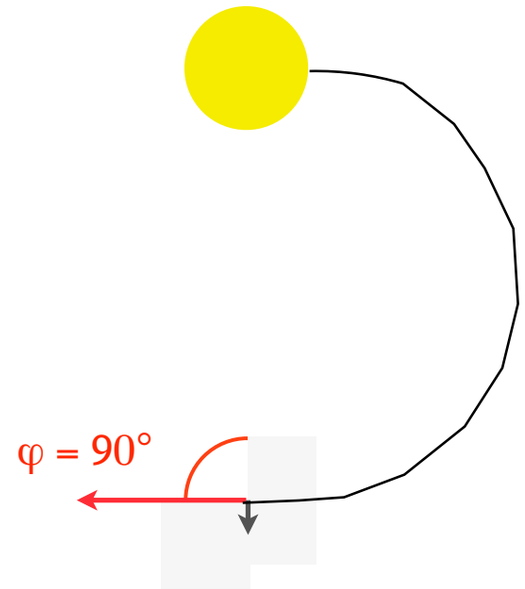


EXTREME SLOW



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