WANNEER DE ZON ZICH OPWINDT

Petra Vanlommel

Solar-Terrestrial Centre of Excellence

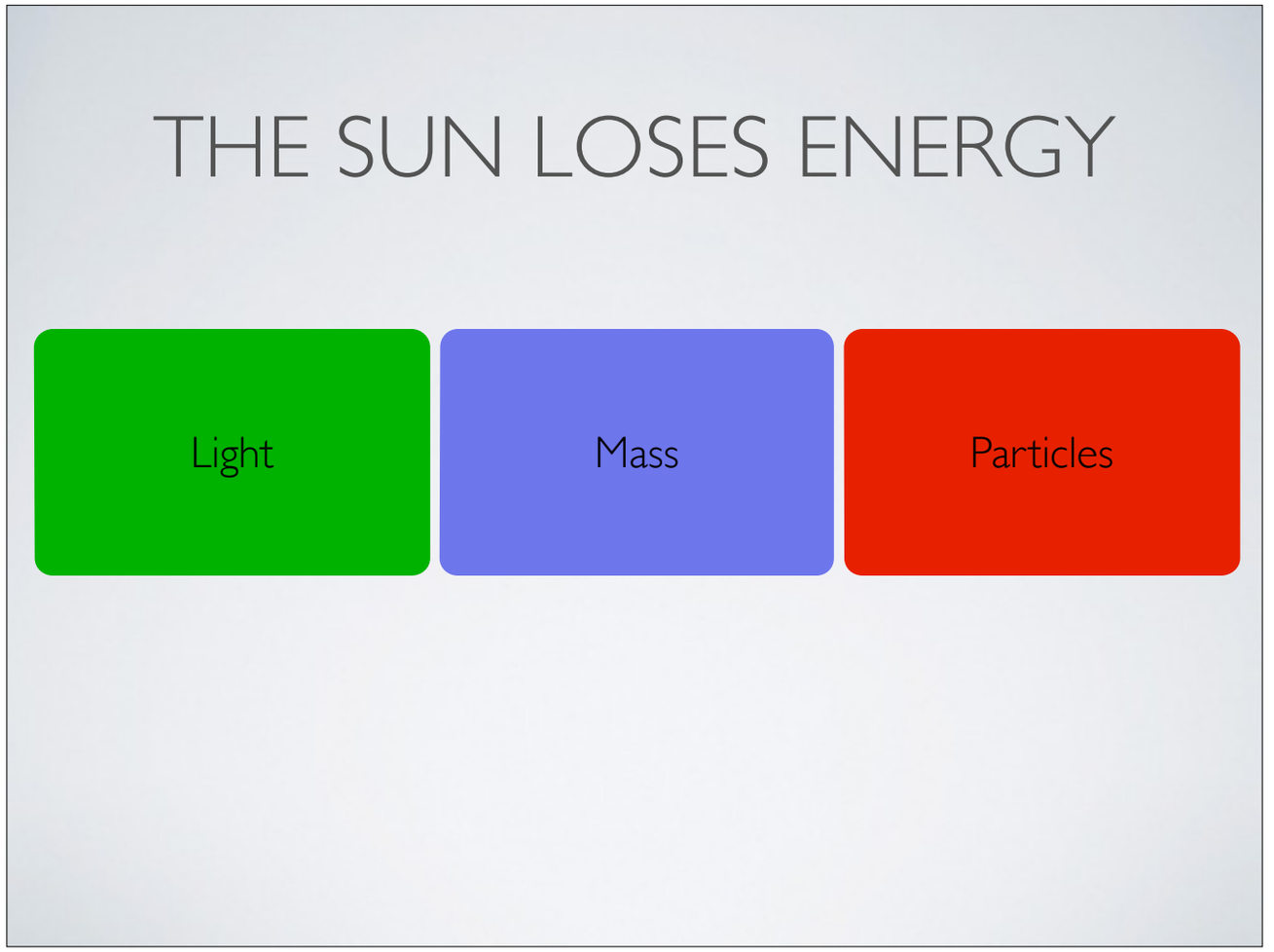


i will drop the word forecast on a regular basis to be conform the title in the program



The sun is the source of 'normal' terrestrial weather. It is also the primary (but not the only) source of space weather. Most aspects of space weather affect us to some extent. The more our society becomes dependent on technology and the more we utilize space, the more we are affected by space weather. Some aspects of space weather are benevolent, and allow activities not otherwise possible such as long range radio communications. Some aspects are benign but fascinating such as the Aurora, and some are malevolent. Like terrestrial weather, it depends on the situation and the event.

It’s the magnetic field that makes the Sun dynamical and forms the seat of space weather.



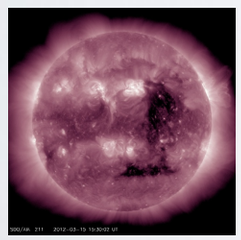
We are all familiar with terrestrial tropospheric weather. It is what we experience all around us; our atmospheric environment. It may be fine, cloudy, stormy or sunny. It may rain or hail. We know about temperature and pressure and humidity. This is all about weather in the lowest 10 km of our atmosphere.

As we go out into space, the atmosphere becomes very thin, until by the time we are in space, it has almost vanished. Almost, but not quite. Even in space there are some atoms which are often moving very quickly. Many forms of energy also move through space and it is the interaction of energy and atoms that produces what we refer to as space weather. In particular, space weather is the changes that occur in the space environment.

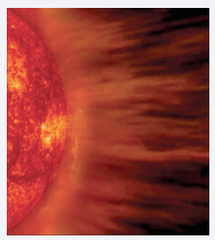
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THE SUN LOSES ENERGY
PHYSICAL REPHRASING

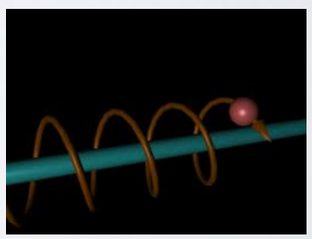
Total Solar Irradiance



Solar Wind



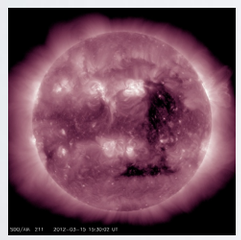
Fast Particles

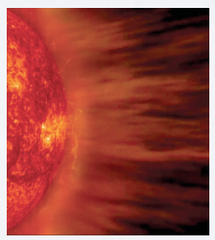


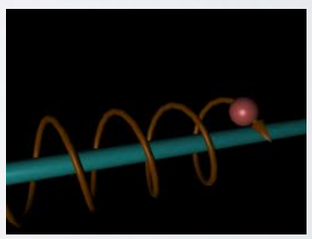
Opgeslagen magnetische energie wordt omgezet in kinetische energie waarbij grote hoeveelheden plasma vanuit alle plaatsen op de zonnebol aan een snelheid om en rond de 400km/s recht de ruimte ingeblazen wordt. De ruimte waar de zonnewind voelbaar aanwezig is definiëren we als de heliosfeer.
Daarnaast hebben we nog een vorm van energie die je niet beschrijft zoals de relatief traag bewegende massa of als een lichtgolf die zich met de lichtsnelheid voortplant, maar als elektrisch geladen individuen of deeltjes die in een schroefbeweging langs magnetische veldlijnen cirkelen.
De globale karakteristieken van deze 3 energievormen beschrijven het ruimteklimaat. Dit is de gemiddelde toestand van de ruimte in de heliosfeer bepaald door de zonnewind, zonnestraling en energetische zonnedeeltjes.

TIJD NODIG OM 1 AU TE OVERBRUGGEN

Minuten	Dagen	Uren





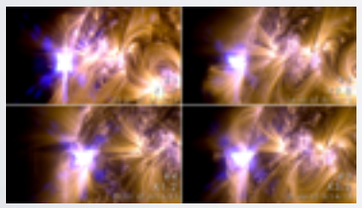


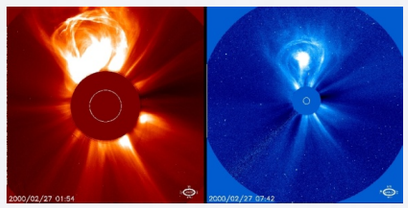
SPACE WEATHER

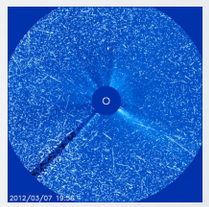
Zonnevlammen

Plasma wolken
Snelle zonnewind

Proton storm







De zonneactiviteit is het geheel aan fenomenen waarbij energie op een impulsieve manier wordt vrijgegeven in de zonneatmosfeer, en die gegenereerd wordt door de evolutie en brutale transformatie van magneetvelden die doorheen het zonneoppervlak lopen.

Ze veroorzaakt impulsieve variaties in de zonne-emissies:
- Intense stralingsuitbarstingen over het gehele electromagnetische spectrum, in het bijzonder in het UV, X- en gamma-stralen, en radio-stralen (met golflengten van centimeters tot decameter).
- coronale massa-uitstoten (CME's
- Productie van deeltjesjets over een breed energiegamma (tot aan het relativistisch regime)

De meest intense zonneactiviteit wordt gelinkt aan actieve gebieden, met een hoge concentratie magneetvelden die zonnevlammen genereren.

De toestand op een bepaald moment is ruimteweer. Het gebeurt regelmatig dat de zon een oprisping heeft ten gevolge van een plotse magnetische instabiliteit en een extra pakket licht, massa en/of deeltjes uitspuwt. Dit komt bovenop de gewone achtergrondstraling, zonnewind of deeltjesstroom en zijn eruptieve ruimteweerfenomenen. We hebben ook niet eruptieve fenomenen die eveneens het weer in de ruimte bepalen. Een coronaal gat is een voorbeeld een niet eruptief fenomeen. Dit is een locale magnetische coronale structuur die lange tijd aanwezig kan zijn en de zonnewind beïnvloedt.

variaties: gradueel of plots

flares: if you don't see them, they don't hurt you

The "solar wind" from the Sun streams past the Earth and is mostly deflected by the Earth's magnetic field. But variations in the solar wind cause changes in the Earth's magnetic field.

Sometimes these changes are gradual increases in density or velocity. Sometimes they are huge clouds of atoms preceded by a shockwave (a little like an oceanic tsunami). The Aurora results from the passage of the solar wind past the Earth.

Occasionally a huge release of magnetic energy, called a solar flare, occurs on the Sun. Flares can produce large quantities of x-rays which affect the Earth's atmosphere. They can also accelerate atomic particles (mostly protons) to very high speeds (a substantial fraction of the speed of light!). These high energy particles are dangerous to man and can reach the stratosphere where jetliners fly.

SPACE WEATHER

Space weather describes the conditions in space that affect Earth and its technological systems. Space weather storms originate from the Sun and occur in space near Earth or in the Earth's atmosphere. These storms generally occur due to eruptions on the Sun known as solar flares, proton storms and the solar wind.



SPACE WEATHER

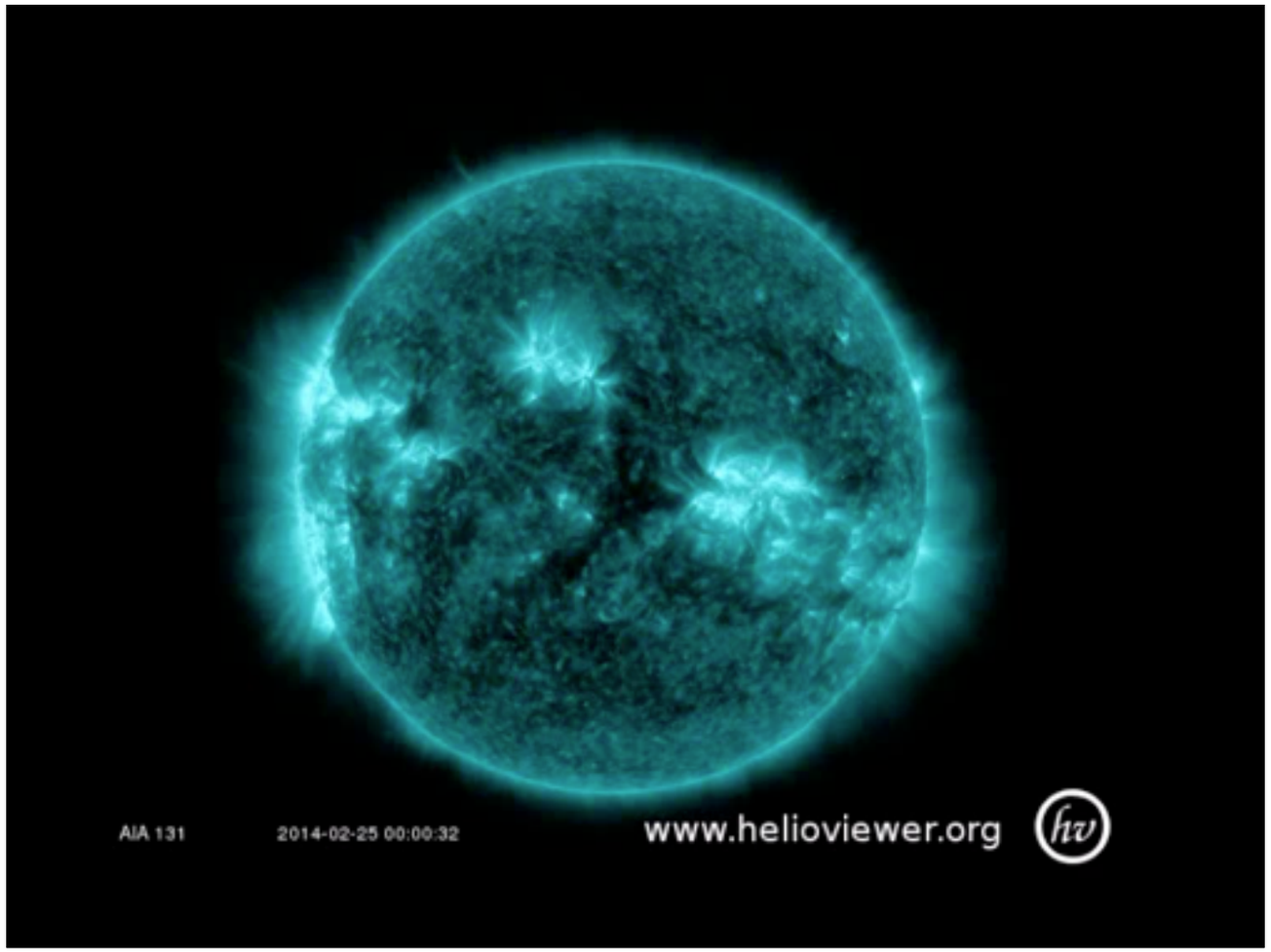
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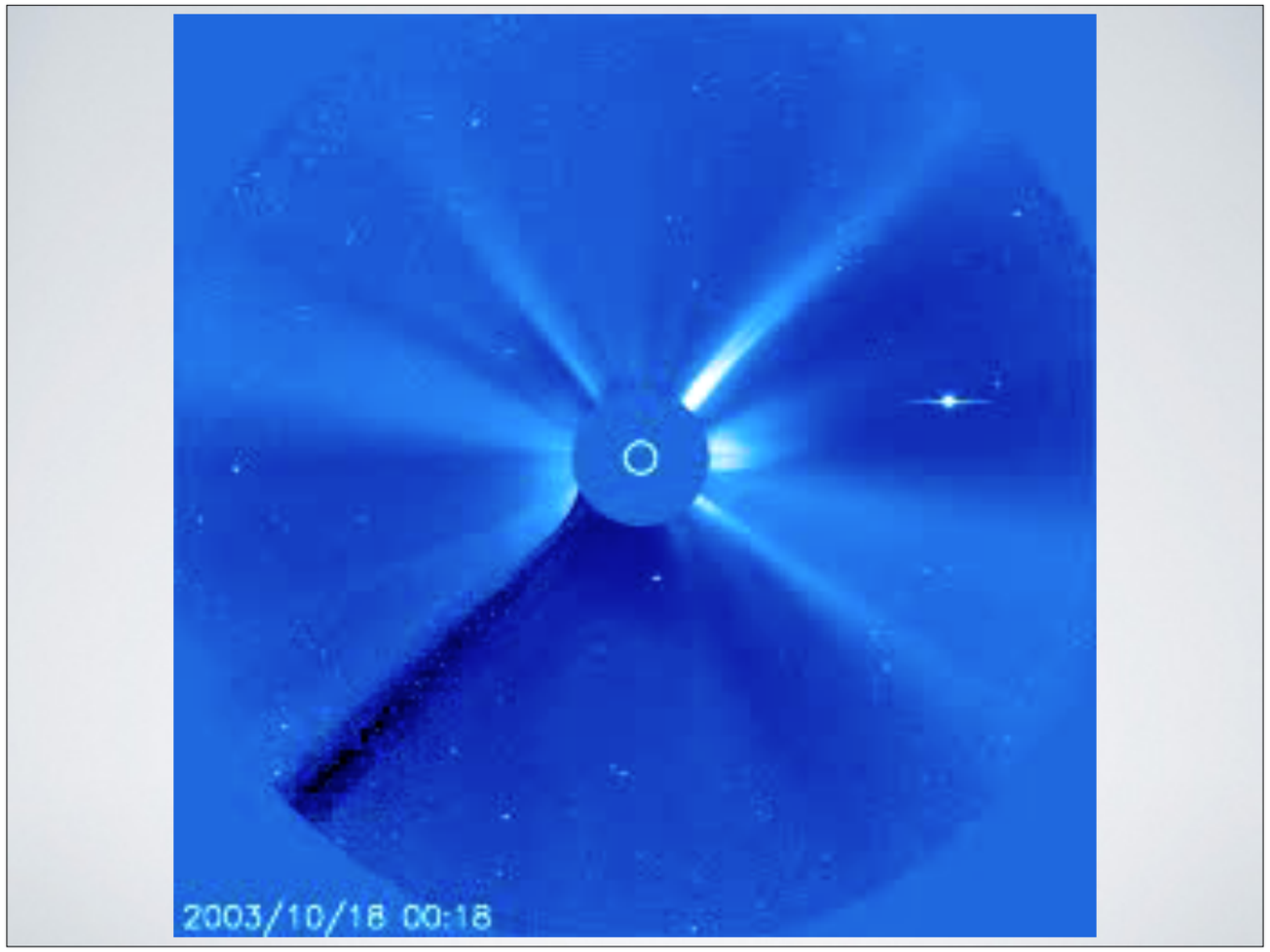


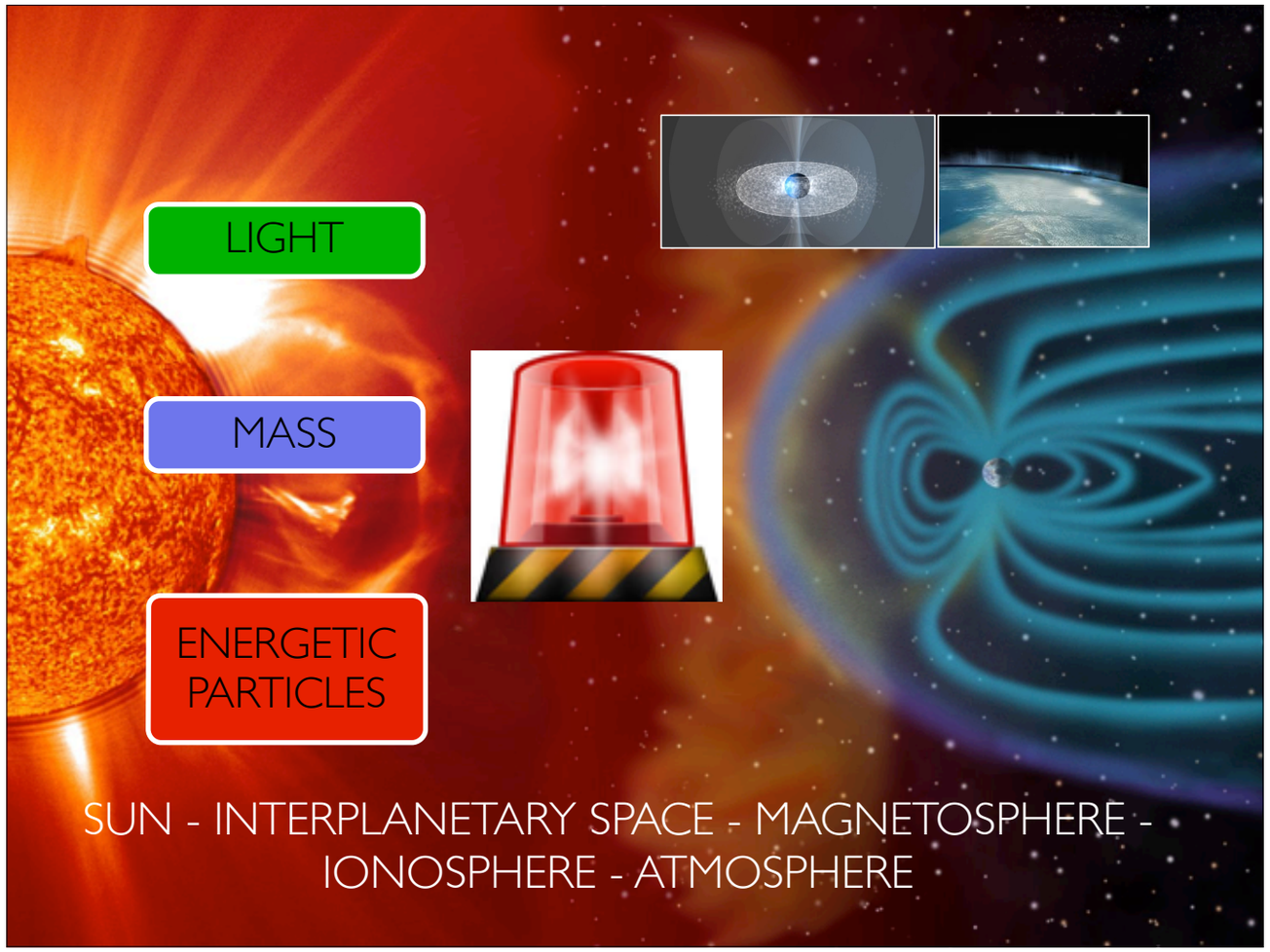


A strong X-class solar flare peaked at 00:49UT today. It reached X4.9 and originated in sunspot region NOAA 1990 near the southeast solar limb. This region is the return of old NOAA 1944 (1-14 January) and NOAA 1967 (27 January - 9 February) from earlier this year. These regions were the source of numerous medium to strong solar flares, and NOAA 1990 seems to continue this tradition. The X4.9 flare was the third strongest solar flare so far this solar cycle, after the X6.9 flare on 9 August 2011 (NOAA 1263) and X5.4 flare on 7 March 2012 (NOAA 1429).

These SDO-images show the flare in successively lower temperatures and closer to the solar surface: From the multi-million degrees corona to the relatively cool (about 6000 degrees) photosphere. The "hot" images provide a better view of the flare (AIA 131) and the post-flare coronal loops (AIA 171; 600.000 degrees), whereas the "cooler" images (AIA 304; 80.000 degrees) give a better view on the ejected material. The intensity images also show the flare for a brief moment (2 white dots over the dark cores of the sunspot), suggesting this event was a rare white light flare (awaiting reports from ground-based observations).

The core filament of the associated coronal mass ejection (CME) is directed away from the Earth. In view of the proximity to the limb, no geomagnetic effects from this fast and impressive CME are expected (pending the availability of further images). The flare was also associated to a proton enhancement (fast energetic particles). However, in view of the slow rise of the proton flux, it is expected that the event threshold will not be reached.

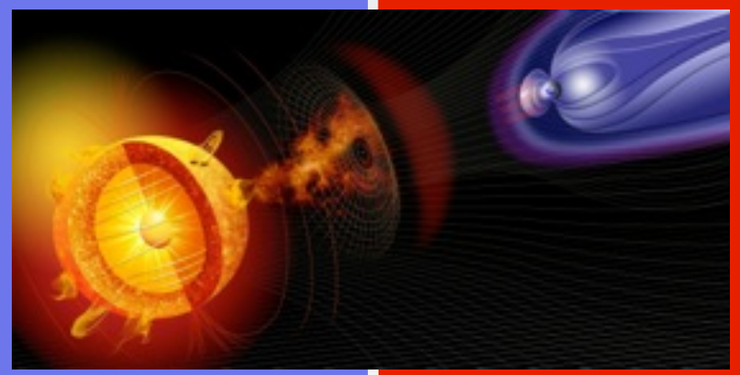

2003/10/18 00:18


LIGHT
MASS
ENERGETIC PARTICLES
SUN - INTERPLANETARY SPACE - MAGNETOSPHERE - IONOSPHERE - ATMOSPHERE

REDDINGSBOEIEN

Het aardmagnetisch schild beschermt ons tegen de zonnewind en ruimtewolken.
De aardatmosfeer beschermt ons tegen straling en lichtstormen

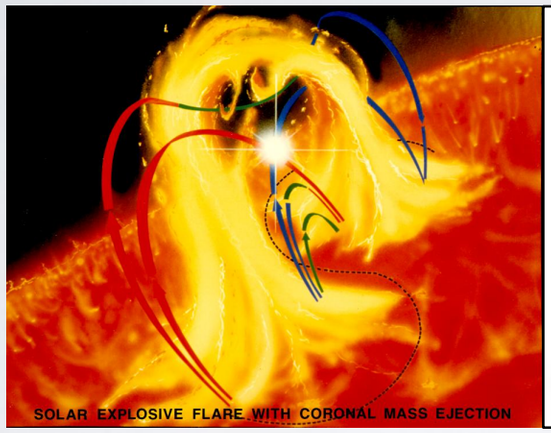




De magnetosfeer en de atmosfeer beschermen het leven op aarde tegen de schadelijke invloed van de Zon (zonneklimaat en zonneweer): de aardatmosfeer wordt niet weggeblazen dankzij de magnetosfeer, hoogenergetische deeltjes worden gereflecteerd, X-straling wordt tegengehouden door de atmosfeer. Het biologisch leven wordt beschermd.

Maar tegelijkertijd zorgen verstoringen in de magnetosfeer en de atmosfeer/ionosfeer veroorzaakt door het ruimteweer voor de nodige technologische problemen.

ONS ANTWOORD





science - forecast - engineering

One solution is to rebuild the ageing power grid to be less vulnerable to solar disruptions.
Another is better forecasting. Scientists using the new Solar Dynamics Observatory spacecraft are hoping to get a better understanding of how the sun behaves as it moves deeper into its next maximum and begins generating bigger storms. (See some of SDO's first sun pictures.)
These studies may help scientists predict when and where solar flares might appear and whether a given storm is pointed at Earth.
"Improved predictions will provide more accurate forecasts, so [officials] can take mitigating actions," said Rodney Viereck, a physicist at the Space Weather Prediction Center.
Even now, the center's Bogdan said, the most damaging emissions from big storms travel slowly enough to be detected by sun-watching satellites well before the particles strike Earth. "That gives us [about] 20 hours to determine what actions we need to take," Viereck said.
In a pinch, power companies could protect valuable transformers by taking them offline before the storm strikes. That would produce local blackouts, but they wouldn't last for long.
"The good news is that these storms tend to pass after a couple of hours," Bogdan added.
Meanwhile, scientists are scrambling to learn everything they can about the sun in an effort to produce even longer-range forecasts.
According to Vierick, space-weather predictions have some catching up to do: "We're back where weather forecasters were 50 years ago."

FORECAST

Flare probability

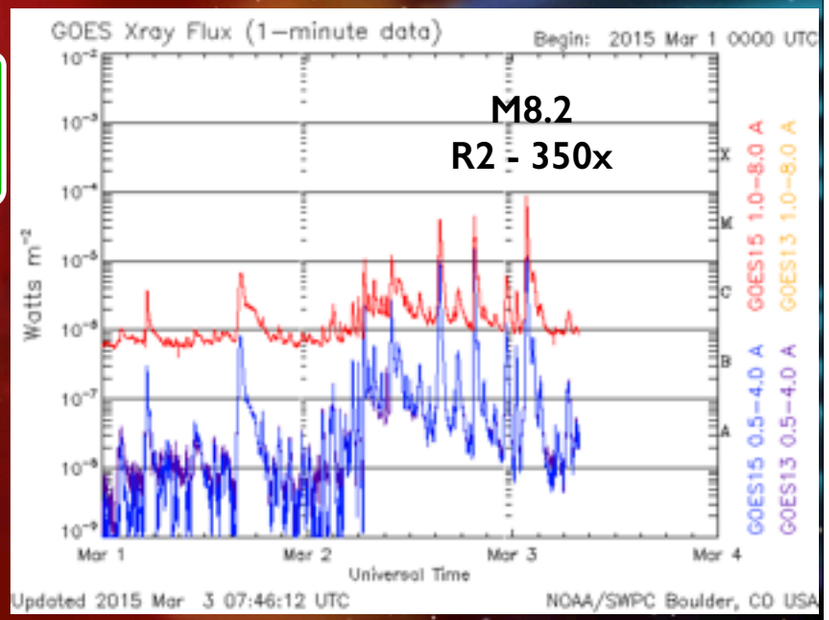
Perturbations of the Geomagnetic field

Probability

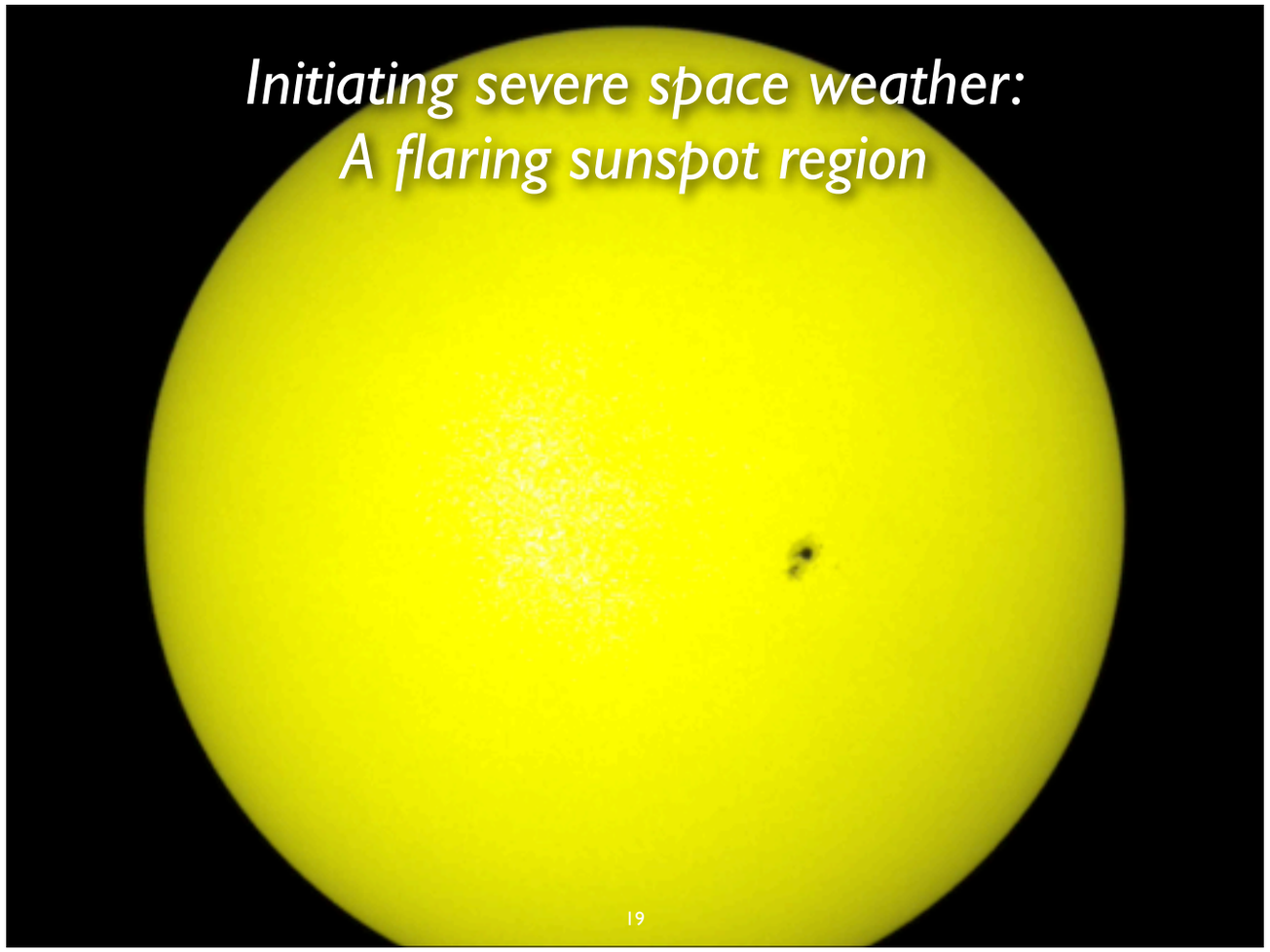

RUIMTEWEERSVOORSPELLING
Flare probability
10 cm flux
Geo-influence
Storm

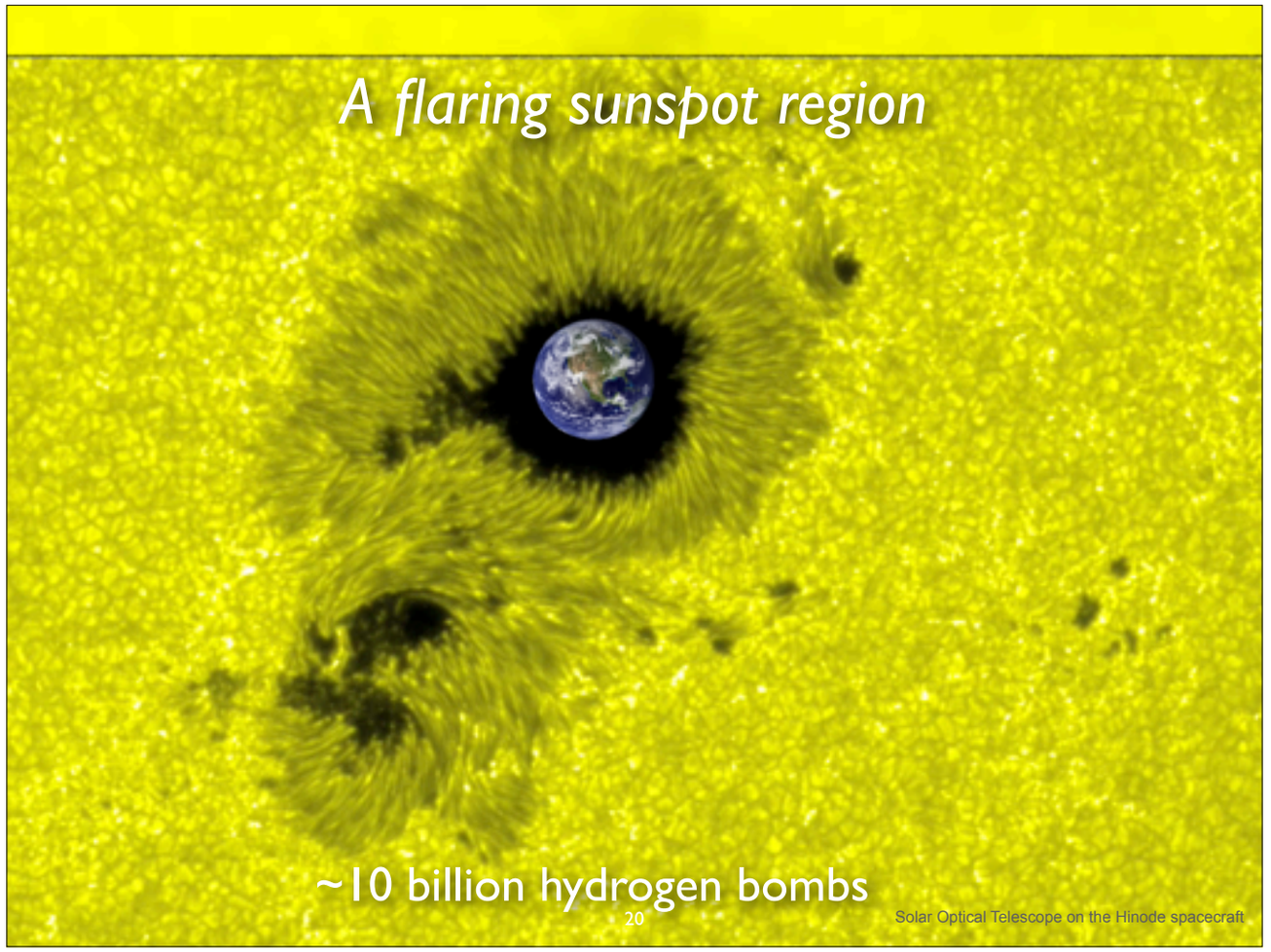
RUIMTEWEERSVOORSPELLING

Flare probability



M8.2
R2M - 350 per cyclus

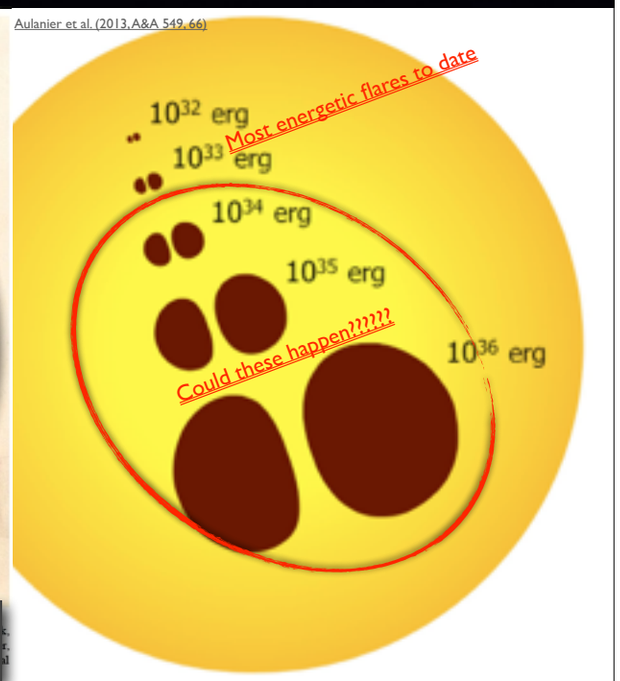

Initiating severe space weather:
A flaring sunspot region


A flaring sunspot region
~10 billion hydrogen bombs
Solar Optical Telescope on the Hinode spacecraft

It takes big sunspots to power superflares



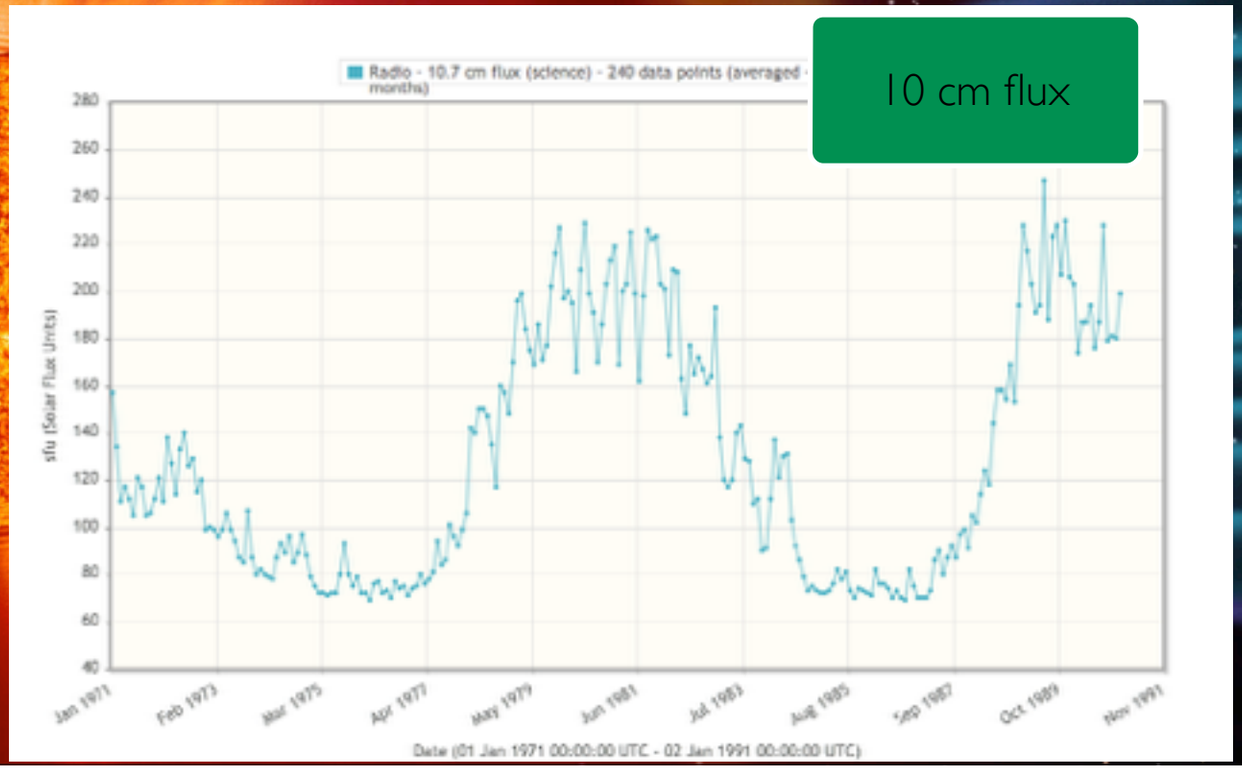
Are these really sunspots on 1128/12/08,
as drawn by John of Worcester?



ook kleinere gebeurtenissen kunnen een grote impact hebben.

John of Worcester (died circa 1140) was an English monk and chronicler.

RUIMTEWEERSVOORSPELLING

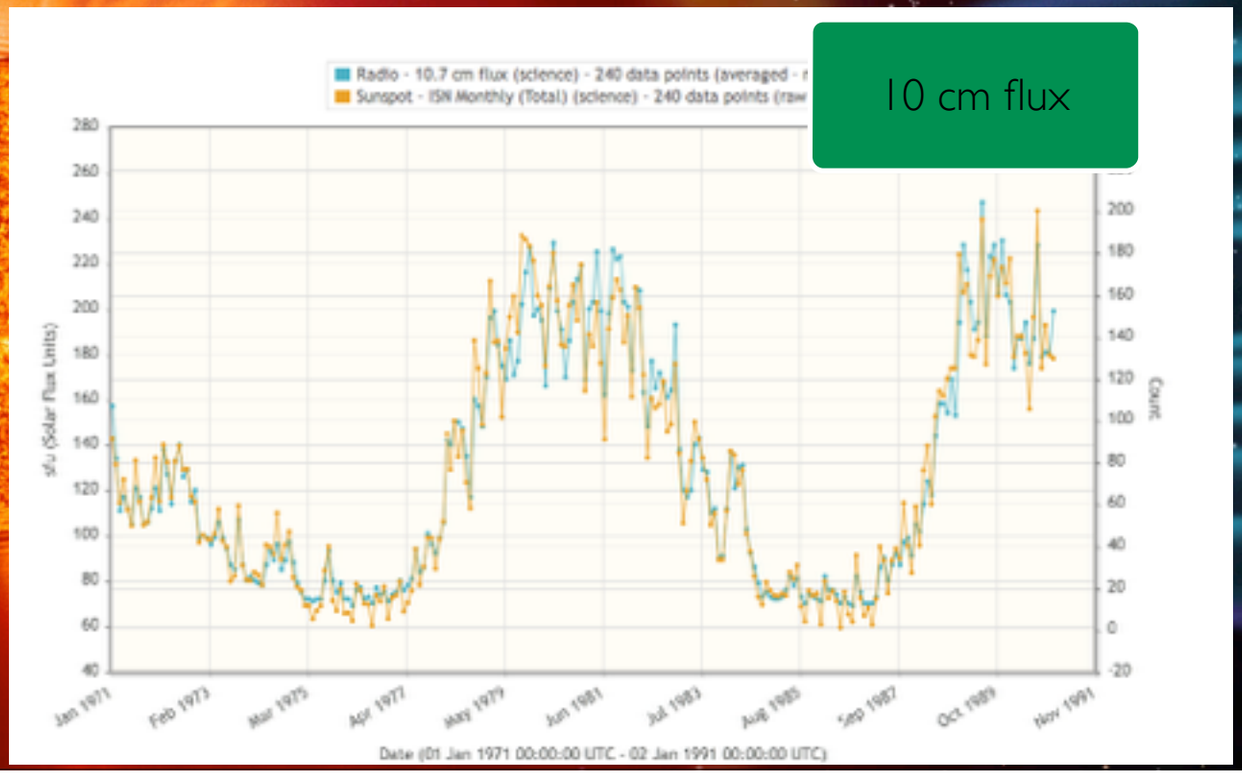


10 cm flux

The 10cm radio flux is a measure for the noise emitted by the Sun at a wavelength of 10.7 cm (frequency around 2800 MHz) and is measured on earth. The 10 cm flux is a full-disc measurement which means that all radiation with a wavelength of 10 cm from the whole visible solar surface is counted (integrated). This flux is a proxy for the solar activity. The curve has a recurrence effects

The sun emits radio energy with a slowly varying intensity. This radio flux, which originates from atmospheric layers high in the sun's chromosphere and low in its corona, changes gradually from day-to-day, in response to the number of spot groups on the disk. Radio intensity levels consist of emission from three sources: from the undisturbed solar surface, from developing active regions (slowly-varying or S-component), and from short-lived enhancements above the daily level (rapidly-varying component). Solar flux density at 2800 megaHertz has been recorded routinely by radio telescopes near Ottawa (February 14, 1947-May 31, 1991) and Penticton, British Columbia, since the first of June, 1991.
The quiet sun level is the flux density which would be observed in the absence of activity. Extrapolation to zero of plots of the 10.7cm flux against other activity indices such as plage area or total photospheric magnetic flux in active regions suggest a quiet sun flux density of about 64 s.f.u. This is rarely attained. Even at solar minimum there is usually some activity; the lowest observed fluxes are usually 65-67 s.f.u. The observed excess of the 10.7cm flux over the quiet sun level is known as the slowly-varying (S-) component.The third contribution (rapidly varying component) is removed (attempt).
Measurement=quiet sun+S-component

RUIMTEWEERSVOORSPELLING



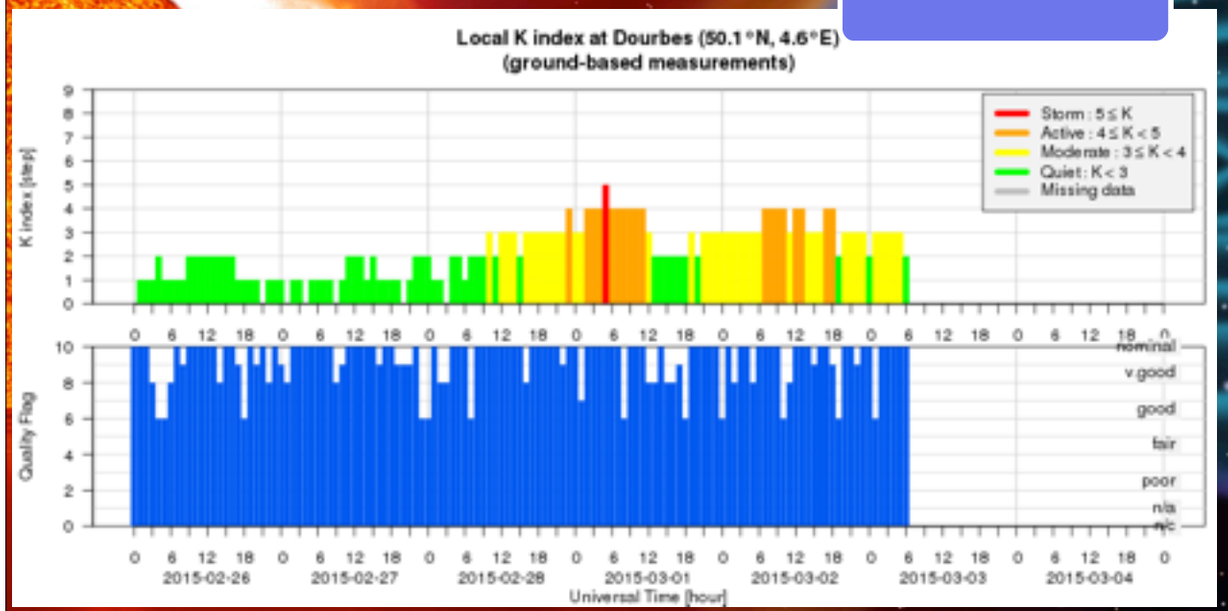
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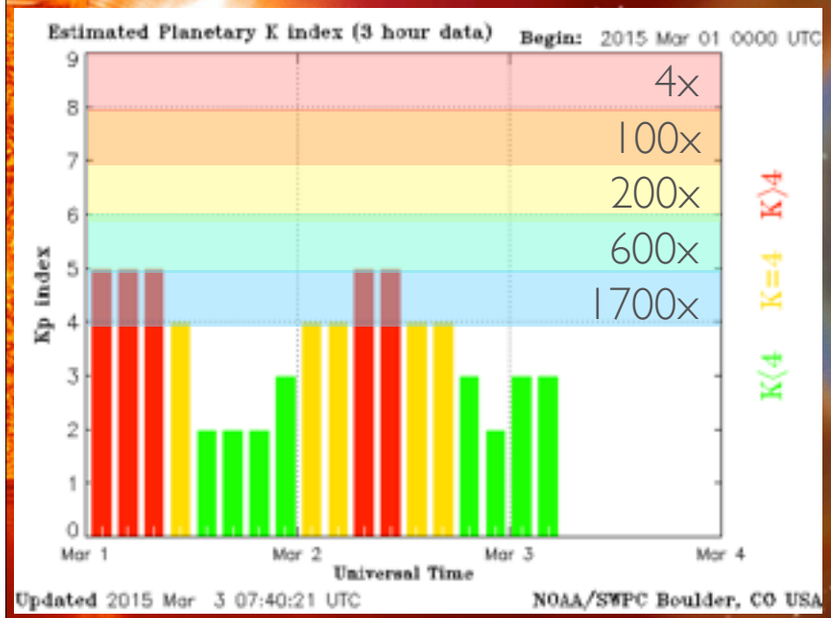
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RUIMTEWEERSVOORSPELLING

Geo-influence



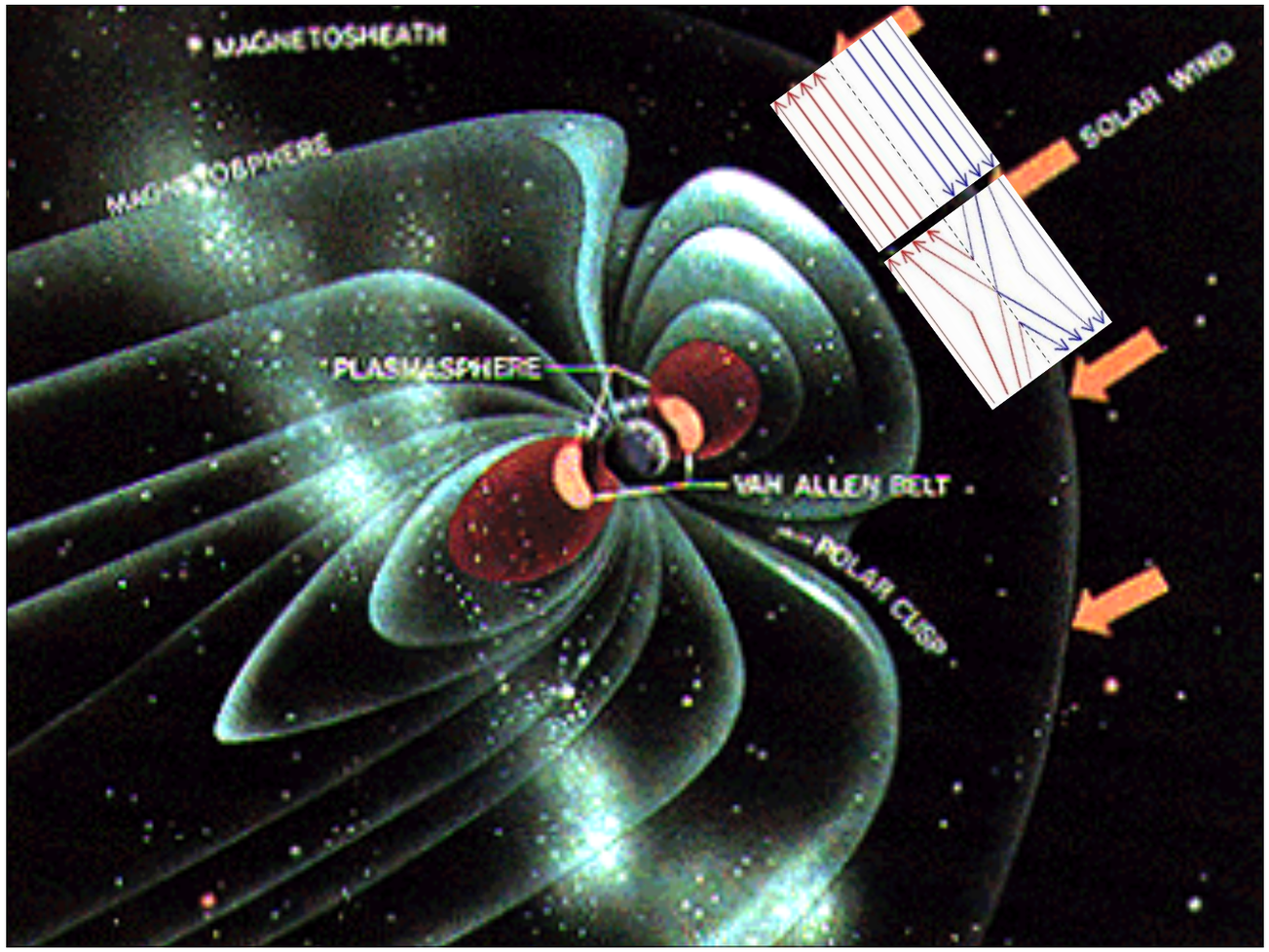
RUIMTEWEERSVOORSPELLING



10 cm flux

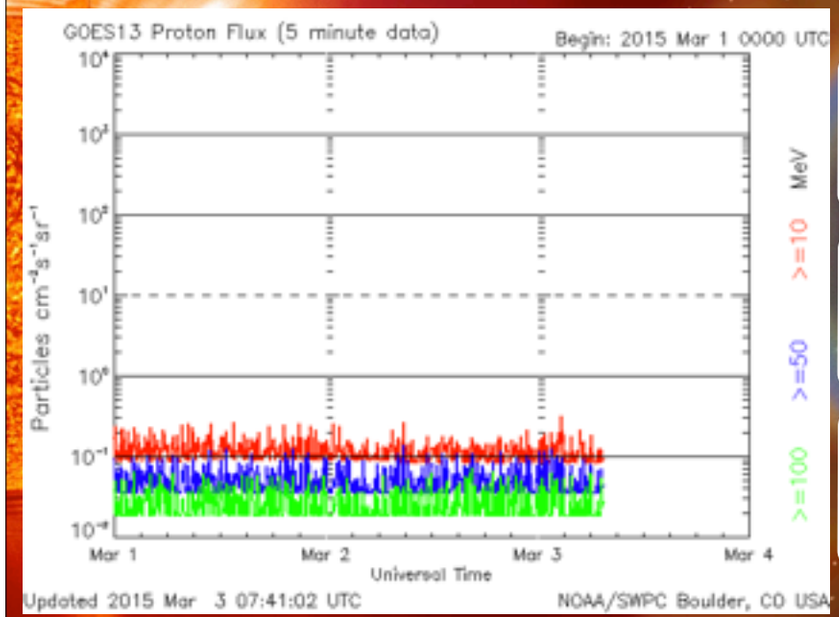
Geo-influence

Storm



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, 0° longitude
1 to 5 nT - IMF at L1

RUIMTEWEERSVOORSPELLING



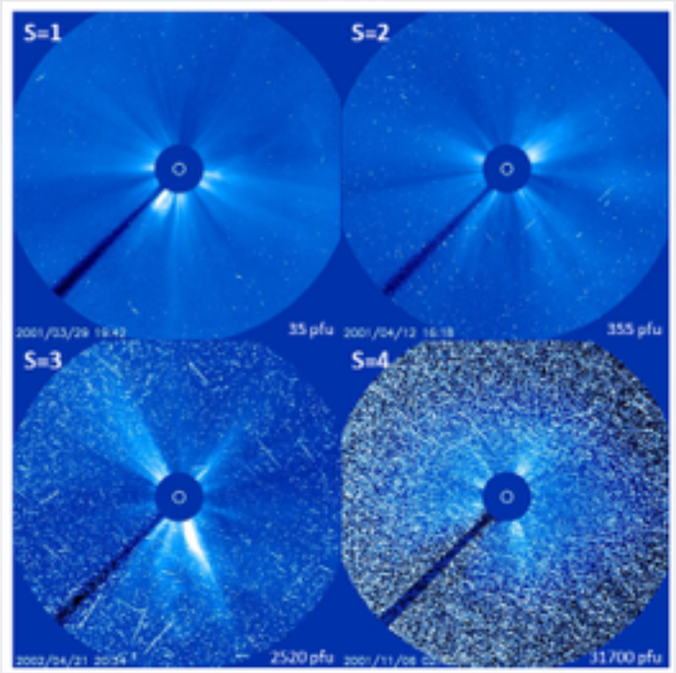
10 cm flux

Geo-influence

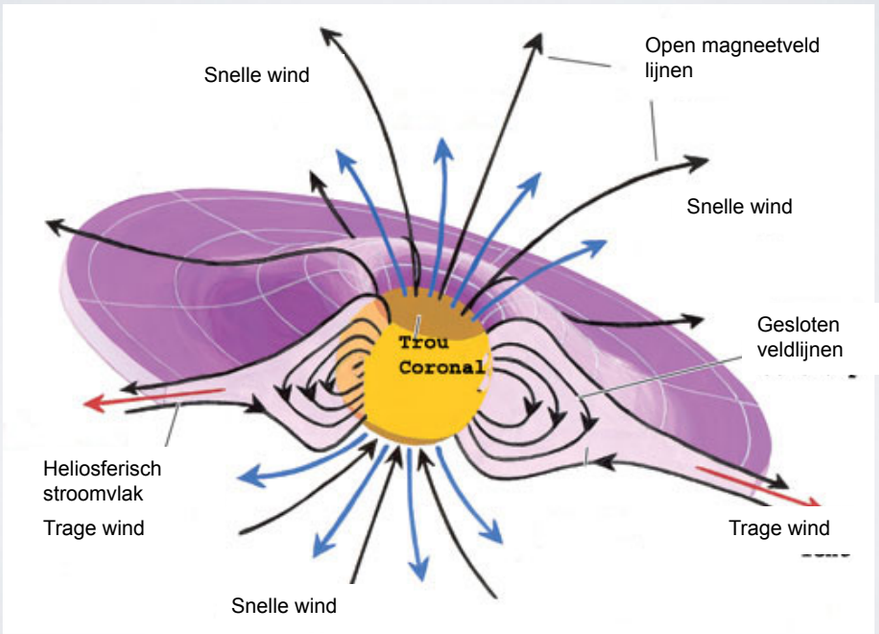
Storm

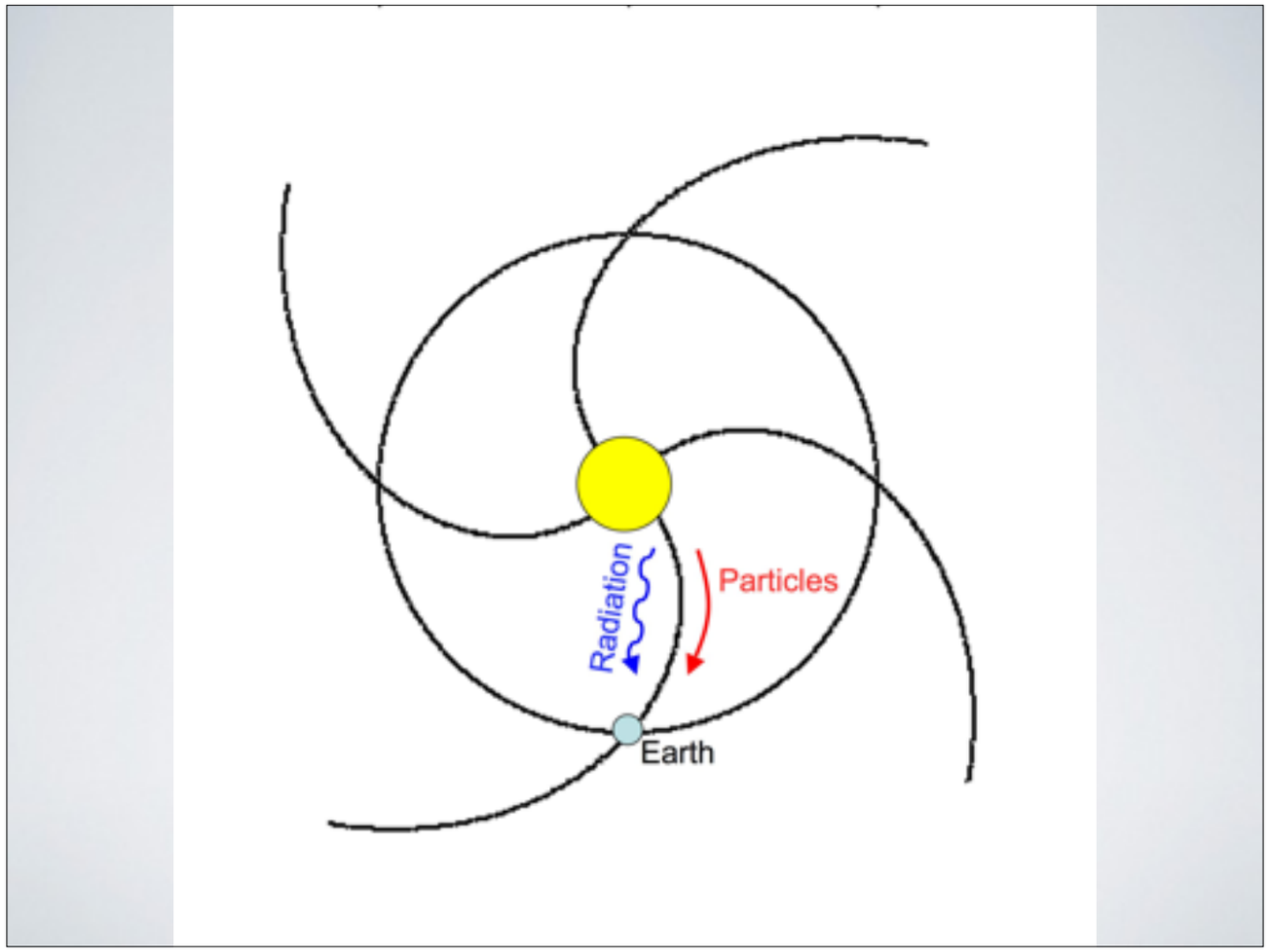
Er zijn er altijd die aankomen via de IMF.
door gebeurtenis op de zon worden ze versnelt en kunnen ze rapper aankomen.

LOGARITMISCH



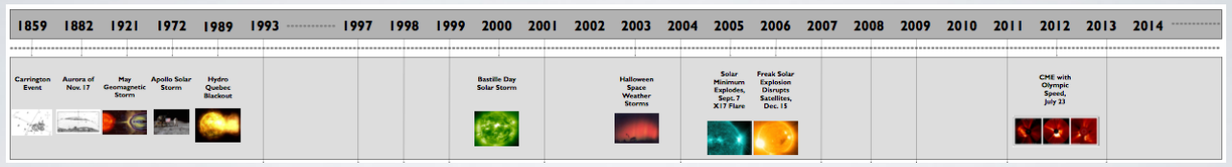
GIGANTISCHE DIPOOL

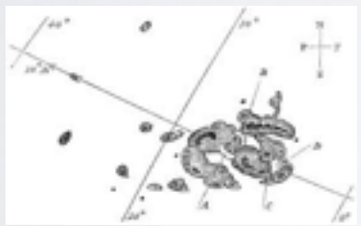




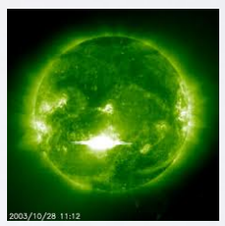
The field lines extending into the interplanetary space remain rooted in the Sun, and rotate with it. The radial outflow of the solar wind resembles the outflow of water from a rotating sprinkler in the garden – the trajectory of water drops is curved by the rotation of the sprinkler. An observer on the Sun following a parcel of solar wind would see just the same. And the magnetic field is aligned with this trajectory. This is why magnetic field lines in the interplanetary medium are curved. When one looks on them from above the Sun's northern pole, they have the shape of an Archimedean spiral, which is also called a Parker spiral, after Eugene Parker who in 1958 developed the first hydrodynamical model of the solar wind with its embedded magnetic field. As seen in the Figure, the Parker spiral magnetic field line connects the Earth with a point to the right of the centre of the solar disk, in the Sun's western hemisphere.

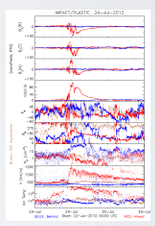
EXTREME EVENTS











From August 28 through September 2, 1859, numerous sunspots were observed on the Sun.
On August 29, southern aurorae were observed as far north as Queensland in Australia.[3]
Just before noon on September 1, the English amateur astronomers Richard Carrington and Richard Hodgson independently made the first observations of a solar flare.[4] The flare was associated with a major coronal mass ejection (CME) that travelled directly toward Earth, taking 17.6 hours to make the 93 million mile journey. It is believed that the relatively high speed of this CME (typical CMEs take several days to arrive at Earth) was made possible by a prior CME, perhaps the cause of the large aurora event on August 29, that "cleared the way" of ambient solar wind plasma for the Carrington event.[4]

Because of a simultaneous "crochet" observed in the Kew Observatory magnetometer record by Scottish physicist Balfour Stewart and a geomagnetic storm observed the following day, Carrington suspected a **solar-terrestrial connection**. Worldwide reports on the effects of the geomagnetic storm of 1859 were compiled and published by Elias Loomis, which support the observations of Carrington and Stewart.
On September 1–2, 1859, one of the largest recorded geomagnetic storms (as recorded by ground-based magnetometers) occurred. Aurorae were seen around the world, those in the northern hemisphere even as far south as the Caribbean; those over the Rocky Mountains were so bright that their glow awoke gold miners, who began preparing breakfast because they thought it was morning.[4] People who happened to be awake in the northeastern US could read a newspaper by the aurora's light.[5] The aurora was visible as far from the poles as Cuba and Hawaii.[6]
Telegraph systems all over Europe and North America failed, in some cases giving telegraph operators electric shocks.[7] Telegraph pylons threw sparks.[8] Some telegraph systems continued to send and receive messages despite having been disconnected from their power supplies.[9]
On Saturday, September 3, 1859, the Baltimore American and Commercial Advertiser reported, "Those who happened to be out late on Thursday night had an opportunity of witnessing another magnificent display of the auroral lights. The phenomenon was very similar to the display on Sunday night, though at times the light was, if possible, more brilliant, and the prismatic hues more varied and gorgeous. The light appeared to cover the whole firmament, apparently like a luminous cloud, through which the stars of the larger magnitude indistinctly shone. The light was greater than that of the moon at its full, but had an indescribable softness and delicacy that seemed to envelop everything upon which it rested. Between 12 and 1 o'clock, when the display was at its full brilliancy, the quiet streets of the city resting under this strange light, presented a beautiful as well as singular appearance."[10]
In June 2013, a joint venture from researchers at Lloyd's of London and Atmospheric and Environmental Research (AER) in the United States used data from the Carrington Event to estimate the current cost of a similar event to the US alone at $0.6–2.6 trillion.[11]

http://science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare/

At 11:18 AM on the cloudless morning of Thursday, September 1, 1859, 33-year-old Richard Carrington—widely acknowledged to be one of England's foremost solar astronomers—was in his well-appointed private observatory. Just as usual on every sunny day, his telescope was projecting an 11-inch-wide image of the sun on a screen, and Carrington skillfully drew the sunspots he saw.

Right: Sunspots sketched by Richard Carrington on Sept. 1, 1859. Copyright: Royal Astronomical Society: more.
On that morning, he was capturing the likeness of an enormous group of sunspots. Suddenly, before his eyes, two brilliant beads of blinding white light appeared over the sunspots, intensified rapidly, and became kidney-shaped. Realizing that he was witnessing something unprecedented and "being somewhat flurried by the surprise," Carrington later wrote, "I hastily ran to call someone to witness the exhibition with me. On returning within 60 seconds, I was mortified to find that it was already much changed and enfeebled." He and his witness watched the white spots contract to mere pinpoints and disappear.
It was 11:23 AM. Only five minutes had passed.
Just before dawn the next day, skies all over planet Earth erupted in red, green, and purple auroras so brilliant that newspapers could be read as easily as in daylight. Indeed, stunning auroras pulsated even at near tropical latitudes over Cuba, the Bahamas, Jamaica, El Salvador, and Hawaii.

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Even more disconcerting, telegraph systems worldwide went haywire. Spark discharges shocked telegraph operators and set the telegraph paper on fire. Even when telegraphers disconnected the batteries powering the lines, aurora-induced electric currents in the wires still allowed messages to be transmitted.
"What Carrington saw was a white-light solar flare—a magnetic explosion on the sun," explains David Hathaway, solar physics team lead at NASA's Marshall Space Flight Center in Huntsville, Alabama.
Now we know that solar flares happen frequently, especially during solar sunspot maximum. Most betray their existence by releasing X-rays (recorded by X-ray telescopes in space) and radio noise (recorded by radio telescopes in space and on Earth). In Carrington's day, however, there were no X-ray satellites or radio telescopes. No one knew flares existed until that September morning when one super-flare produced enough light to rival the brightness of the sun itself.

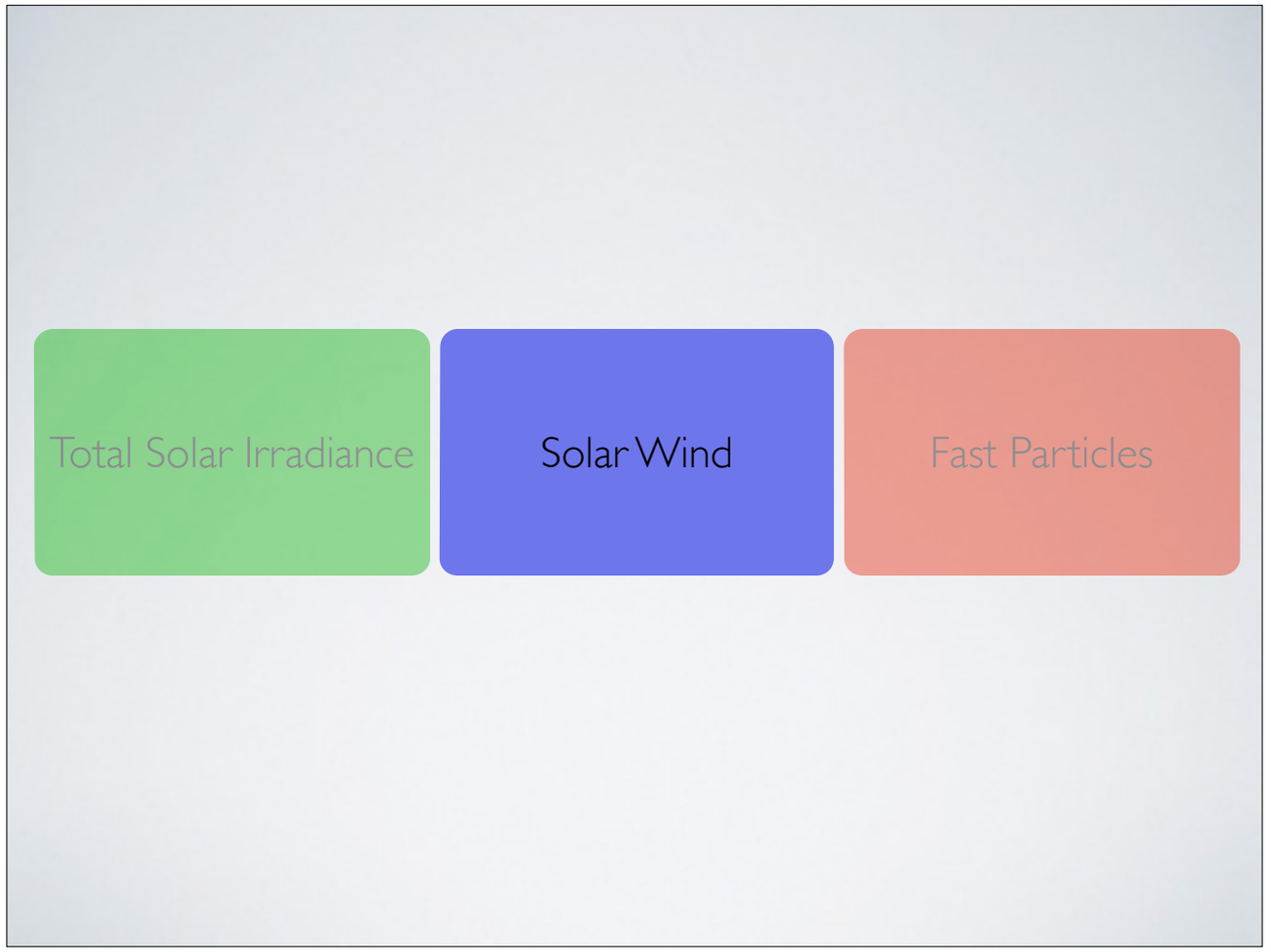
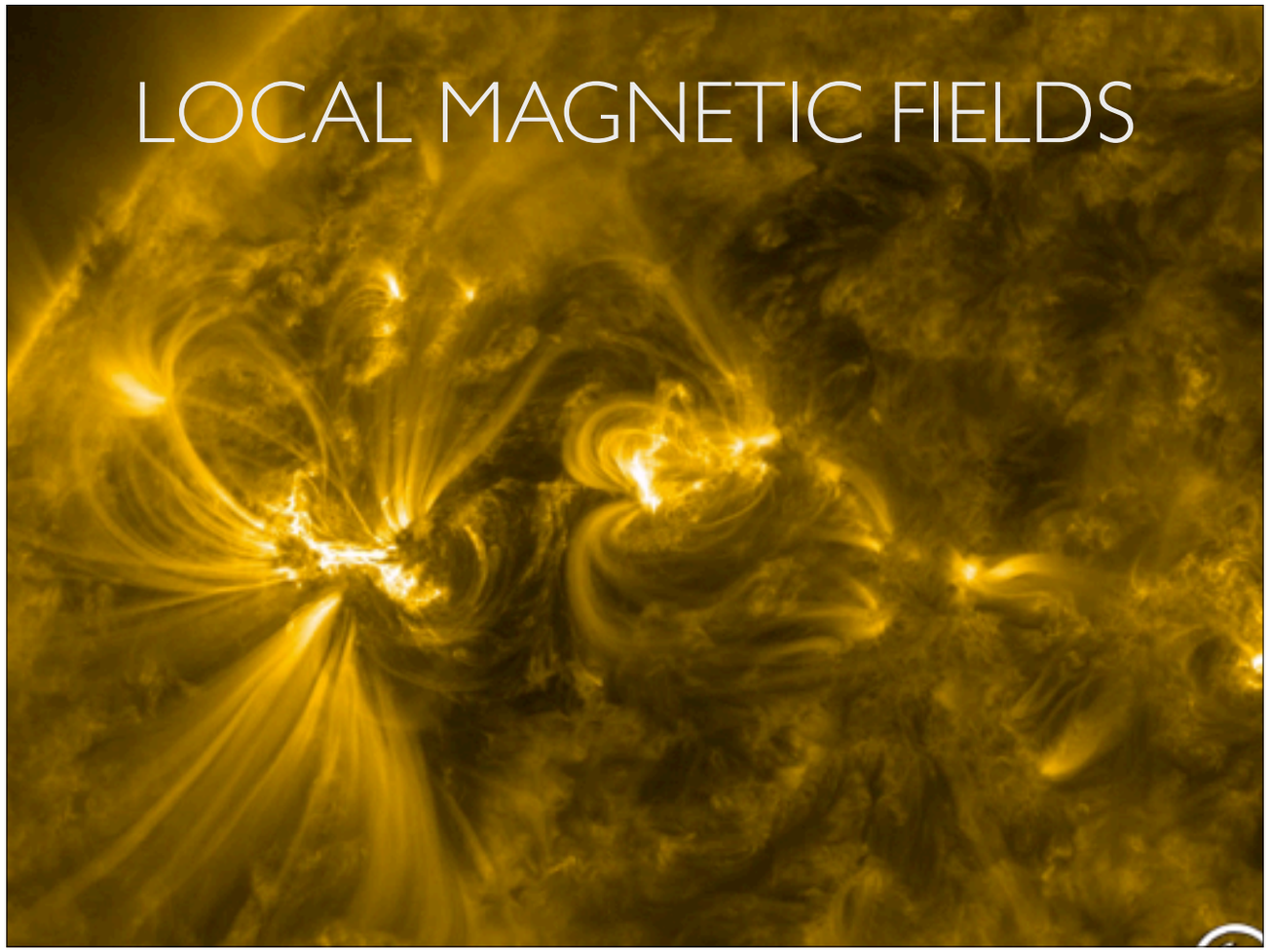

Total Solar Irradiance
Solar Wind
Fast Particles


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

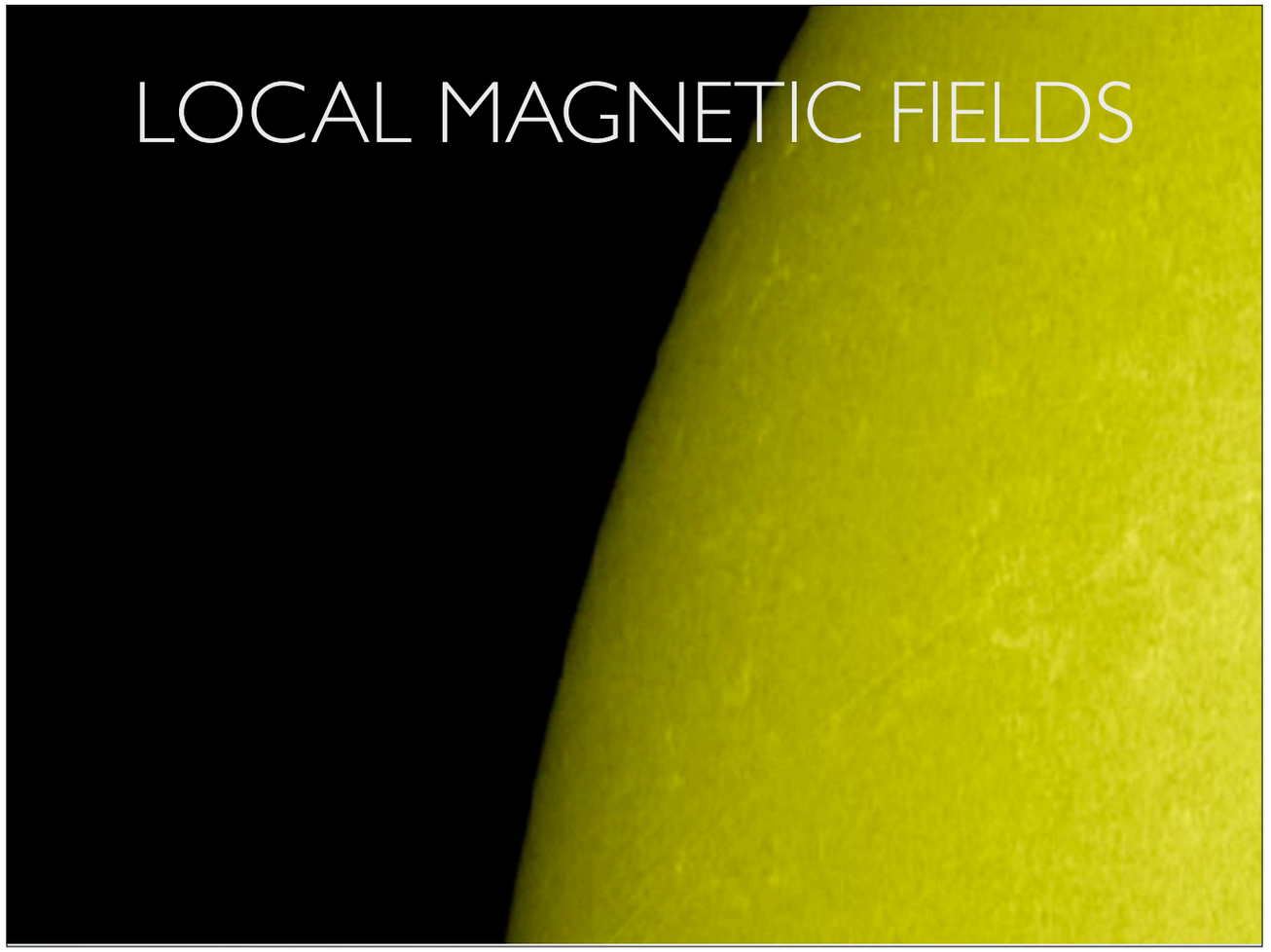
LOCAL MAGNETIC FIELDS

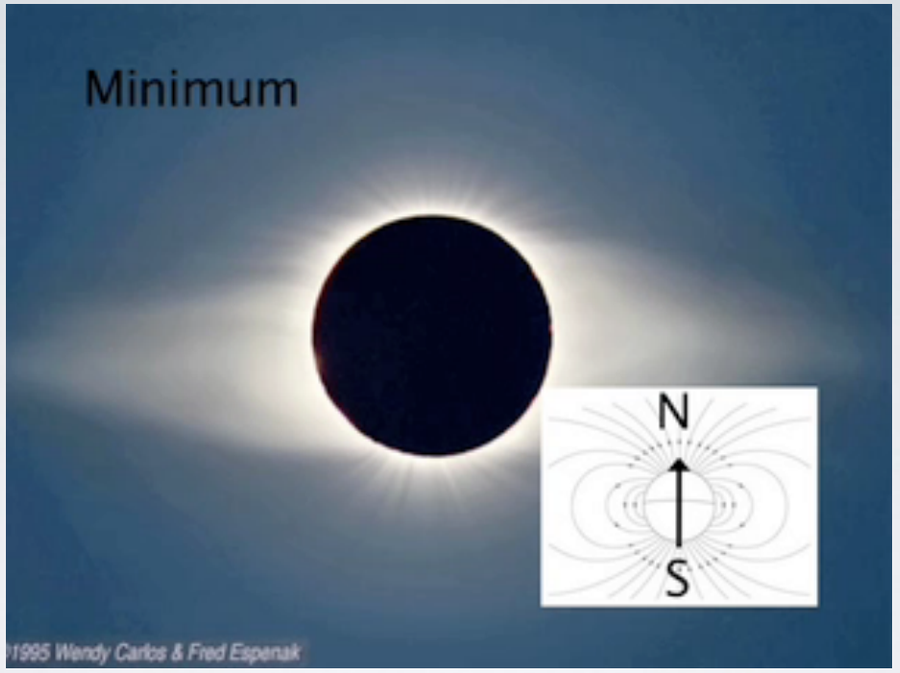


Sinds de start van het ruimtetijdperk, hebben we de zon op andere manieren kunnen bestuderen: dynamisch, energiek, geweldadig.
Samen met de start van het ruimtetijdperk, zijn onze hoogtechnologische systemen uitgebouwd: navigatie (GNSS), satellieten, radio communicatie, grote energietoevoer...

Met die hoogtechnologische systemen bestuderen we de zon maar tegelijkertijd is onze maatschappij zeer kwetsbaar geworden. Het is een kluwen van afhankelijkheid.

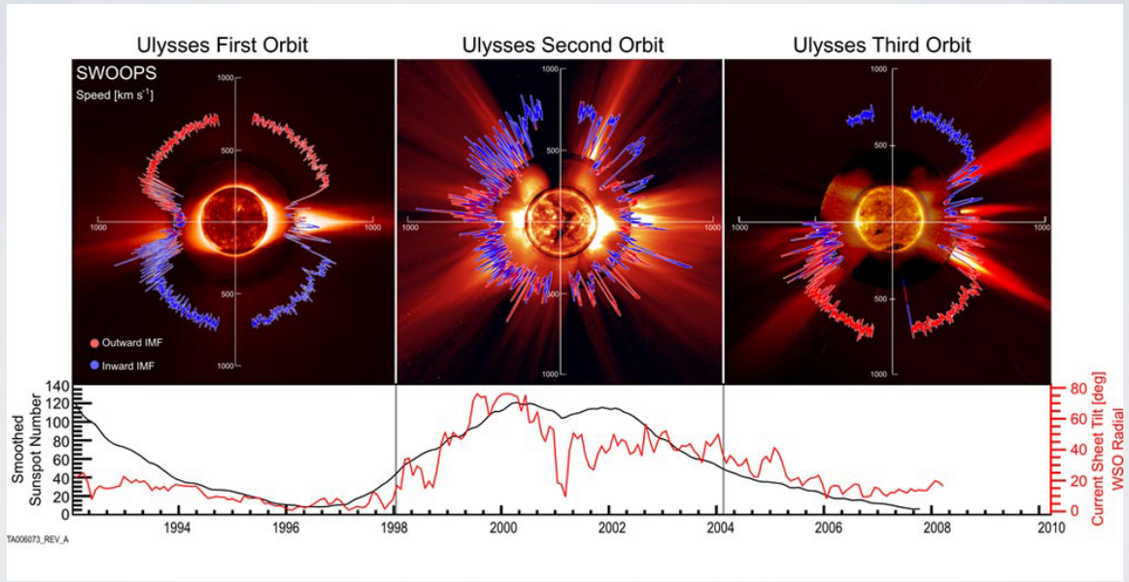
LOCAL MAGNETIC FIELDS





ZONNECORONA

SOLAR WIND

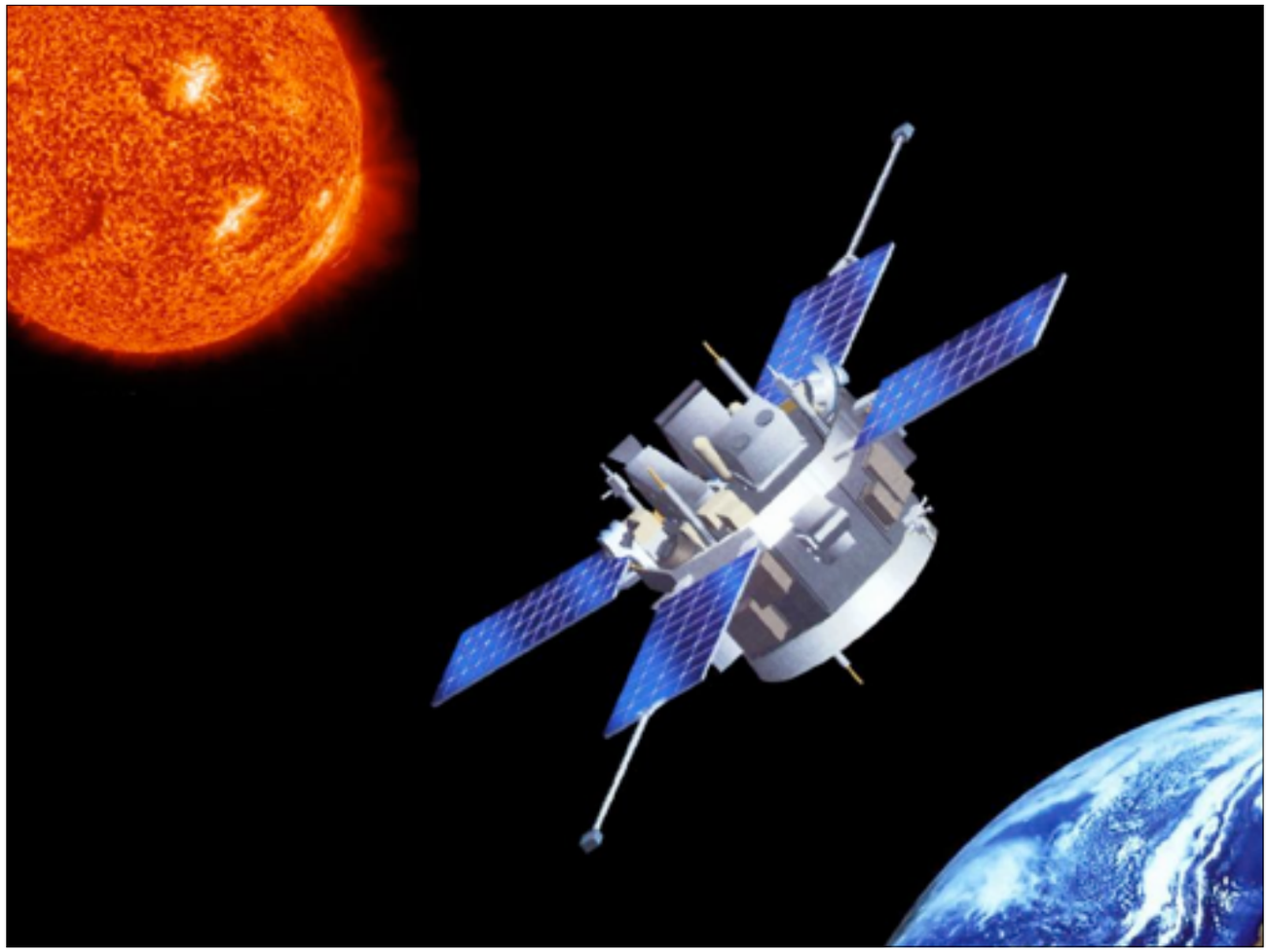


solar wind is not the same on all places of the solar disk.

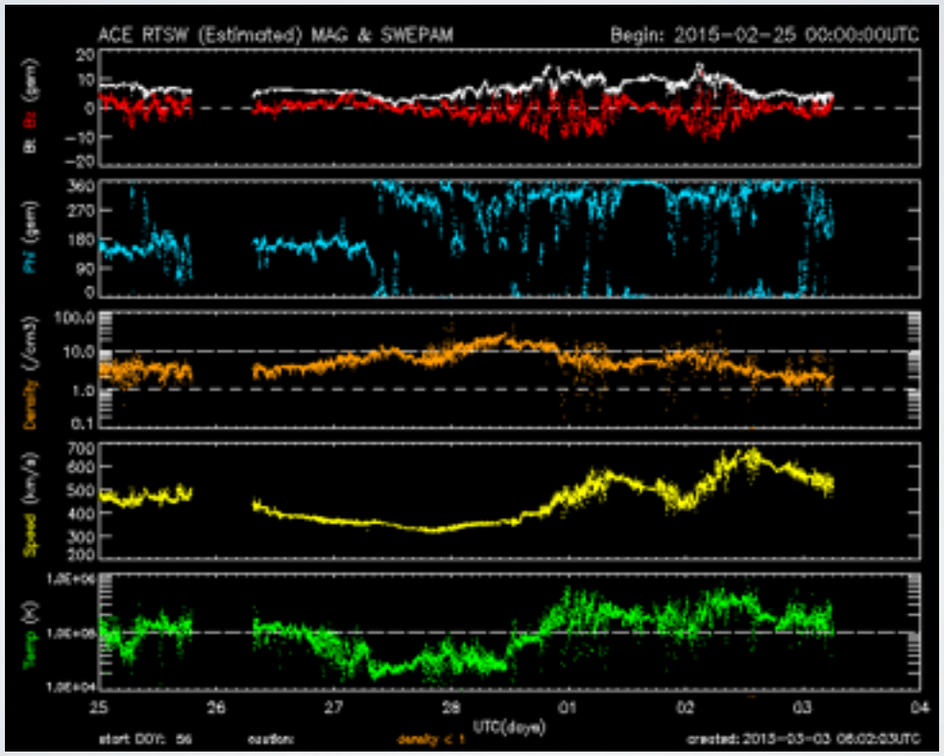
minimum: more structured

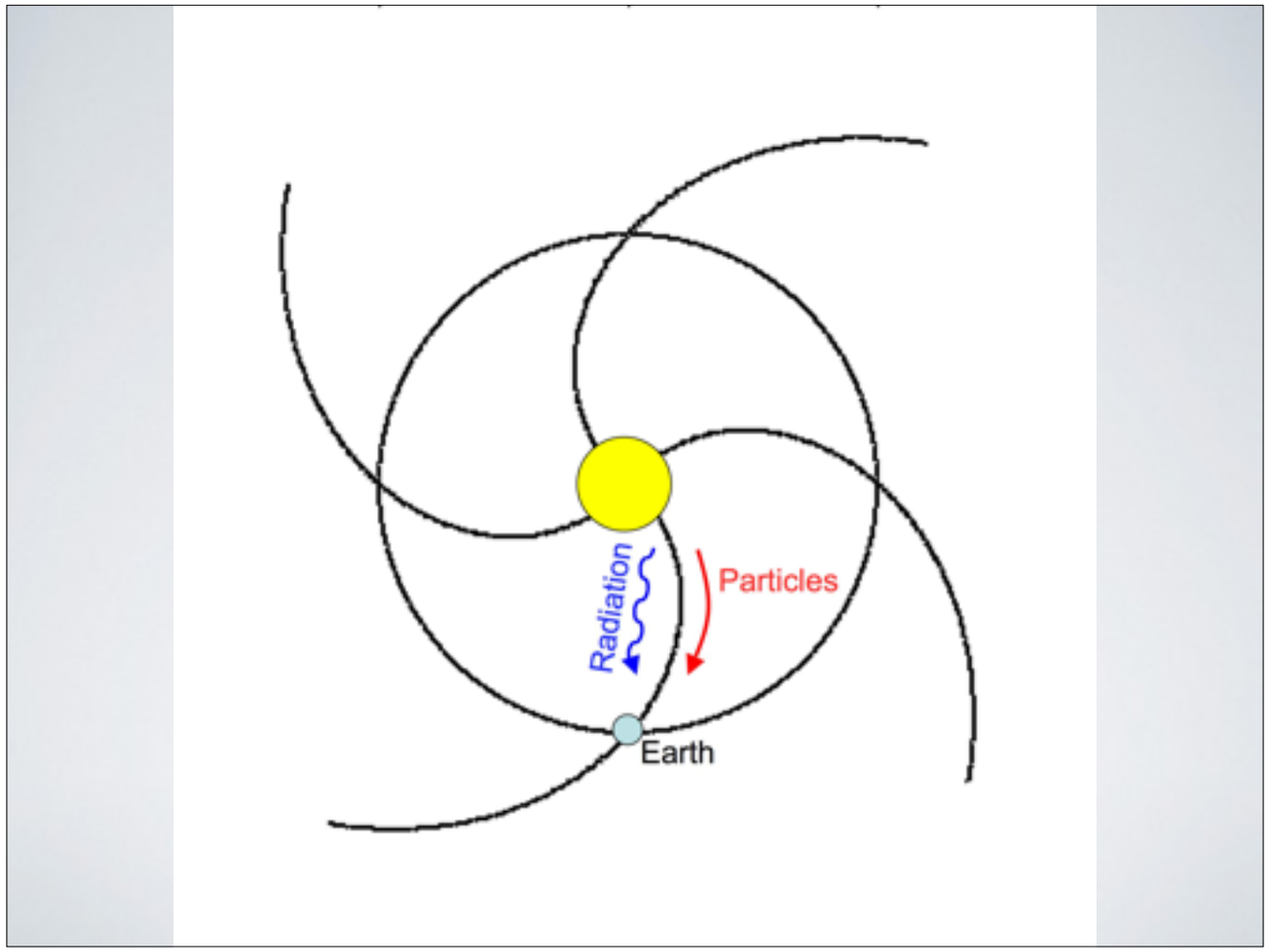
maximum: global and local magnetic field mingle strongly

fast solar wind streams are associated with coronal holes and open field regions of the corona while slow streams come from the closed field regions primarily concentrated near the equatorial (or streamer) belt.



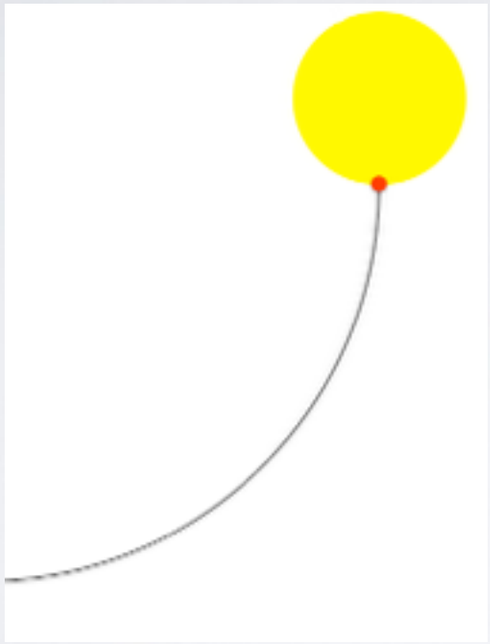
SOLAR WIND - IN SITU



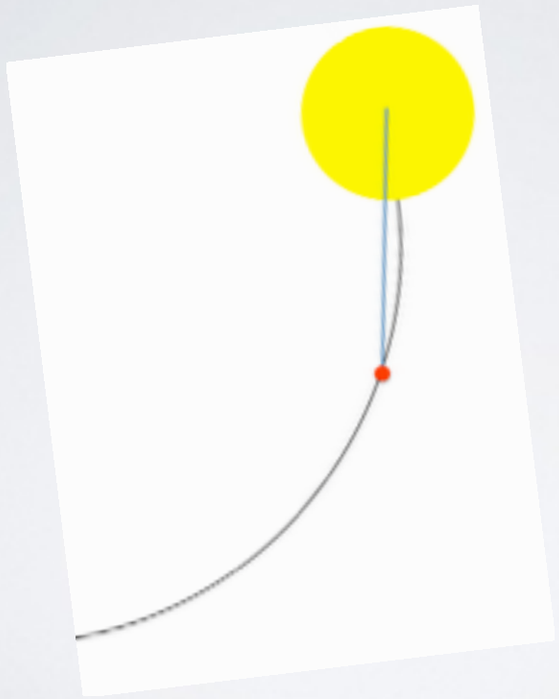


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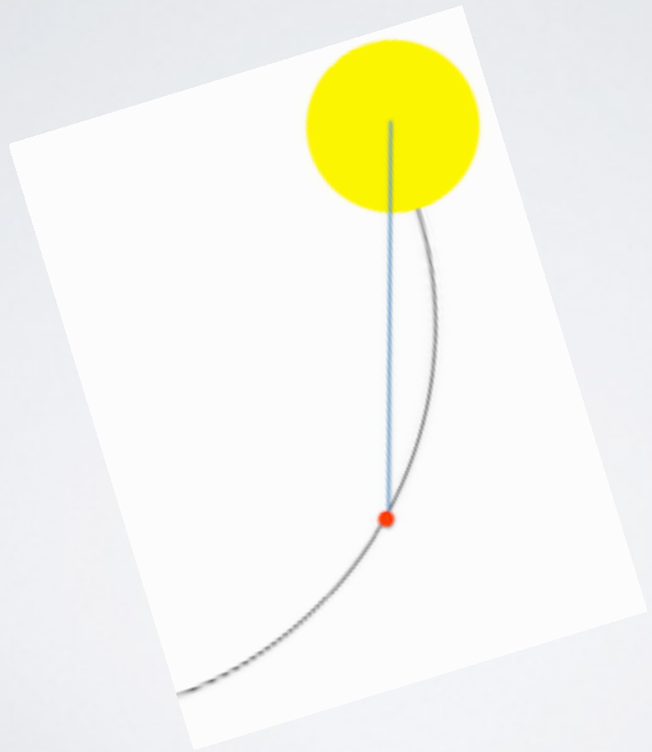
RADIAL



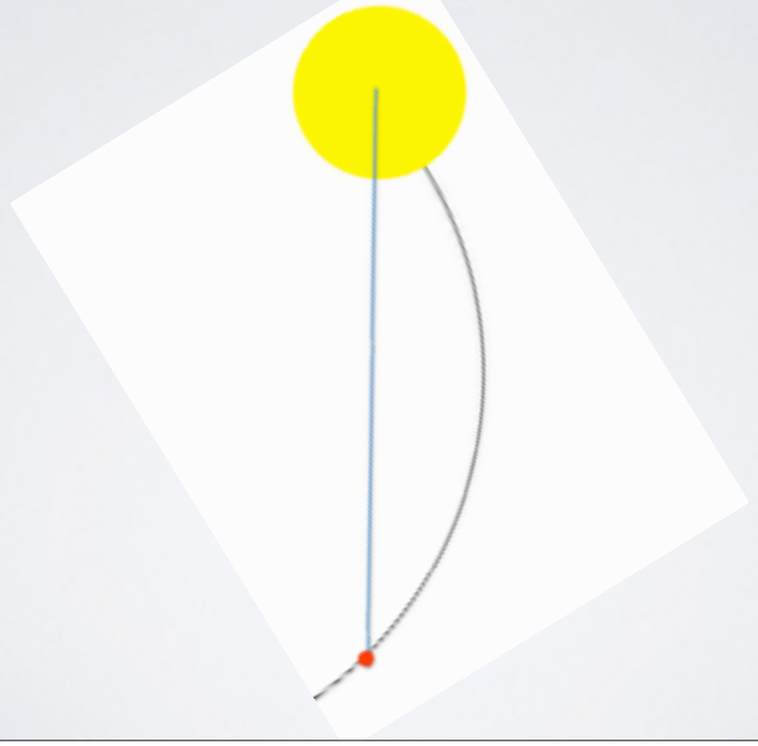
RADIAL



RADIAL



RADIAL



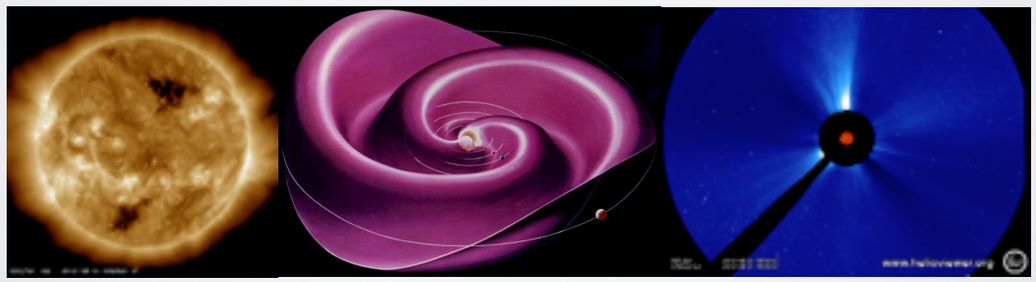
VARIATIONS

Non-eruptive

Coronal Hole
Sector Boundary Crossing

Eruptive

Coronal Mass Ejection

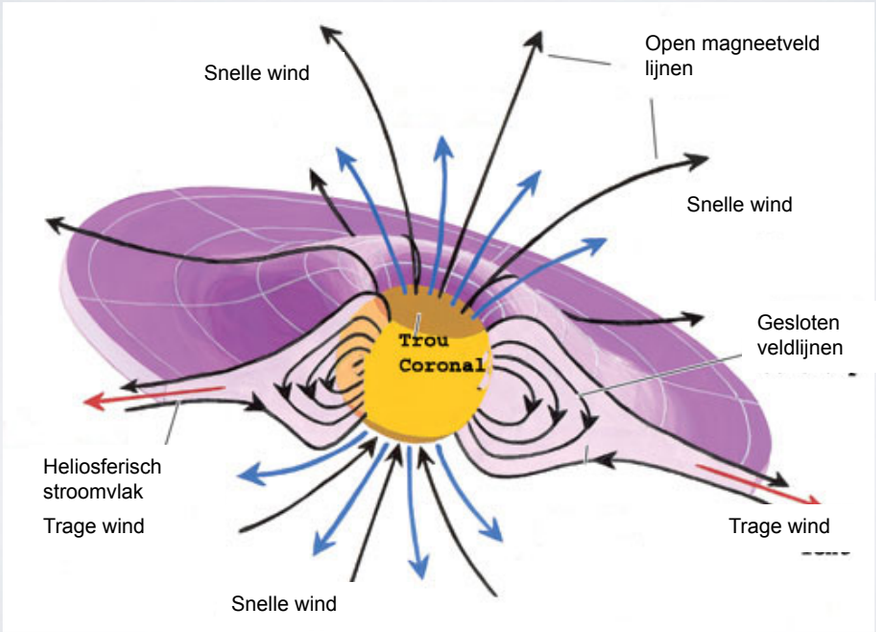


CME: A new, discrete, bright white light feature in the coronograph field-of-view with a predominantly, radial outward velocity.

the peak K are higher for CMEs
the total length of the geomagnetic storms is much bigger at solar minimum when the nr of CIRs are higher compared to the nr of CMEs.

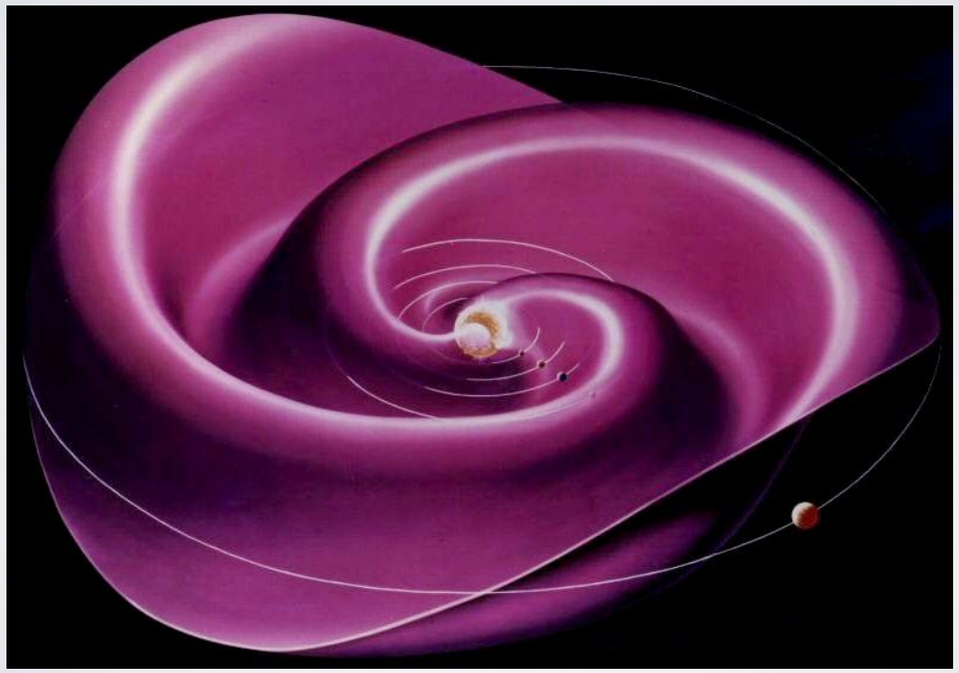
SECTOR BOUNDARY CROSSING

HELIOSPHERIC CURRENT SHEET



De zon is in feite een gigantische magnetische dipool, een staaf met een positieve en negatieve magnetische kant, waarbij magnetische lijnen van de magnetische noordpool naar de magnetische zuidpool worden geleid. Deze veldlijnen worden echter ter hoogte van de evenaar door de zonnewind meegesleurd: het dipoolveld wordt extreem uit gerokken waardoor een gebied ontstaat met veldlijnen die van de zon weg wijzen en een gebied met veldlijnen die naar de zon wijzen. Het heliosferisch stroomvlak is de grens hiertussen en is in feite de extensie van de magnetische zonne-evenaar. De zonnewind blaast vanuit het ganse zonneoppervlak geladen deeltjes de ruimte in.

BALLERINA SKIRT

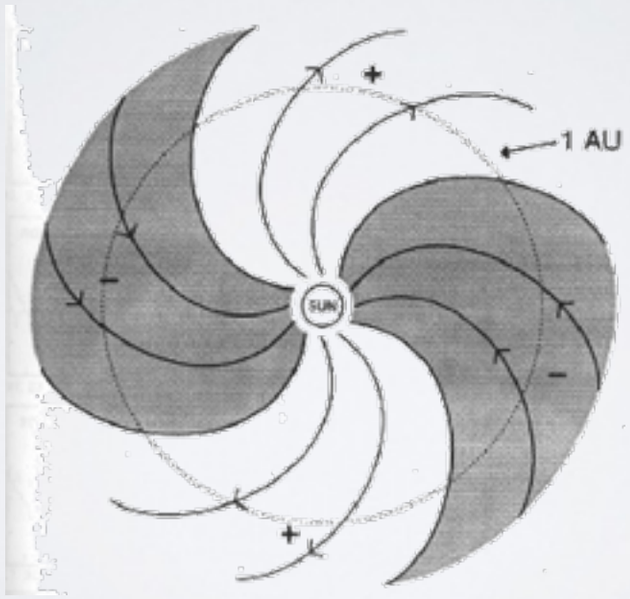


Neither the solar rotation axis nor the effective dipole axis are perpendicular to the ecliptic plane. Accordingly, the Sun's rotation causes the heliospheric current sheet to move up and down at a fixed observer's position, with associated changes in the plasma density and the direction (towards/away) of the magnetic field. This wavy pattern of the current sheet is sometimes referred to as the \ballerina skirt"

distinct, long-lasting intervals of uniform solar wind field direction exist, called \sectors"

De deeltjes van de zonnewind bewegen zich radiaal van de zon weg, maar zijn wel steeds gebonden aan de magnetische veldlijnen die door de rotatie van de zon opgedraaid worden in een spiraal. Het was E. Parker die in de jaren 50 met het theoretische concept van de zonnewind en de spiraal op de proppen kwam. Deze theorie werd nadien bevestigd door satellietwaarnemingen. Parker is dan ook terecht de godfather van de zonnewind en meer dan het vermelden waard. Wanneer de dipool-as niet parallel staat met de rotatieas van de zon heeft het heliosferisch stroomvlak de vorm van een elegante ballerina jurk met 2 mooie golven.

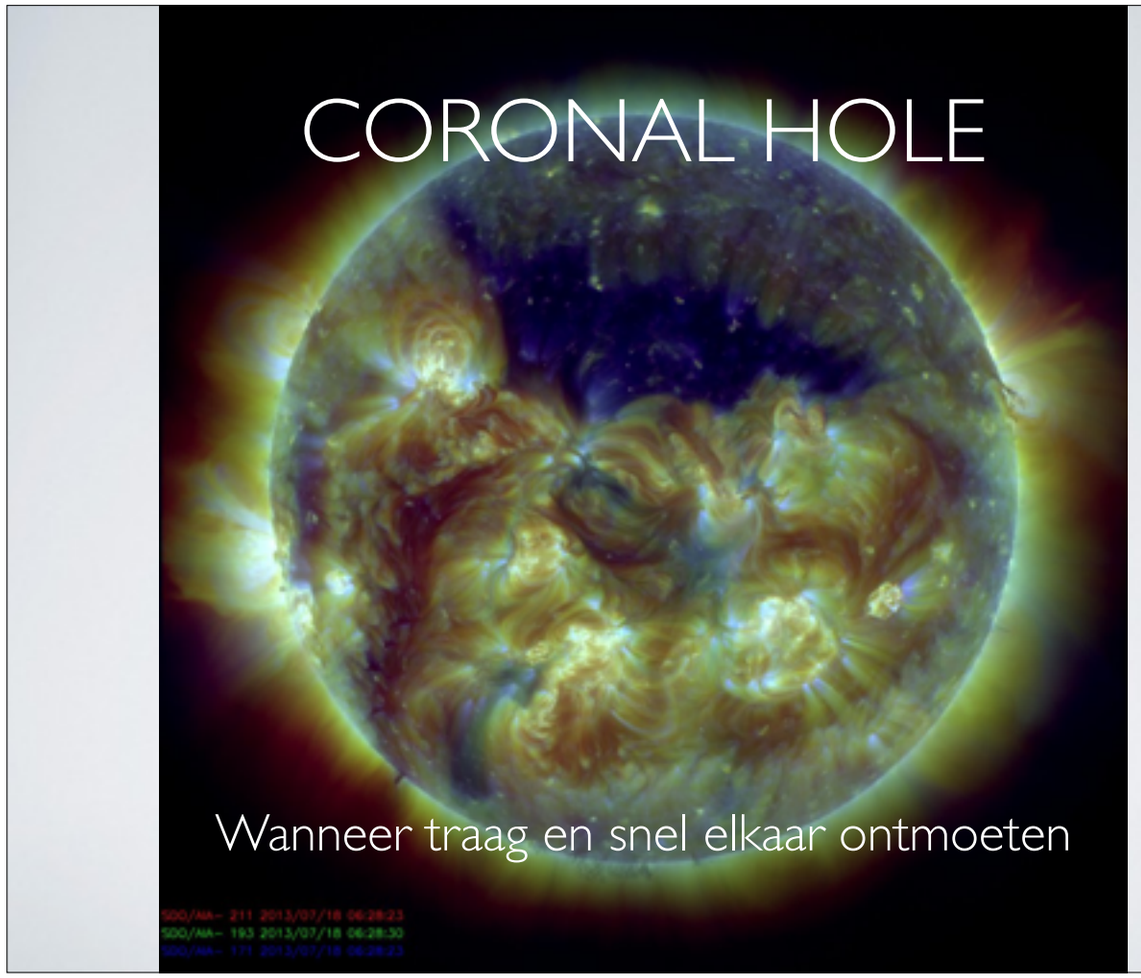
MAGNETIC SECTORS



Cravens, 1997

distinct, long-lasting intervals of uniform solar wind field direction exist, called ``sectors''

changes in the **plasma density** and the **direction (towards/away) of the magnetic field**.

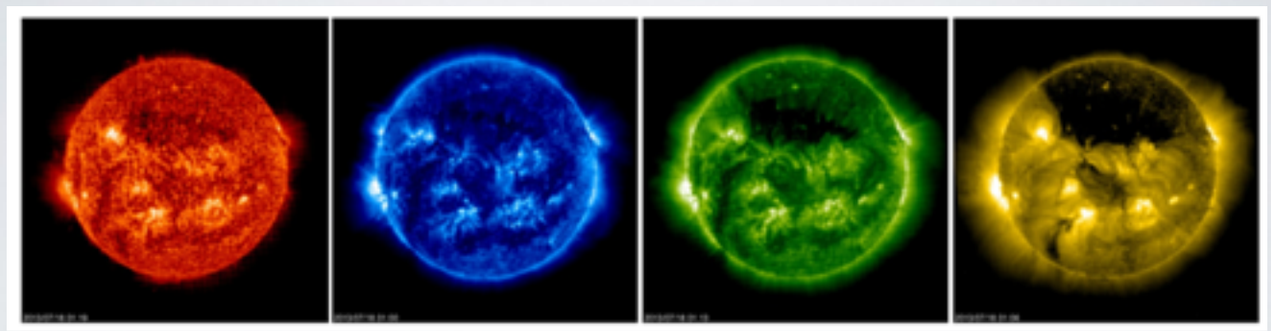


gelinkt aan unipolar magnetische velden, i.e. open field structure, stretching into space source of fast solar wind, kunnen geomagnetische stormen veroorzaken, typisch minder sterk dan deze veroorzaakt door CME's

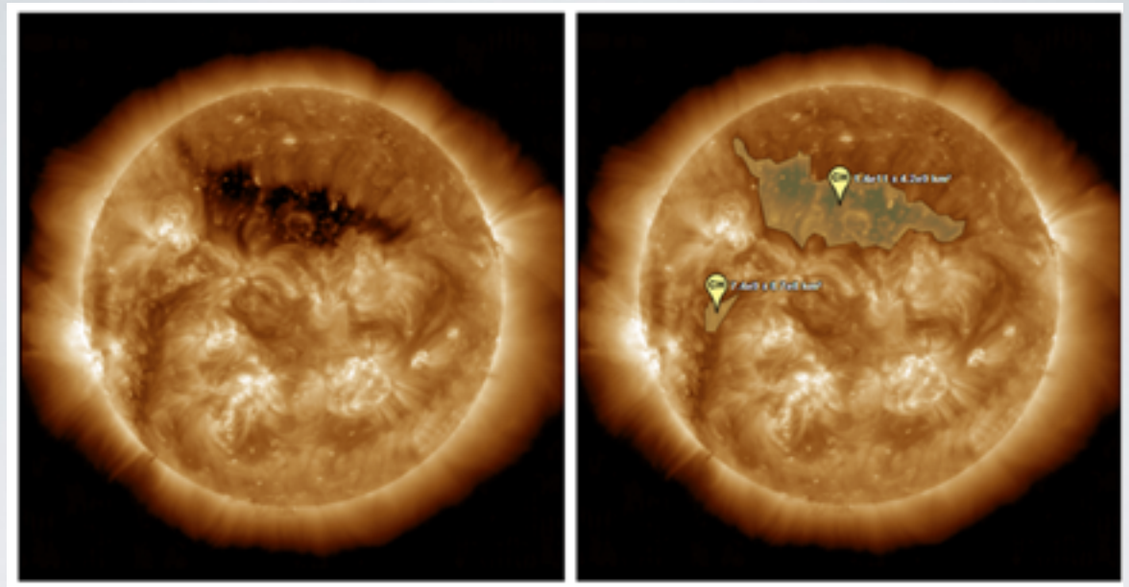
during solar minimum, high speed streams from CH dominate the interplanetary medium activity.
persistent, ze komen typisch om de 27 dagen terug in beeld.

In contrast to solar maximum, where polar CH are not very important, during the descending phase of the solar cycle such coronal holes have major even dominant effects on the interplanetary medium. Polar CH extend from the polar regions down to the equator and sometimes even fast past the equator.
during the descending phase of the solar cycle, when the holes migrate down to lower latitude as fingers, the streams emanating from the holes corotate at 27 day intervals (as seen at Earth) and thus plasma from these streams impinge on the Earth's magnetosphere at periodic intervals and cause recurrent geomagnetic storms.

heliographic latitude
at the central meridian

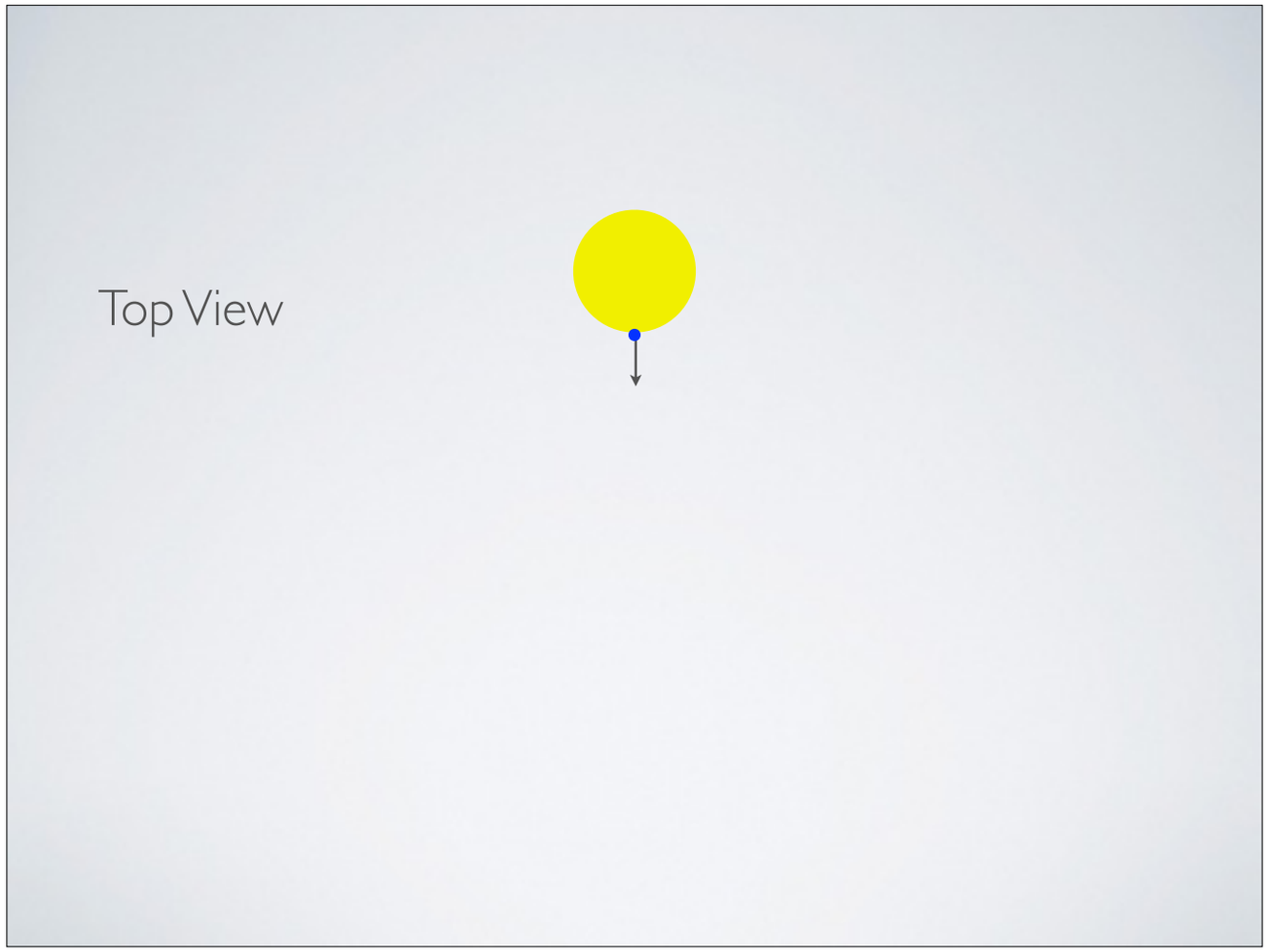


So, how big is this solar feature and how does it compare to other coronal holes? The size of a coronal hole is usually determined by measuring the area of the dark patches of which it consists. However, for reasons explained in a previous STCE Newsletter (http://www.stce.be/news/171/welcome.html), the outlook of a coronal hole can be quite different from one filter to the other. An illustration of this effect can be seen in the SOHO-images underneath (ranked from cool to hot temperatures – left to right; http://sohowww.nascom.nasa.gov/). This is important to keep in mind, when comparing areas over many years as observed by different spacecraft.

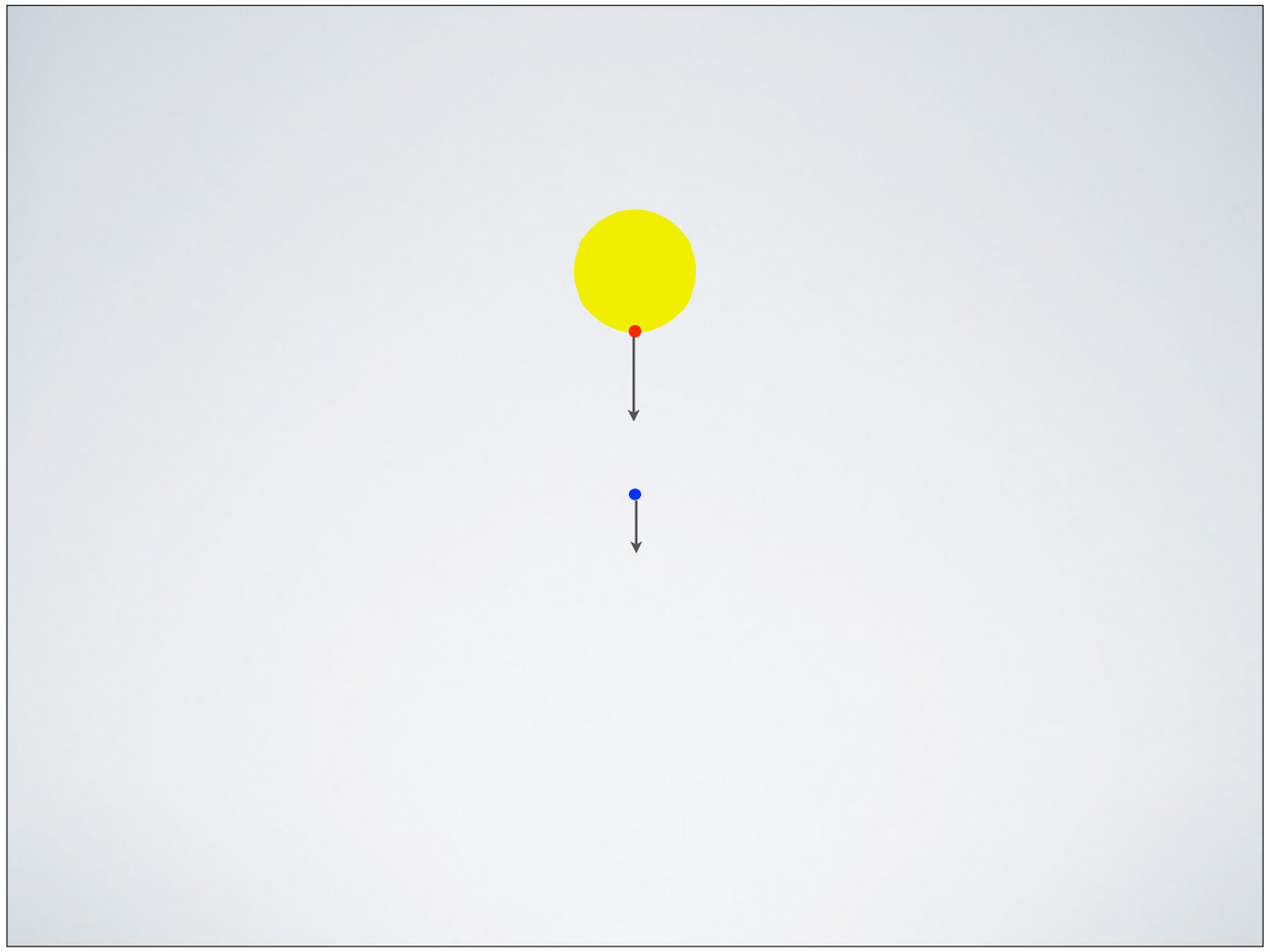


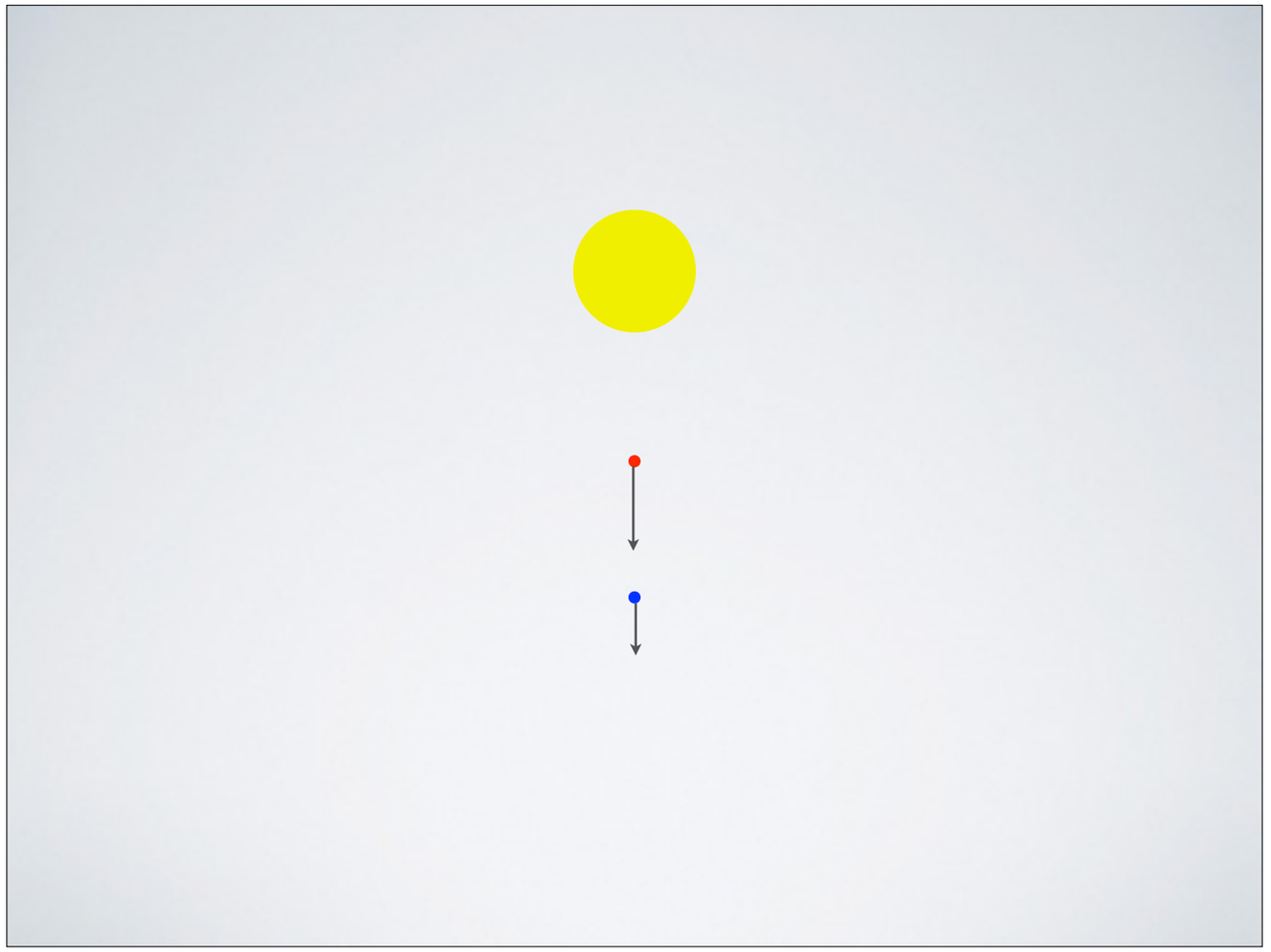
HELIOVIEWER.ORG
MAGNETISCH VELD ALS BASIS

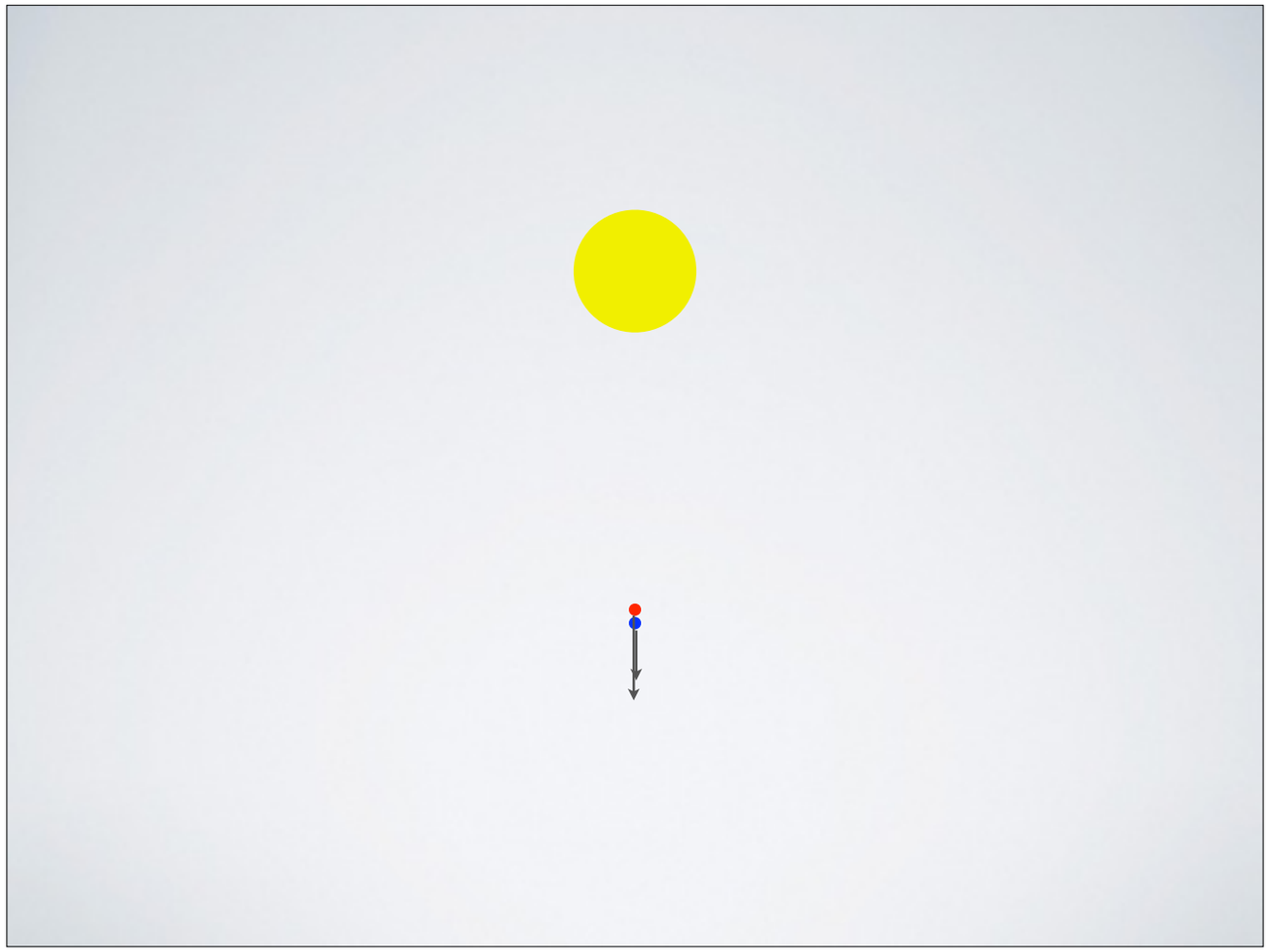
Helioviewer added some new features to their renowned website (http://www.helioviewer.org/). It now also contains a tool displaying the area of the visible coronal holes. Interestingly, these areas are detected from modeling the Sun's magnetic field, and not from observing a dark region in a coronal temperature bandpass. Using this method, the maximum area of this coronal hole was determined to be 150 billion km2 on 17 July, or nearly 300 times the total surface of the Earth.

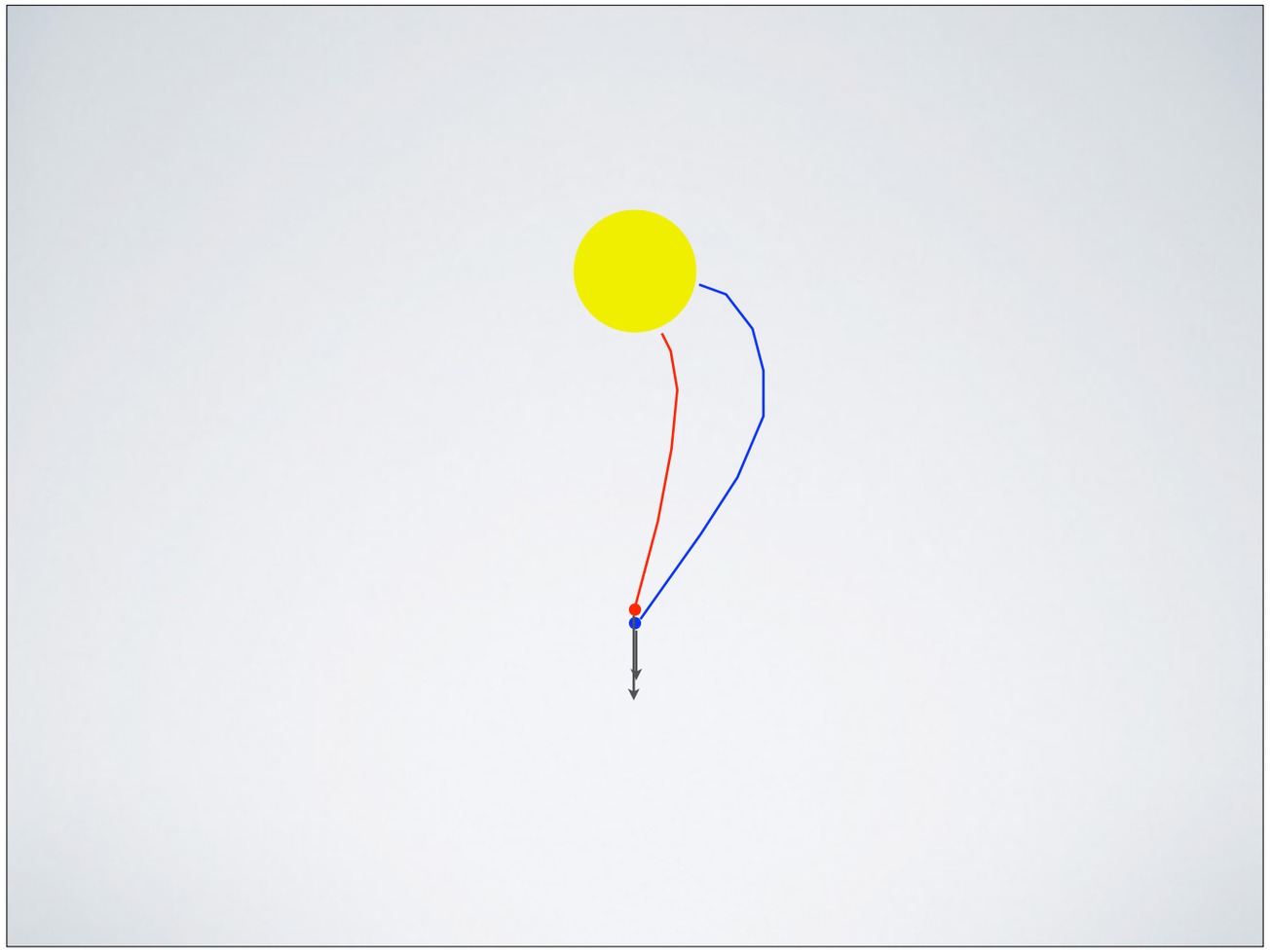


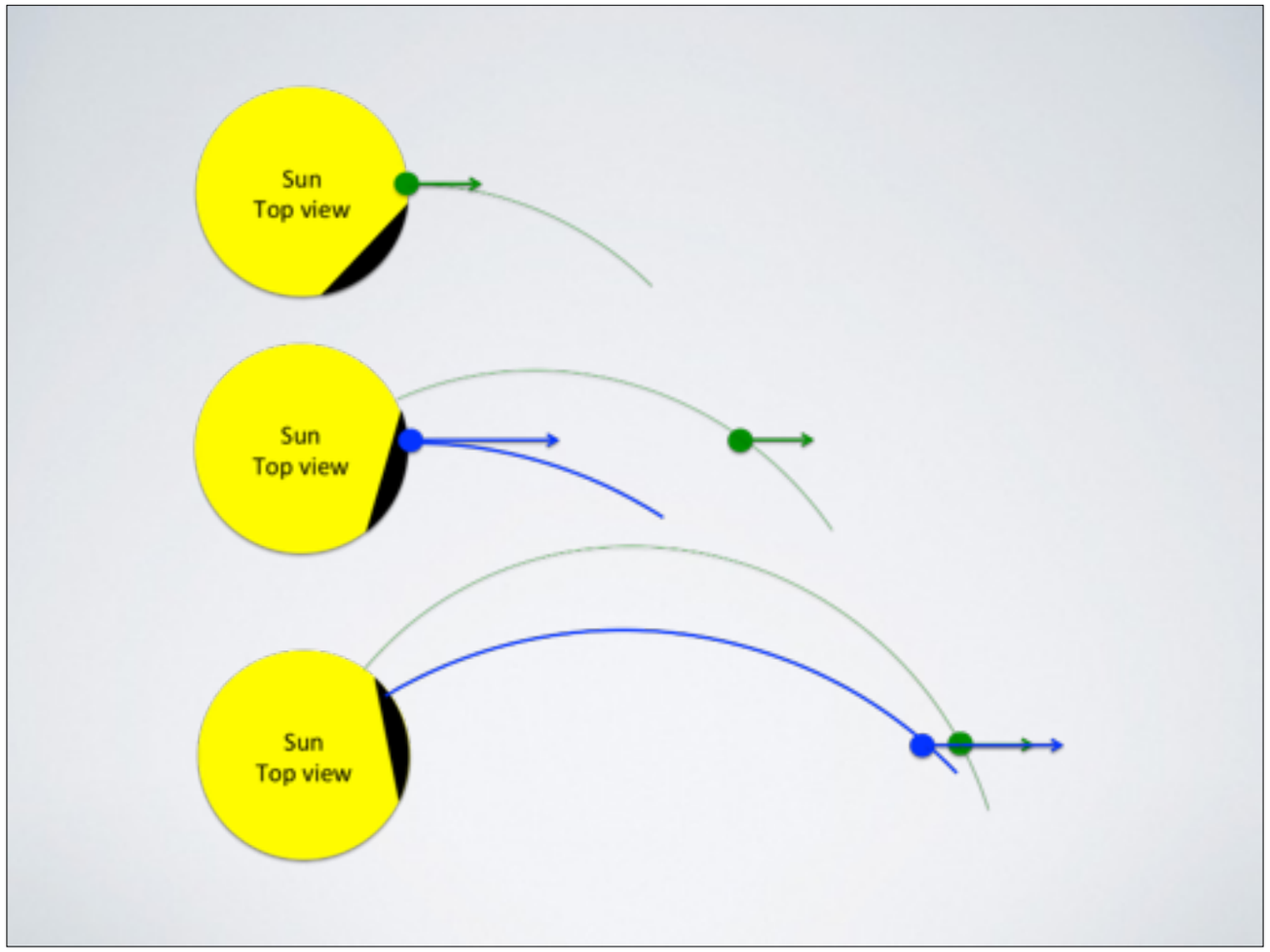
heliographic latitude
at the central meridian





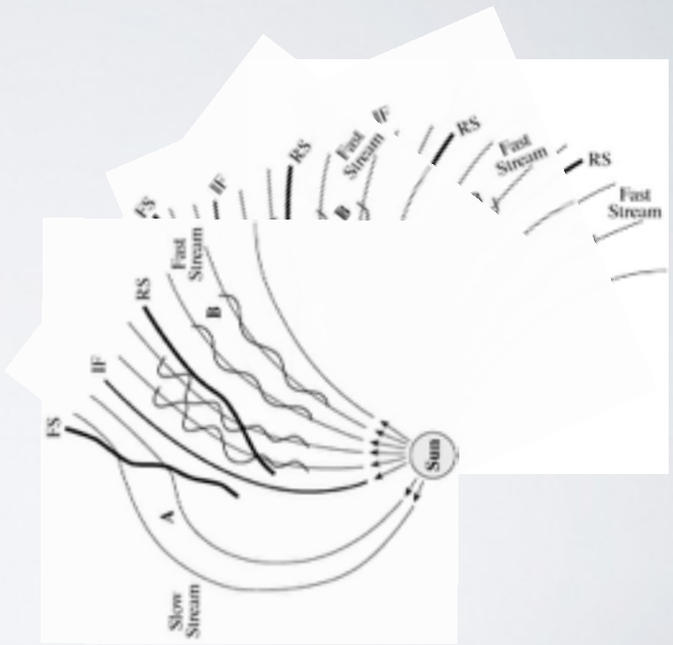





Sun
Top view
Sun
Top view
Sun
Top view

CORONAL HOLE

- Co-rotating structure
- Shocks are present, usually behind 1AU
- Radial!
- No extra mass-flux



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.

As the wind expands radially, the flow follows the same spiral pattern, but fast wind "catches up" to slow wind and crashes into it. At the interface between the fast and slow wind (b), a large pressure pulse forms and eventually steepens to create a forward and reverse shock pair. The thin boundaries separating the streams are called co-rotating interaction regions or CIRs.

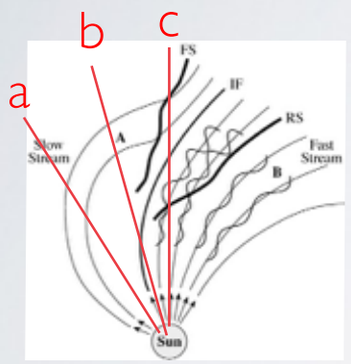
continue toevoer, oorzaak blijft aanwezig

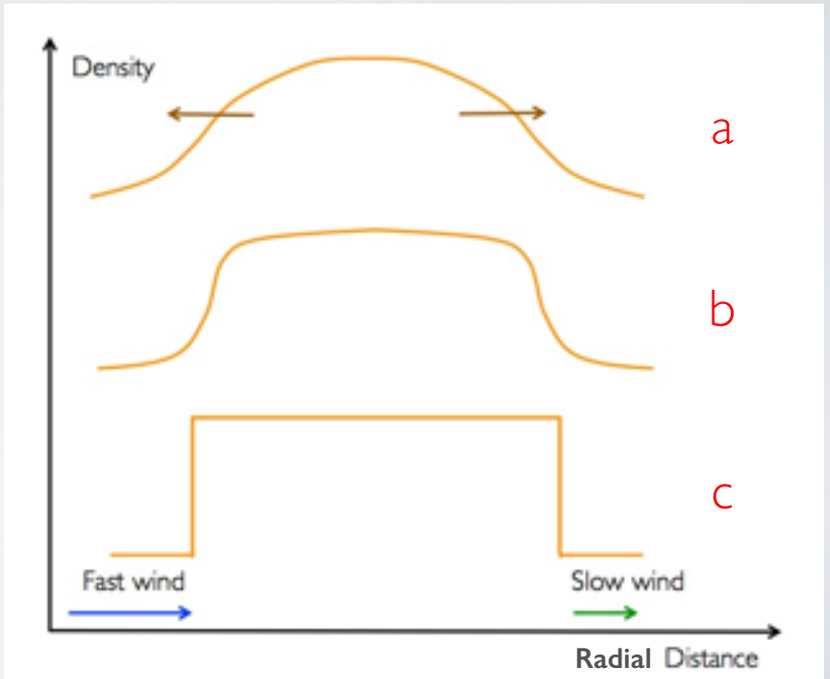
When fast solar-wind streams, emanating from coronal holes, interact with slow streams, they can produce Co-rotating Interaction Regions in interplanetary space. The magnetic fields of the slow streams in the solar wind are more curved due to the lower speeds, and the fields of the fast streams are more 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

LEVELLING WORKS AHEAD





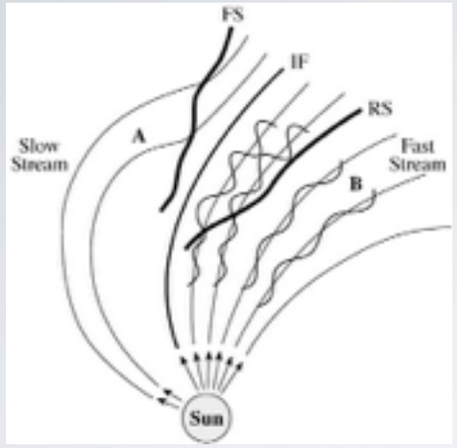
distance= radial distance
in het bovenste profiel zit de snelle zonnewind de trage zonnewind op zijn hielen, maar oefent nog geen al te grote druk uit.
Naarmate de snelle zonnewind de trage zonnewind meer en meer op de hielen zit, krijg je een hoekig dichtheidsprofiel.

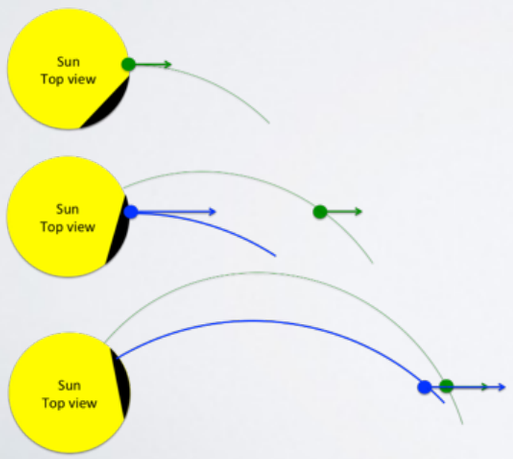
De natuur wil dat die berg weg: de rechtse flank beweegt tov van de berg naar rechts: forward shock, de linkse flank beweegt tov van de berg naar links: reversed shock, beweegt naar de zon toe maar wordt door de wind weggevoerd van de zon weg.

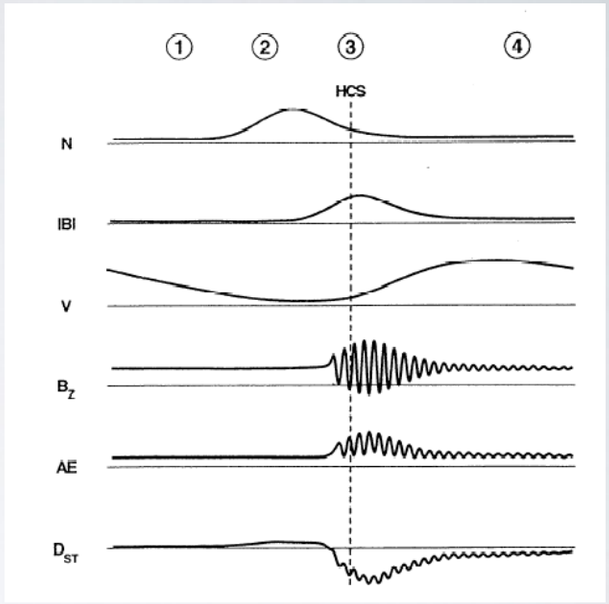
The density profile of the interaction region (co-rotating interaction region, CIR) looks like a hill that moves away from the Sun. In front of the hill, you have a slow wind while a fast wind is trailing. Nature tries to expand the dense structure to get rid of the density hill and put a flat density landscape in place. By moving the front flank to the right and the behind flank to the left, the density curve is stretched and flattened; and both flanks will be steepened to finally result in a crude passage from low/high to high/low density which mathematicians like to call a step function and solar physicians have a mouth full of a shock.

The front flank needs to move of course faster than the slow plasma in front of it. The shock in the front is called a forward shock, the shock trailing the high density region is called a reversed shock. For all shocks, it is the difference in speed between the slow and the fast solar wind that drives the whole system. When a forward shock driven by a CIR passes an instrument that makes in situ measurements, the speed, density and temperature suddenly increase. When a reversed shock passes, the speed increases, but density and temperature decrease.

Once passed the reversed shock, you end up in the fast stream emanating from the coronal hole with a typically low density and high speed such that the plasma flux is the same and in the part where you have a slow but dense plasma.

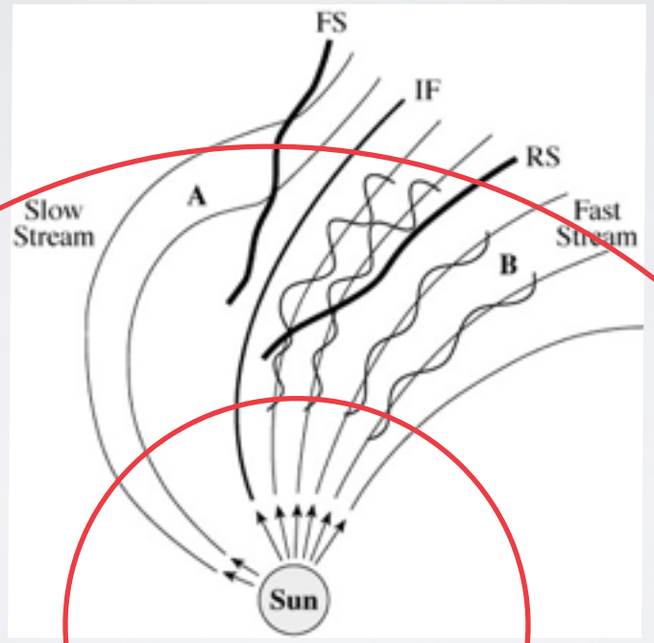

FS
IF
RS
Slow Stream
A
B
Fast Stream
Sun

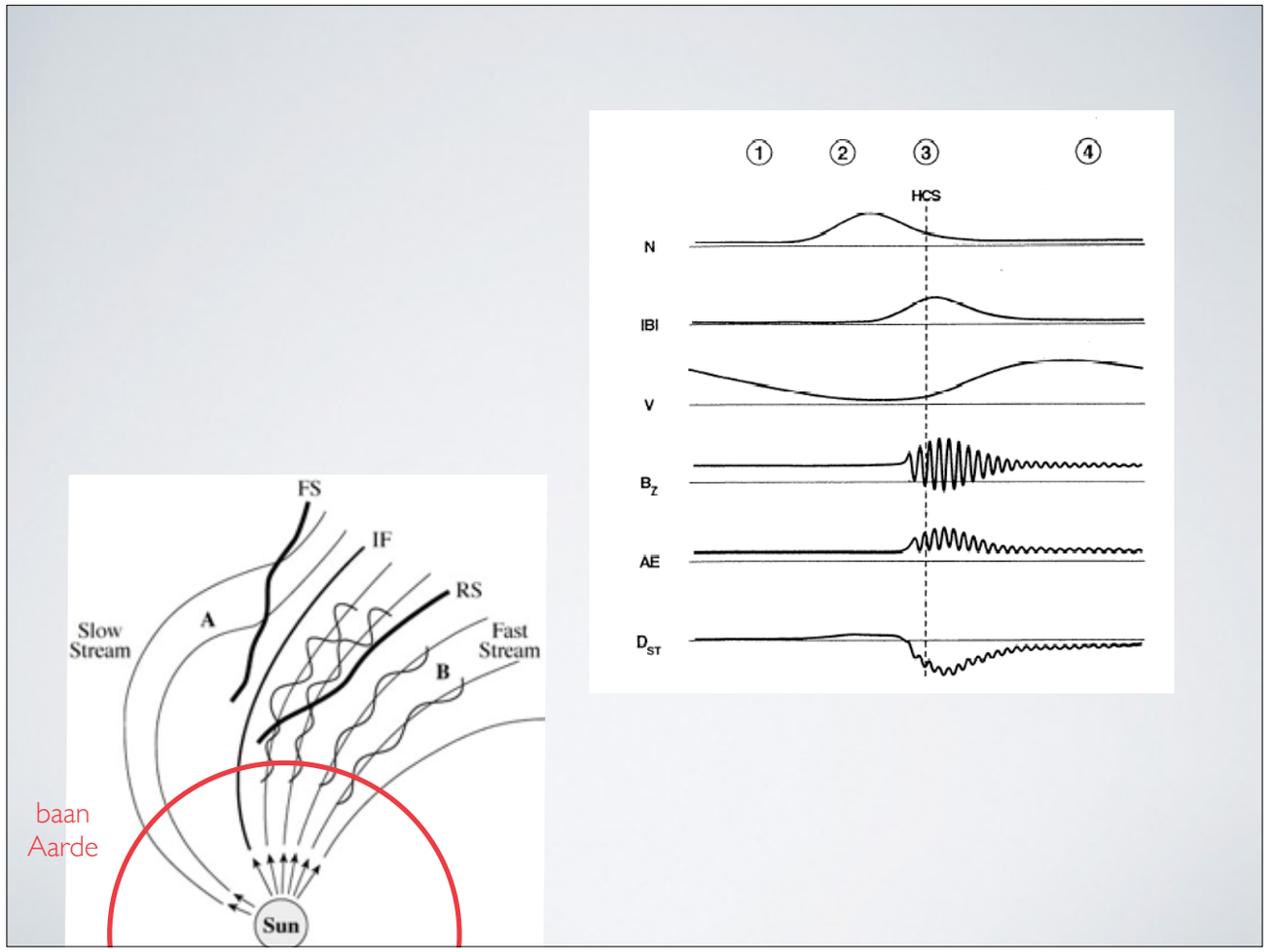

Sun
Top view
Sun
Top view
Sun
Top view


1
2
3
4
HCS
N
IBI
V
B_Z
AE
D_{ST}

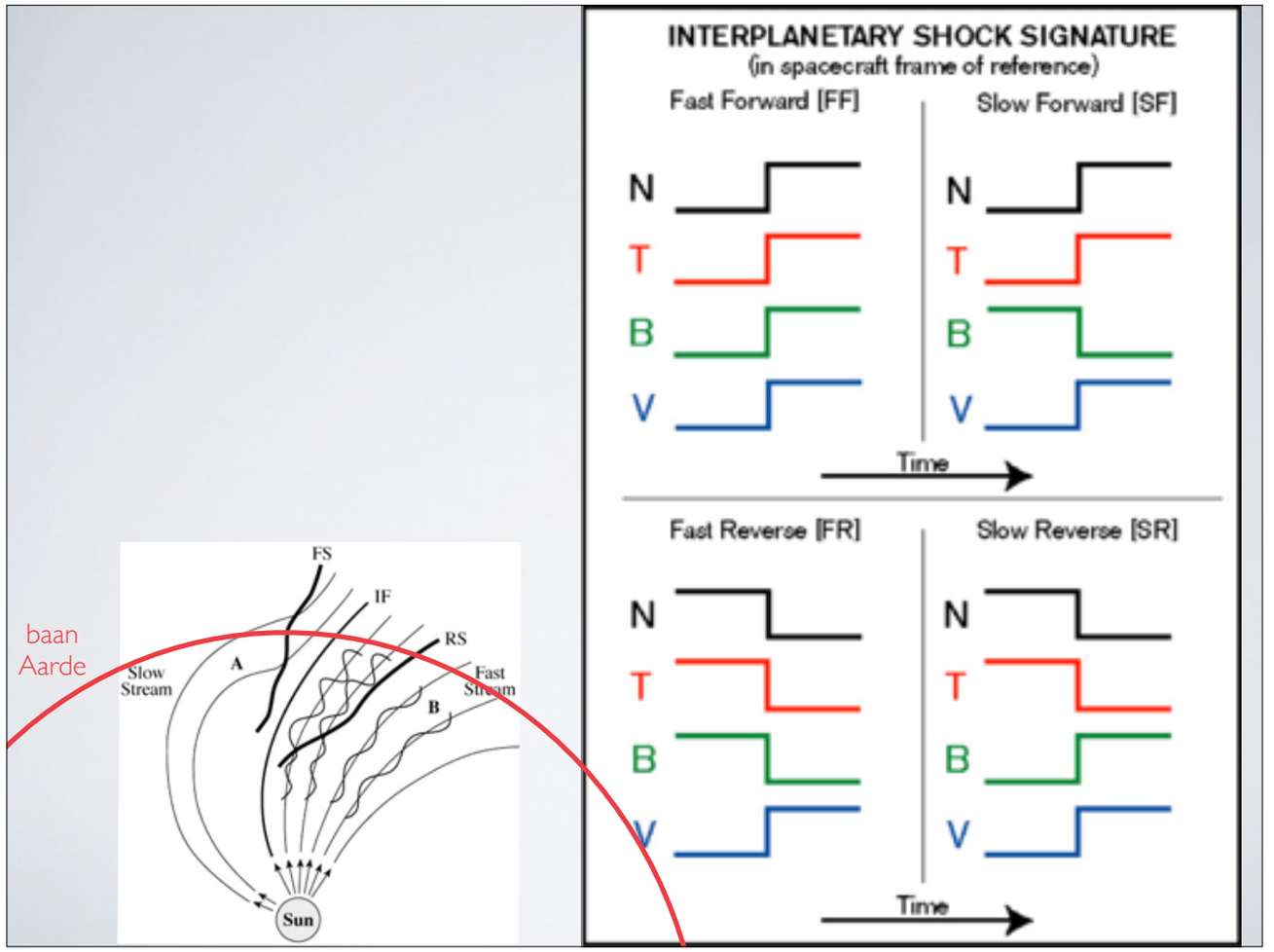
TIJD - BOOGLENGTE

baan
Aarde



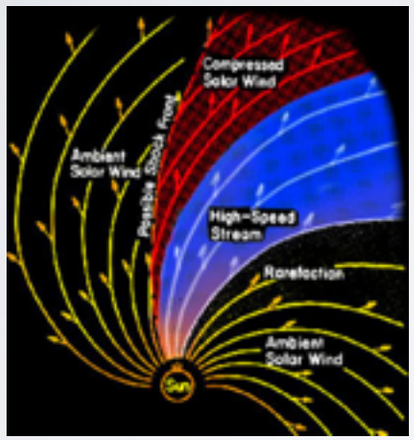


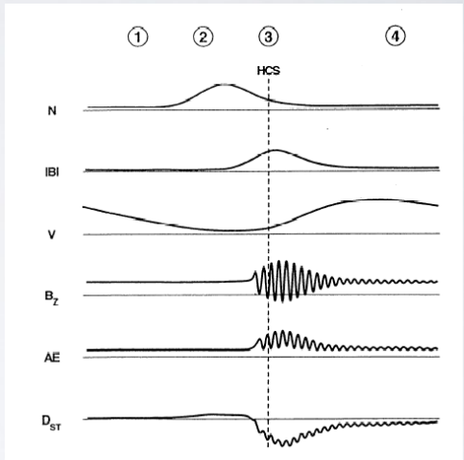
The Dst is a geomagnetic index which monitors the world wide magnetic storm level. It is constructed by averaging the horizontal component of the geomagnetic field from mid-latitude and equatorial magnetograms from all over the world. Negative Dst values indicate a magnetic storm is in progress, the more negative Dst is the more intense the magnetic storm. The negative deflections in the Dst index are caused by the storm time ring current which flows around the Earth from east to west in the equatorial plane. The ring current results from the differential gradient and curvature drifts of electrons and protons in the near Earth region and its strength is coupled to the solar wind conditions. Only when there is an eastward electric field in the solar wind which corresponds to a southward interplanetary magnetic field (IMF) is there any significant ring current injection resulting in a negative change to the Dst index. Thus, by knowing the solar wind conditions and the form of the coupling function between solar wind and ring current, an estimate of the Dst index can be made.



The front flank needs to move of course faster than the slow plasma in front of it. The shock in the front is called a forward shock, the shock trailing the high density region is called a reversed shock. For all shocks, it is the difference in speed between the slow and the fast solar wind that drives the whole system. When a forward shock driven by a CIR passes an instrument that makes in situ measurements, the speed, density and temperature suddenly increase. When a reversed shock passes, the speed increases, but density and temperature decrease.

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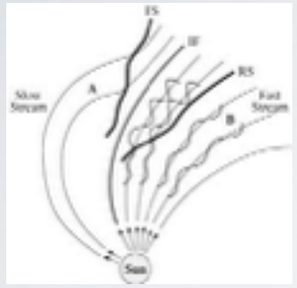


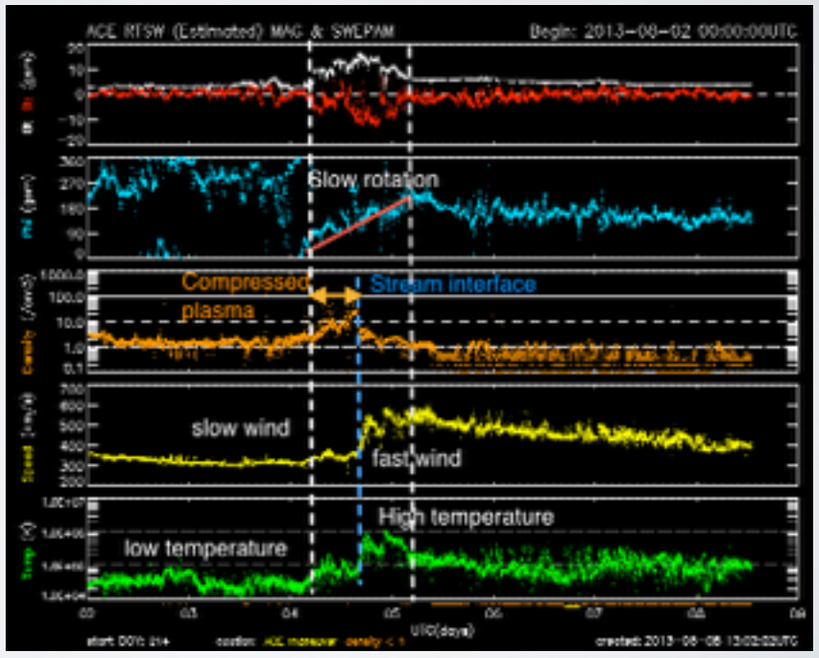


The Dst is a **geomagnetic index** which monitors the world wide magnetic storm level. It is constructed by averaging the horizontal component of the geomagnetic field from mid-latitude and equatorial magnetograms from all over the world. Negative Dst values indicate a magnetic storm is in progress, the more negative Dst is the more intense the magnetic storm. The negative deflections in the Dst index are caused by the storm time **ring current which flows around the Earth from east to west in the equatorial plane**. The ring current results from the differential gradient and curvature drifts of electrons and protons in the near Earth region and its strength is coupled to the solar wind conditions. Only when there is an eastward electric field in the solar wind **which corresponds to a southward interplanetary magnetic field (IMF)** is there any significant ring current injection resulting in a negative change to the Dst index. Thus, by knowing the solar wind conditions and the form of the coupling function between solar wind and ring current, an estimate of the Dst index can be made.

The **Auroral Electrojet Index, AE,** is designed to provide a global, quantitative measure of **auroral zone magnetic activity produced by enhanced Ionospheric currents** flowing below and within the auroral oval.

ZONDER SCHOK





On Aug 4, an interaction region of a slow and fast solar wind arrived near Earth. This interaction region is indicated in the ACE graphs with white dotted lines in the figure below, denoting the beginning and the end of this particular solar wind event. The magnetic field became much stronger as there is a clear bump in the white curve in the top panel. The plasma is also more compressed in such a region where the slow and fast wind interact. The blue dotted line is the so-called stream interface. It is a rather abrupt transition where the solar wind speed increases suddenly and the plasma becomes hotter and less dense.
The magnetic field rotated from the sector where the magnetic field points towards the Sun (Phi = 0° or 360°) to a sector with the magnetic field pointing outwards (Phi = 180°). A rotation is however atypical for this sort of solar wind structures. In normal circumstances - if you could ever speak about normal circumstances in space weather physics - the Phi-parameter fluctuates. In the interaction region, it seems that the magnetic field has difficulties with choosing a clear pointing direction.

High speed

Increasing V profile

High temperature

High B (normally below 20nT) - high variability

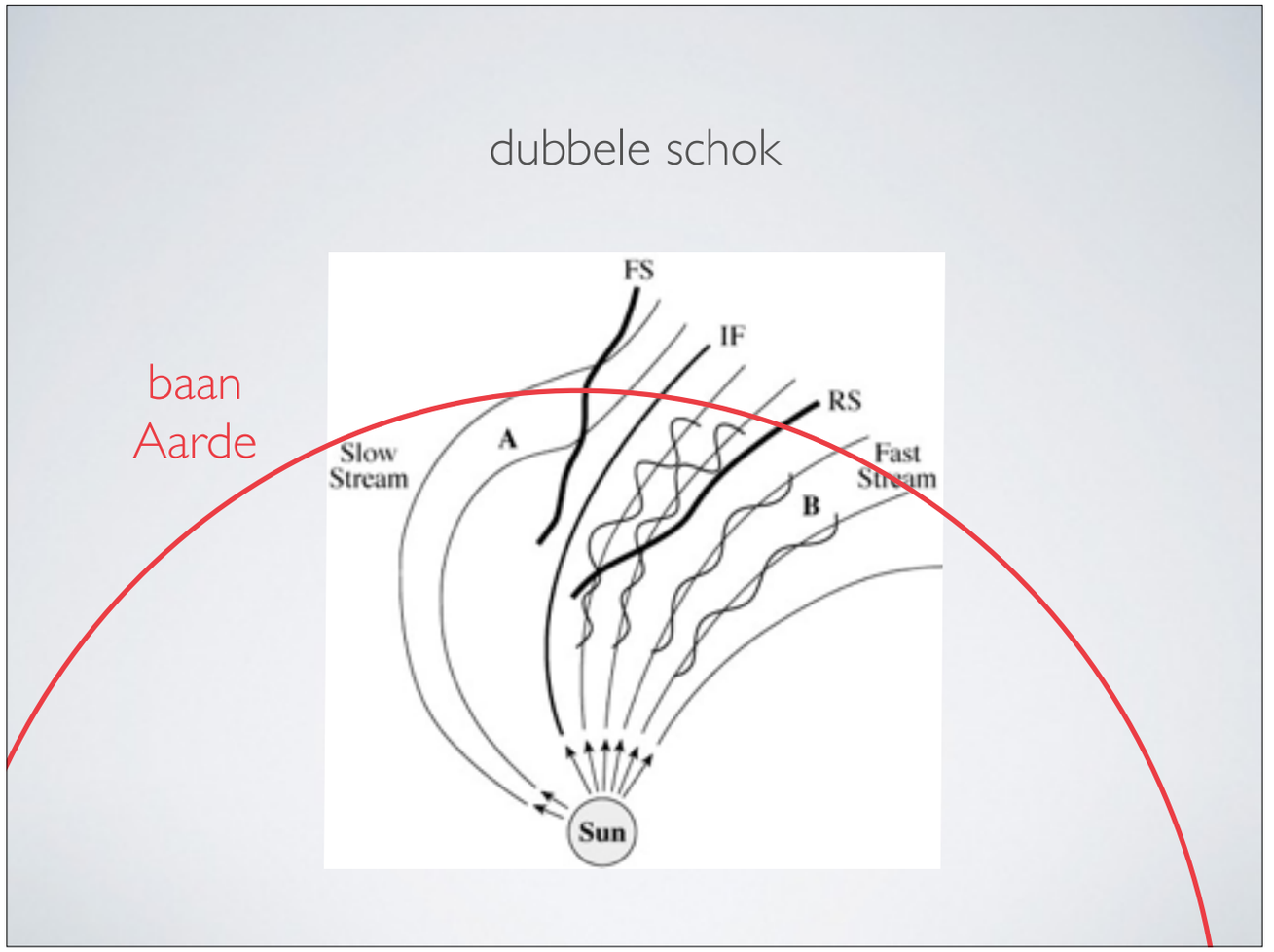
Stream interface: compression, highest values of everything (except speed)

Shocks (not very often at 1AU)

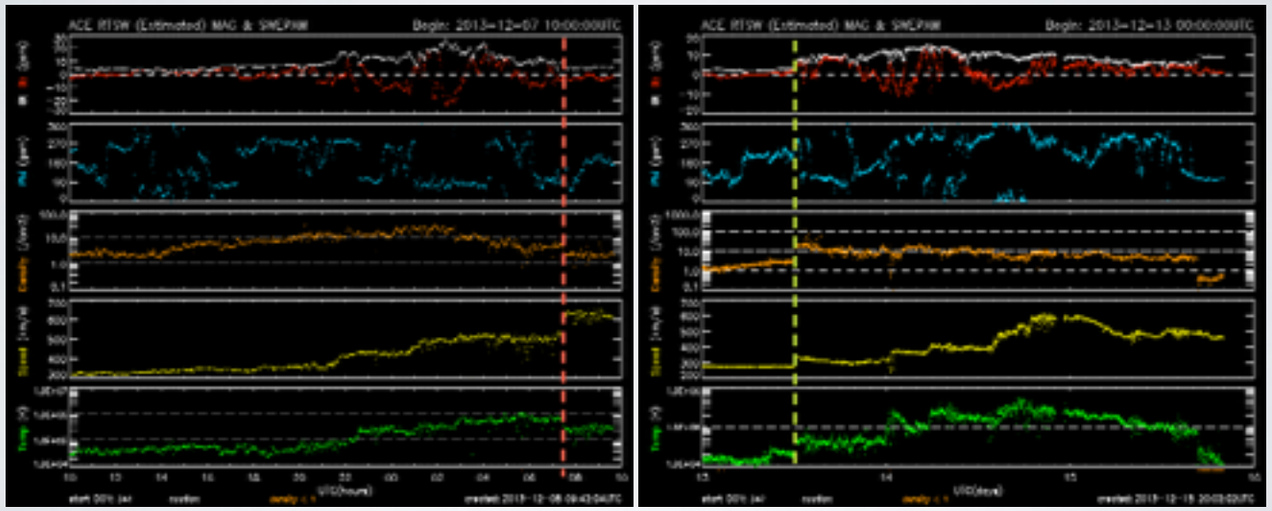
CH at ~40W on the Sun

The high speed part can also be geoeffective if V is > 600 and Bz <-5nT

dubbele schok

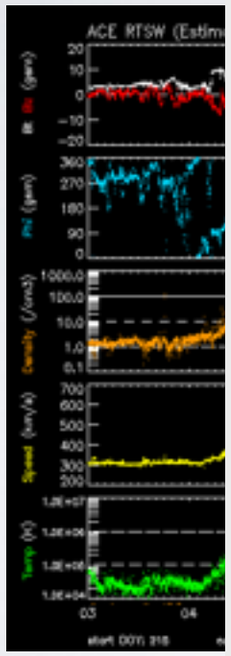


MET - EXCEPTIONEEL



Forward and Reversed Shocks are usually formed well behind Earth which is at 1AU. So, the reversed shock on December 8 and the forward shock on December13 recorded by ACE were exceptional.

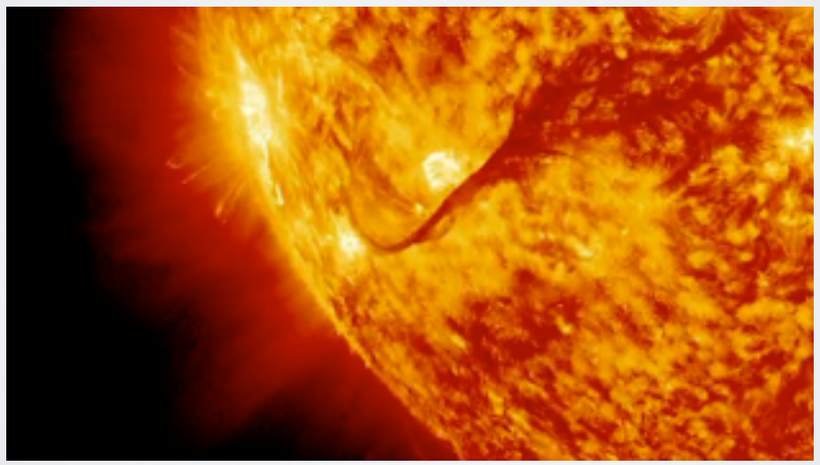
INTERPRETEREN



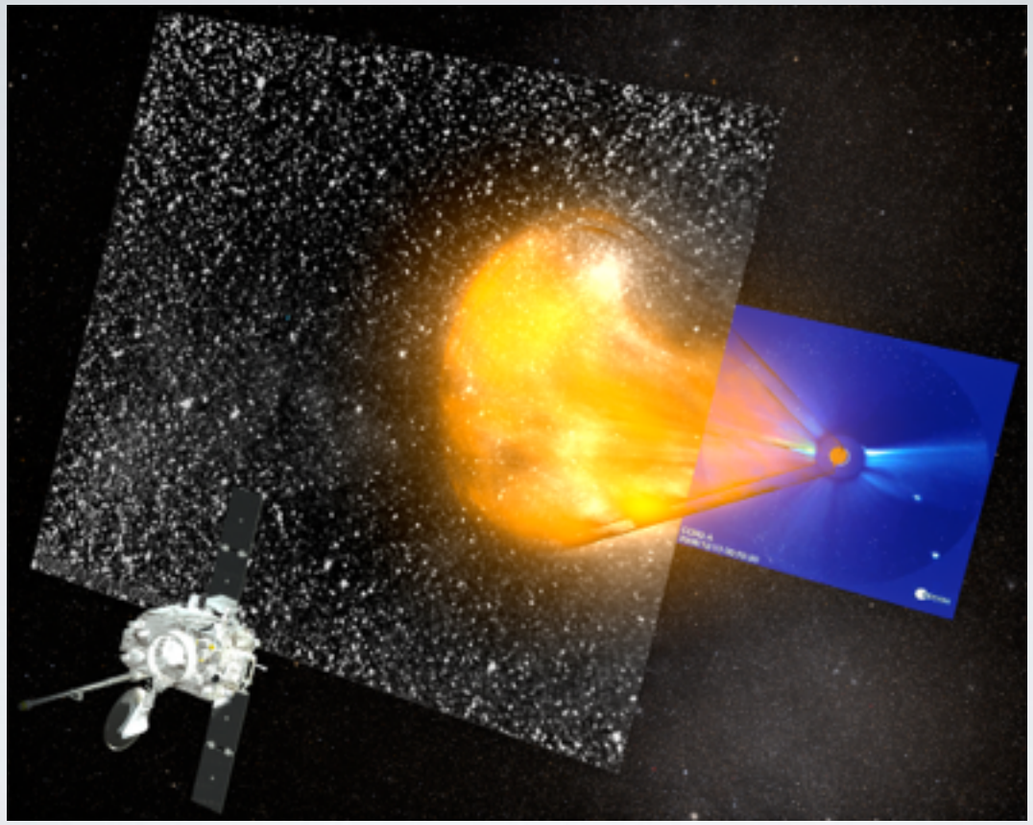
zonder een volledig beeld
wanneer is het plasma vertrokken dat je in situ waarneemt?

CME

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

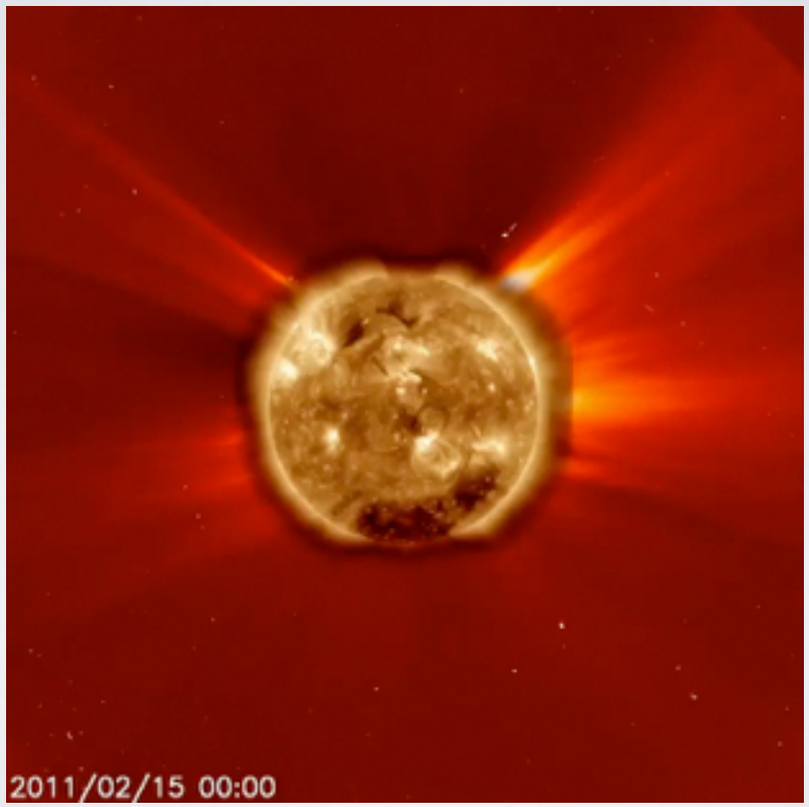


enorm groot
lage dichtheid, maar enorm groot en daardoor massief.

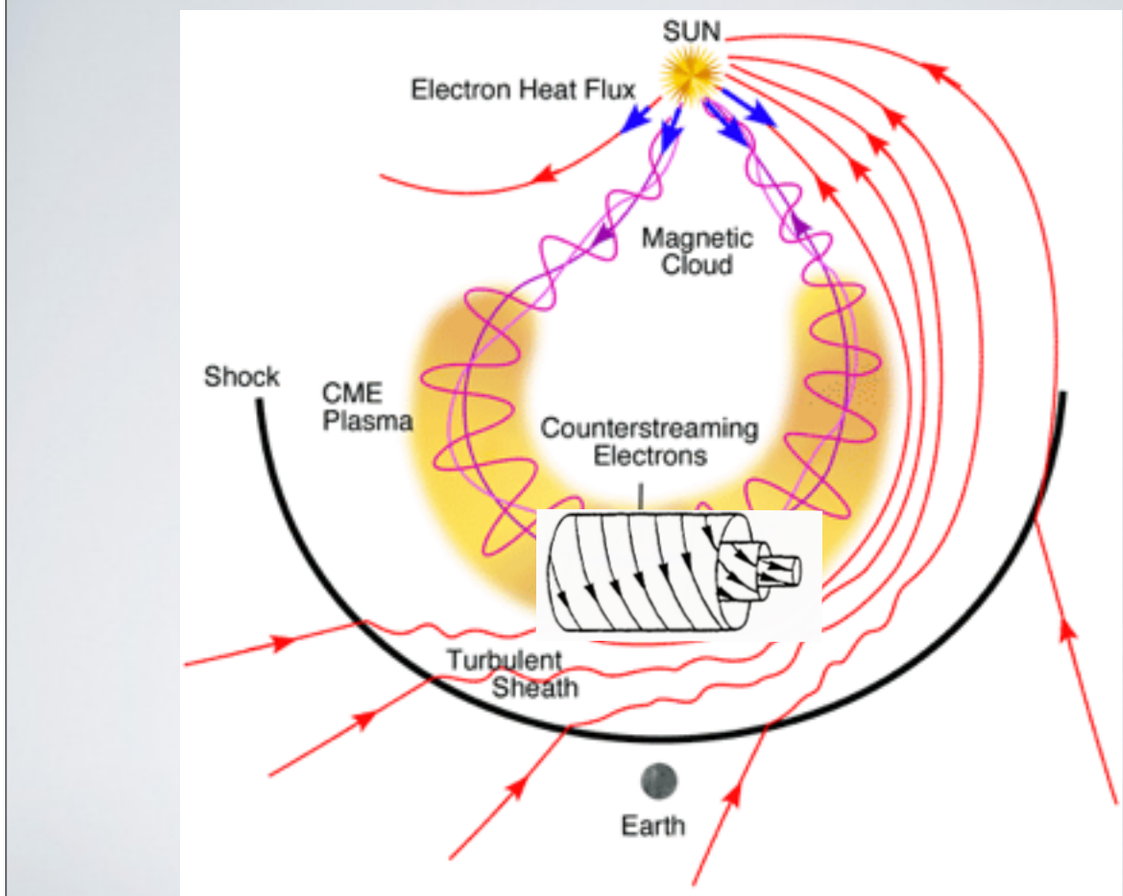


TRANSIENT - EXTRA MASS

HALO CME



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.



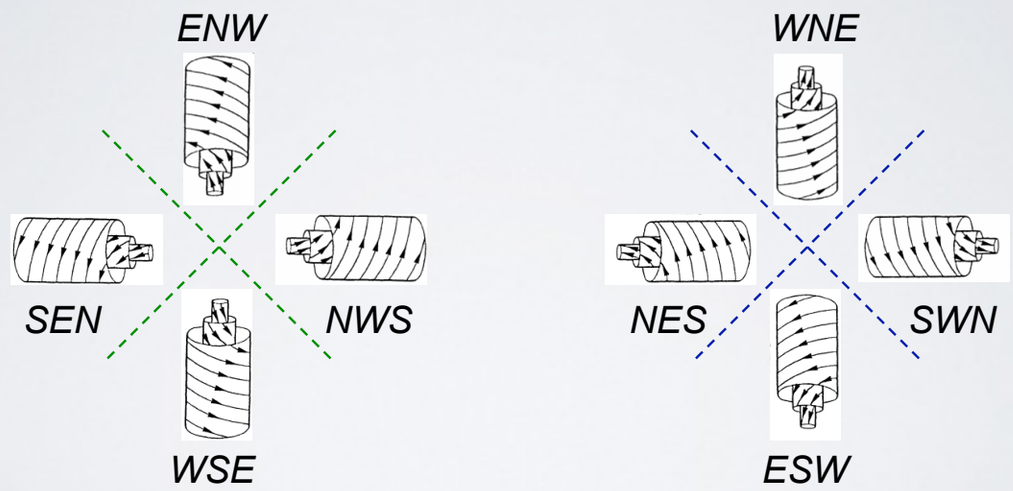
Shock, if ICME is fast enough
Shocked sheath plasma
compressed - heated - strong B - varying direction of B
Driver gas, i.e. ICME
cool - steady strong B - large scale smooth field rotation (Large-scale smooth field rotation (magnetic cloud)) : in about 30% of cases
- decreasing speed

A CME-driven shock has larger angular extent than the CME itself!
To be geoeffective, the CME-associated disturbance should:
1) arrive to the Earth;
2) have a suitable magnetic field configuration: IMF Bz component should be negative (southward), strong enough and long-lasting.

tijdelijke oorzaak
afmetingen: film van bart van der holst, michigan
http://csem.engin.umich.edu

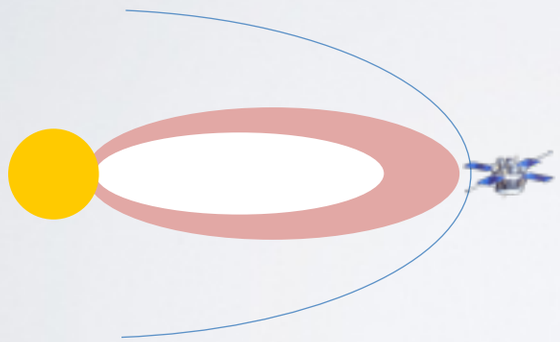
Even CMEs originating at the limb can arrive to the Earth (provided they are wide enough). In Most of such cases however, only the inerplanetary shock is observed as the angular extend of the shock is larger than that of a corresponding CME. The CME thus misses the Earth and only the shock arrives. (magnetically connected)
An example: October 21, 2003: EIT wave observed above the eastlimb, as it was propagating from the active region behind the limb as indicated by the

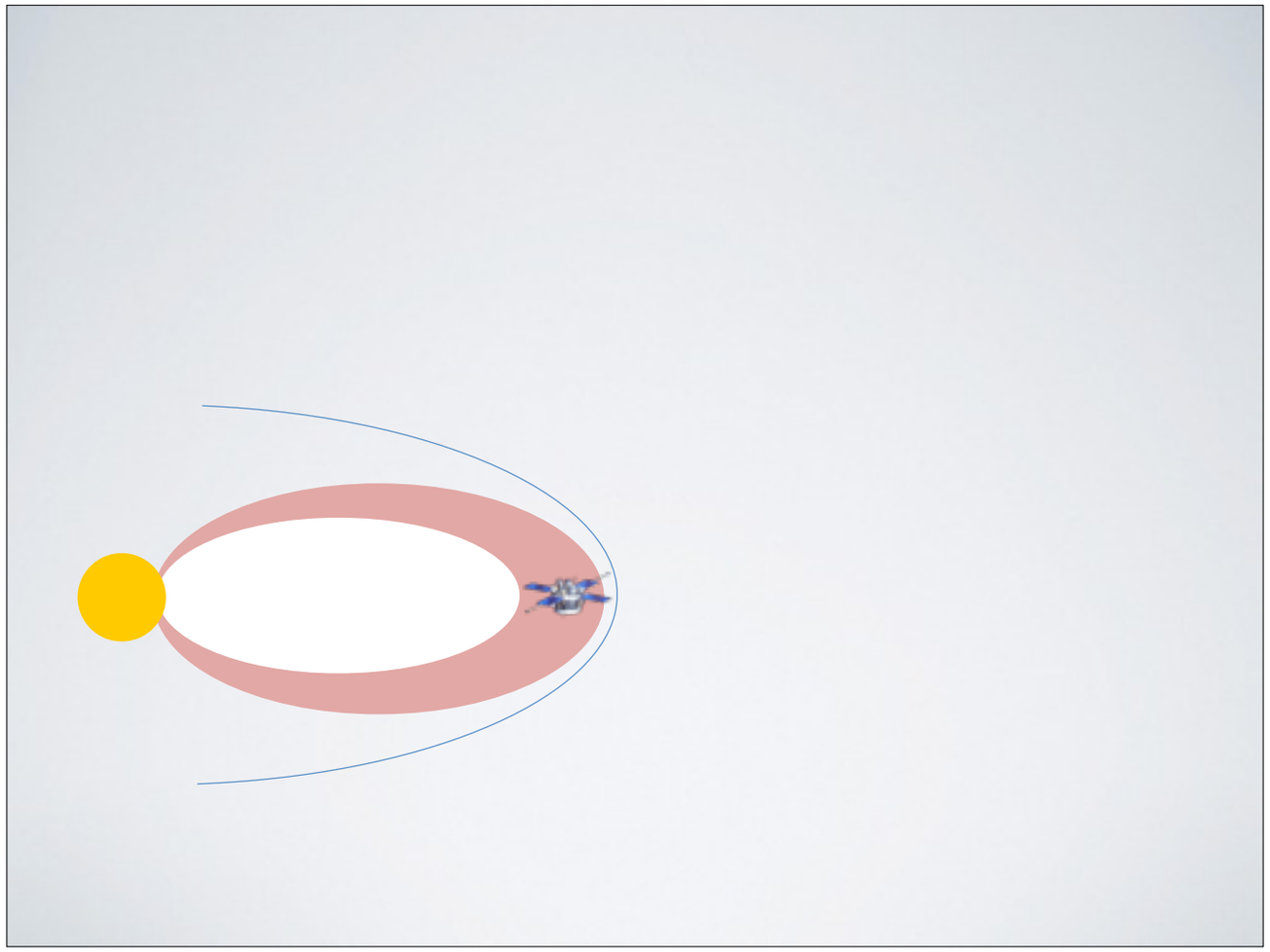
ORIENTATIE

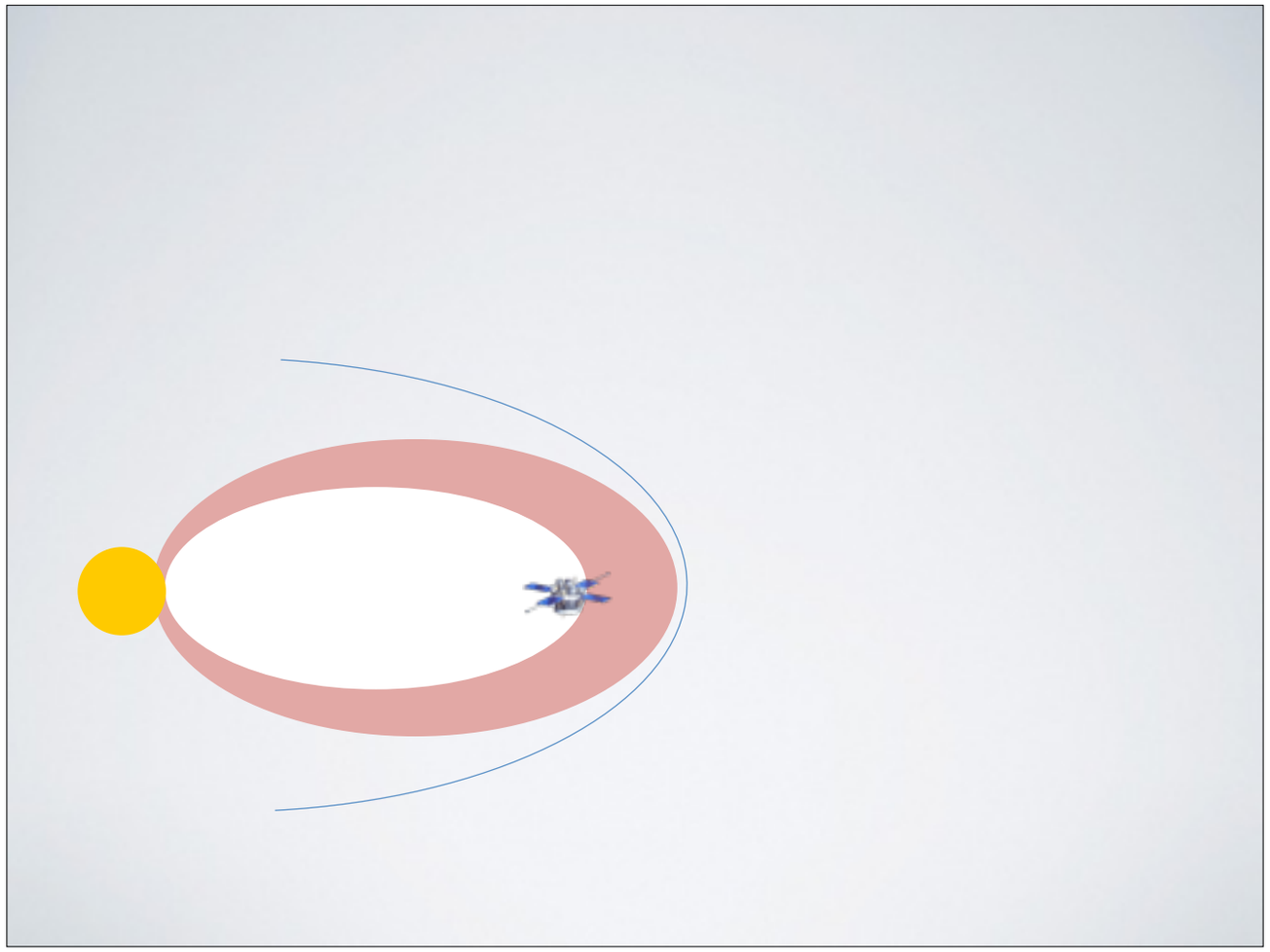


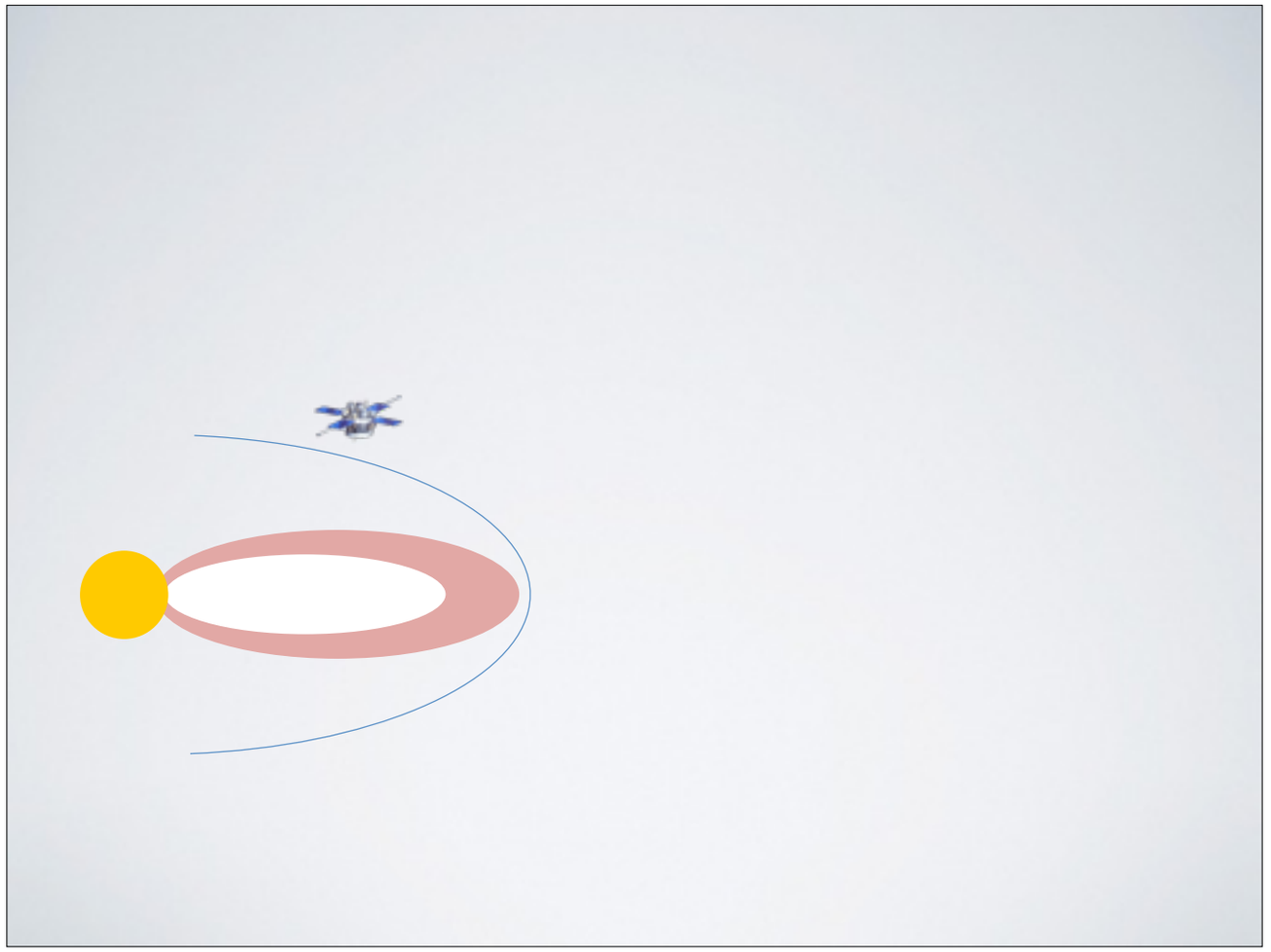
6 out of 8 flux rope types contain southward Bz!
Additionally, one should not forget the sheath plasma!

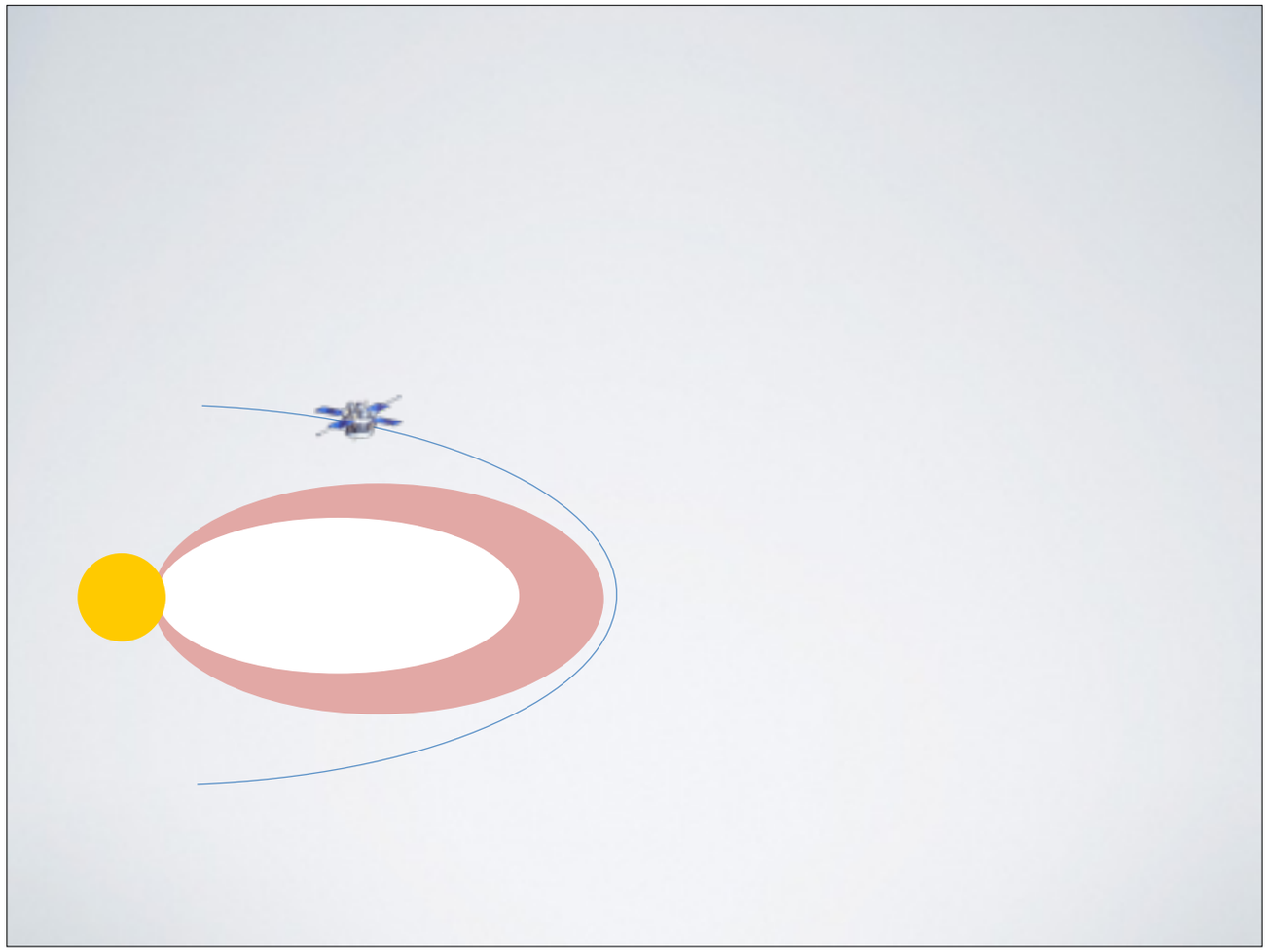
PATH

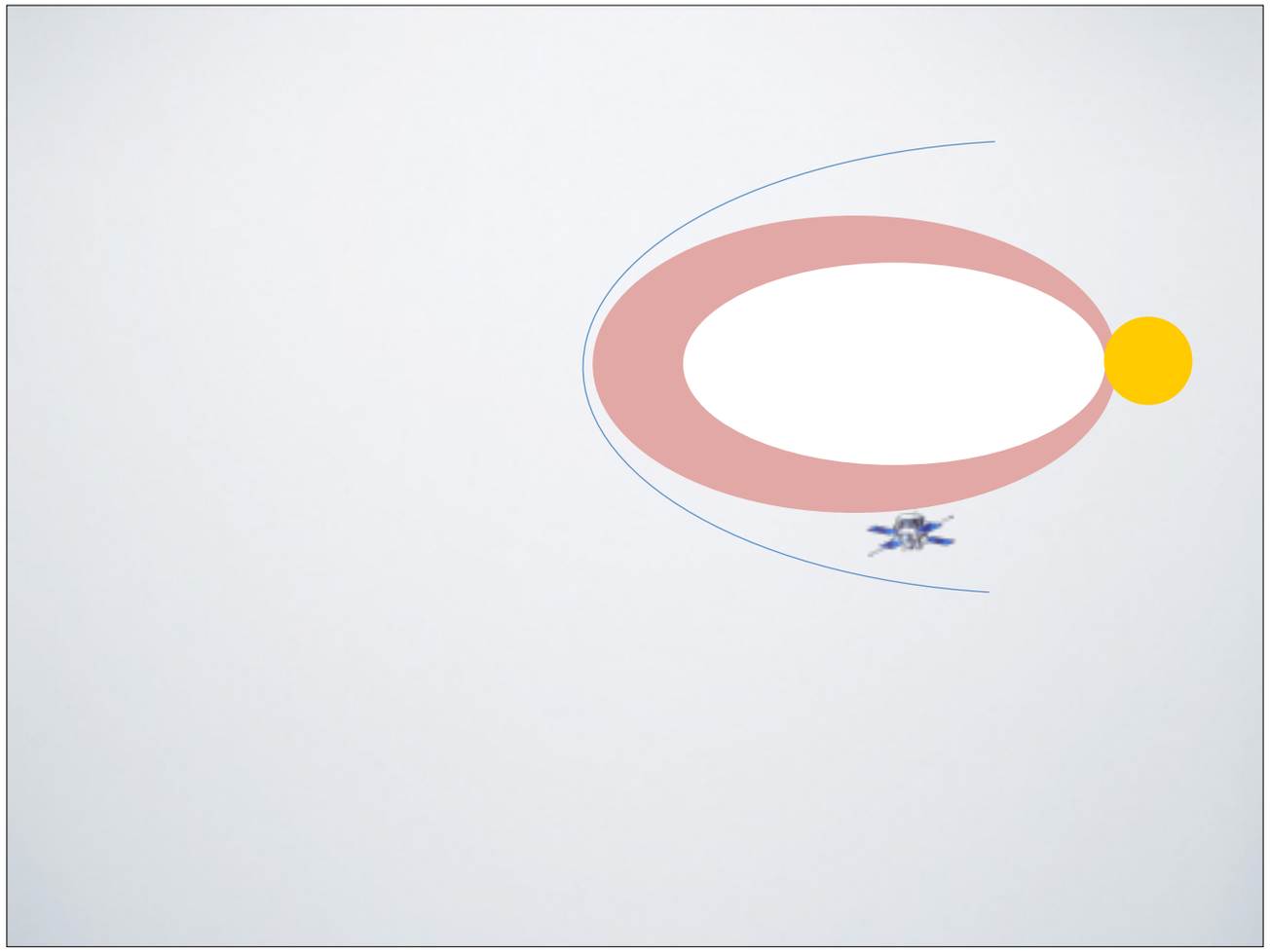




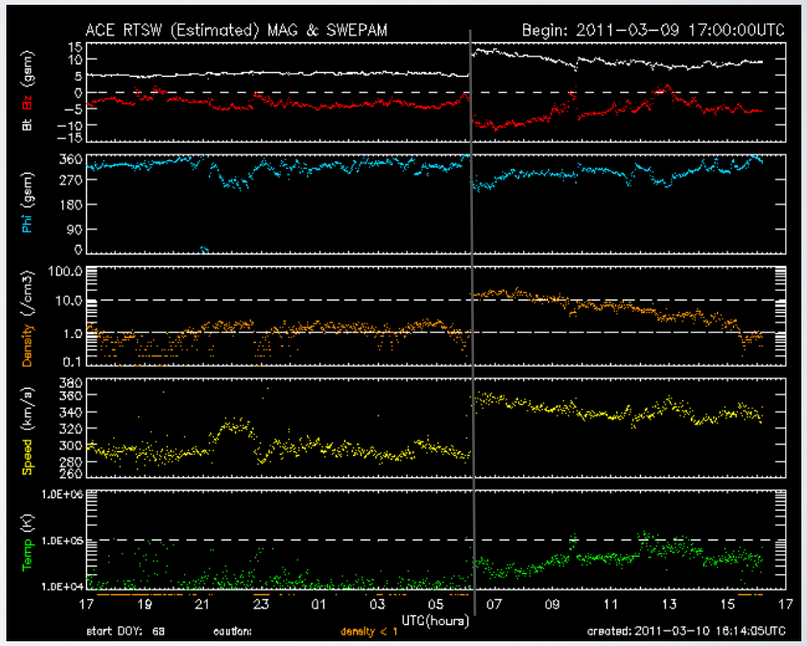






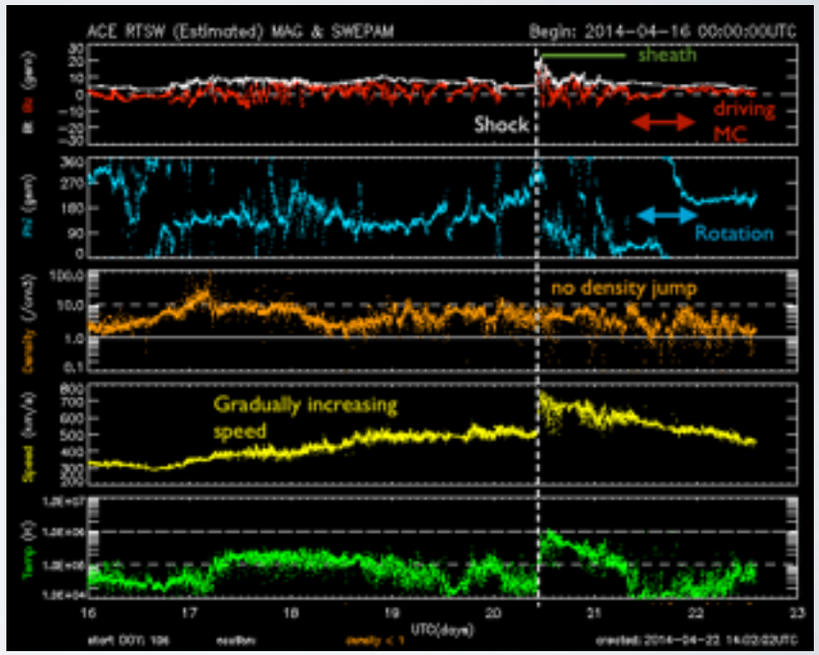


- Shock
- Short sheath
- High B
- Smooth rotation in Bz
- Decreasing speed



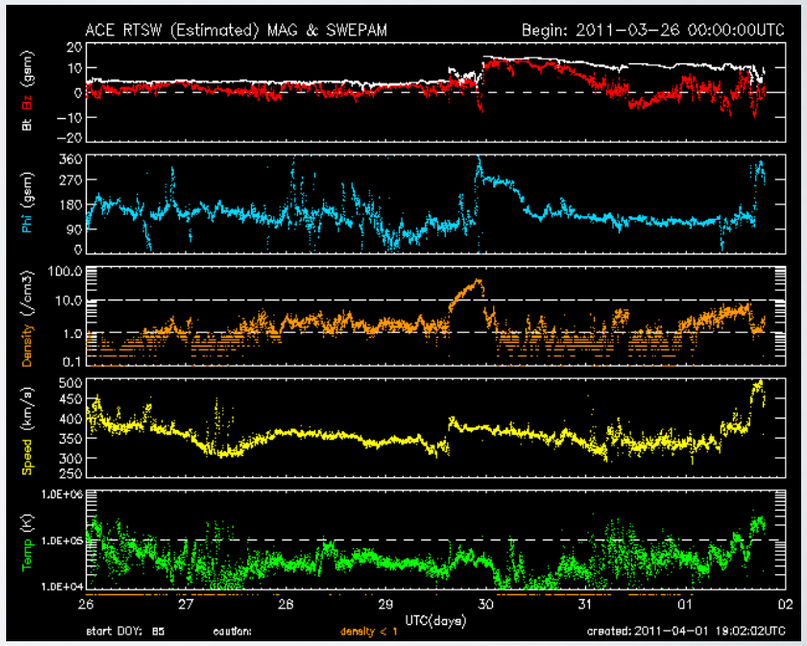
niet co-rotating
radiële passage

- Shock
- Sheath
- Rotation in Phi
- Low T
- Decreasing speed

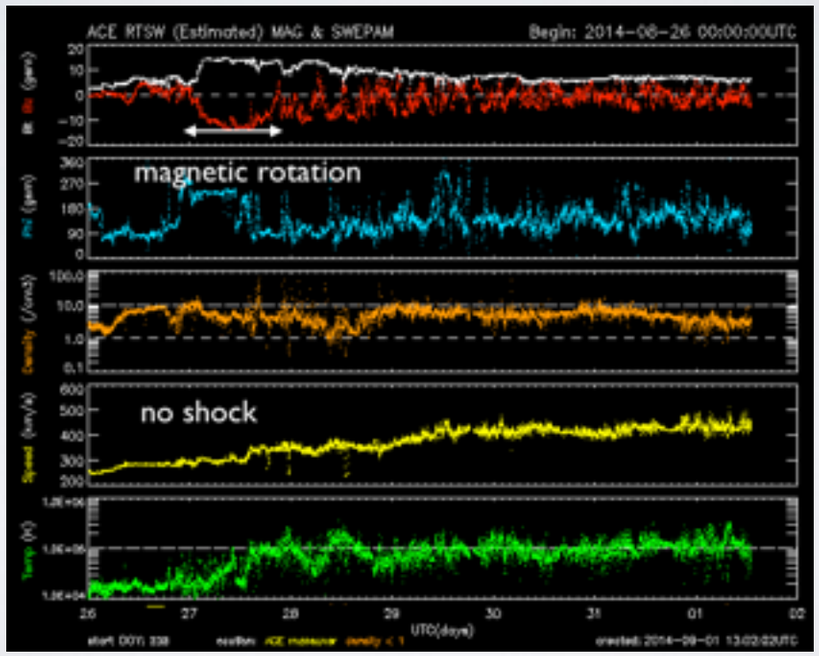


niet co-rotating
radiële passage

- Shock
- Sheath
- High B
- Smooth rotation in Phi
- Decreasing speed
- Low T



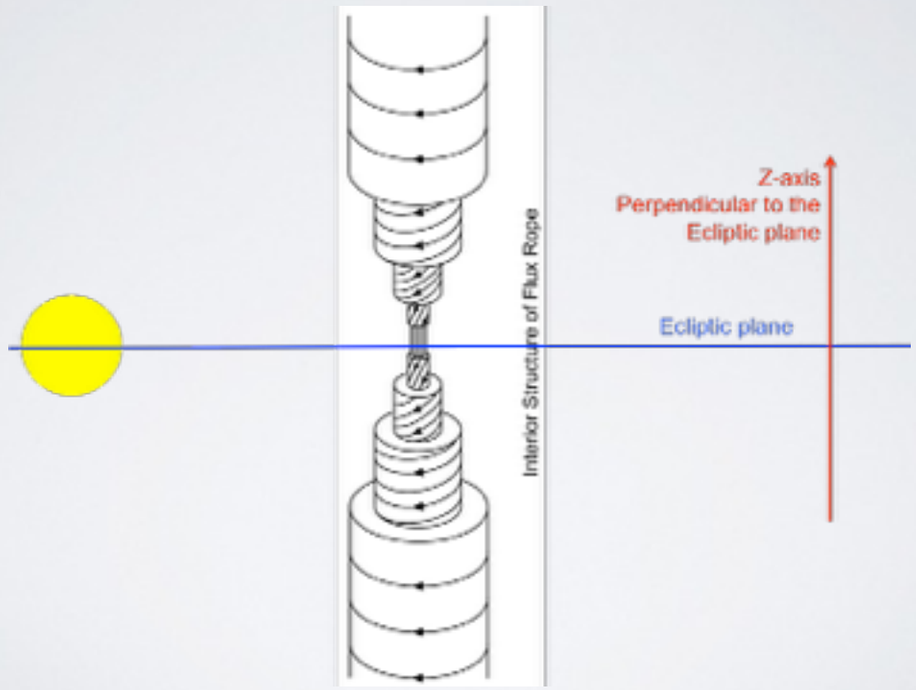
MAGNETIC CLOUD



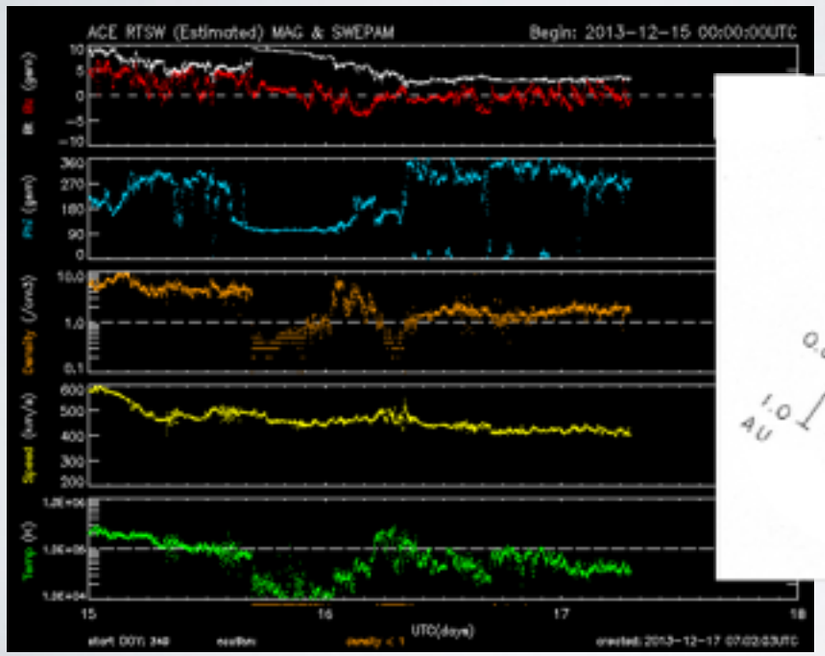
Solar wind observations of ACE indicated the passage of a magnetic cloud on August 27 which can be probably traced back to two consecutive C6 flares on August 22, one peaking at 12:27UT and one peaking at 15:52 UT both associated with partial halo CME's with very similar coronagraphic appearance.
How to interpret the ACE data?
The first signs of a magnetic structure were detected around 0:00 UT on August 27. There was no shock preceding the magnetic structure: the density (orange) nor the solar wind speed (yellow) did not jump suddenly to a higher or lower value. No problem, we can live without shocks.
Although, the data show clearly a magnetic rotation: Bz (red) evolves from zero to a strong negative value back to zero. It means that the magnetic flux rope is oriented vertical such that the magnetic field at the border of the tube that passes first ACE is oriented along the plane perpendicular to the z-axis. When the tube moves further, the Bz-component grows negative and is maximum near the center of the tube. Then Bz becomes again zero telling us that the magnetic field is oriented along the plane perpendicular to the z-axis but now in the opposite direction compared with the front side of the tube. If these sentences are too much to understand at once, reread them with the cartoon below in mind. The flux rope cartoon is taken from an article 'Magnetic stress in solar system plasmas' , Aust. J. Phys, 52, 1999 by C.T. Russel. The ecliptic plane is reduced to a line since the cartoon presents a side view of the system. The flux rope moves to the right and passes at some point ACE.

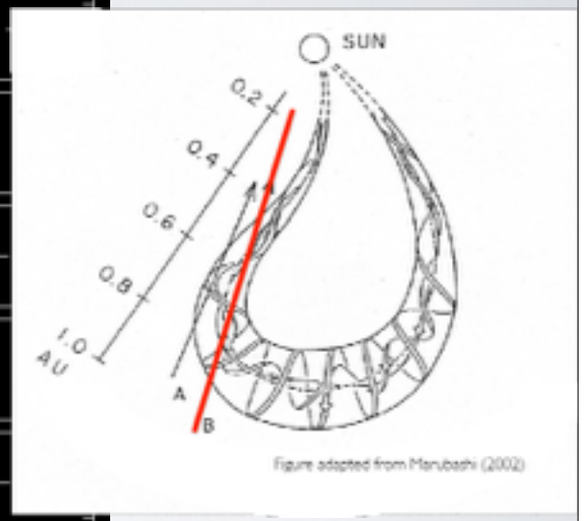
There is however 1 particularity: you expect the temperature to drop while passing a magnetic cloud. This is not really the case. But again, no problem. The magnetic rotation is clear enough to determine the 'thing' as a magnetic cloud.

FLUX ROPE


Z-axis
Perpendicular to the
Ecliptic plane
Ecliptic plane
Interior Structure of Flux Rope

ICME ZONDER SCHOK

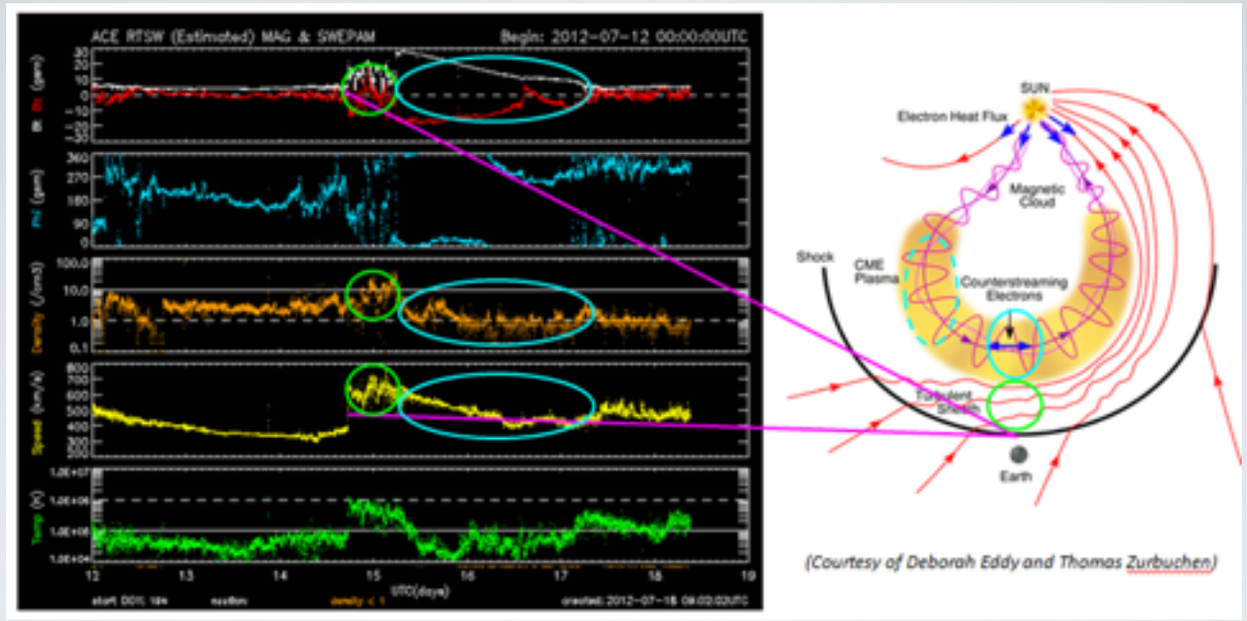


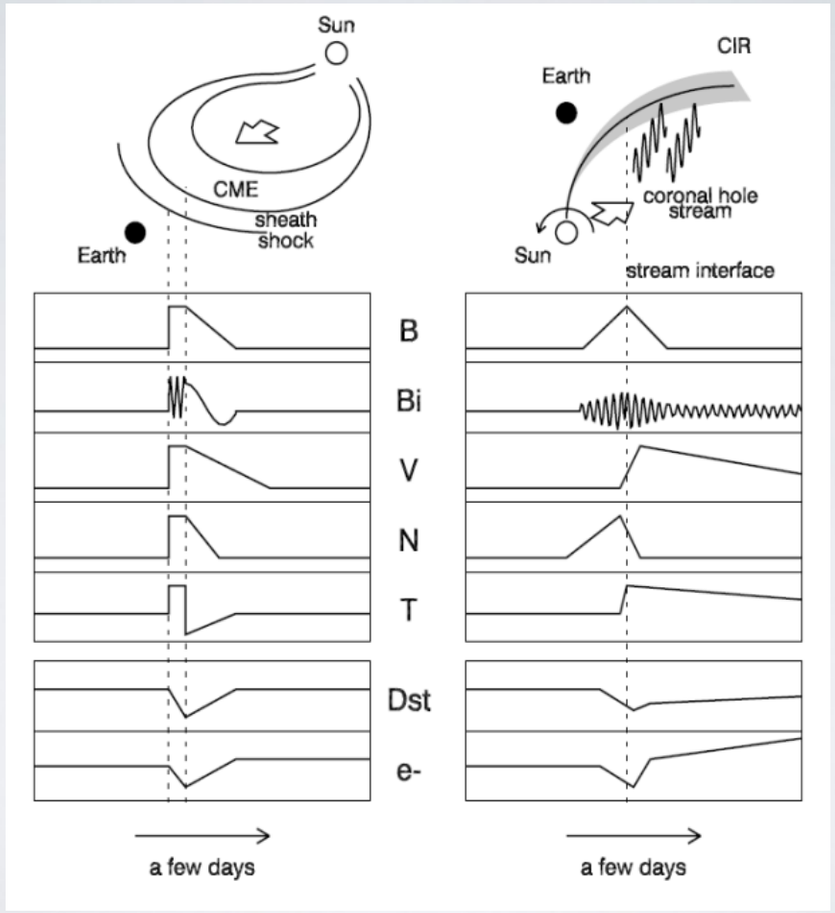


On December 15, 2013 between 16UT and 17UT, a few solar wind parameters suddenly jumped to a lower/higher value: the magnetic field increased, while the temperature and density dropped. The magnetic field strength had a smooth profile indicating that ACE passed through a flank of an interplanetary CME (ICME).

As the CME travels further in space, ACE located at 1AU (Astronomical Unit) 'sees' that part of the CME along the path of the red line in the cartoon.

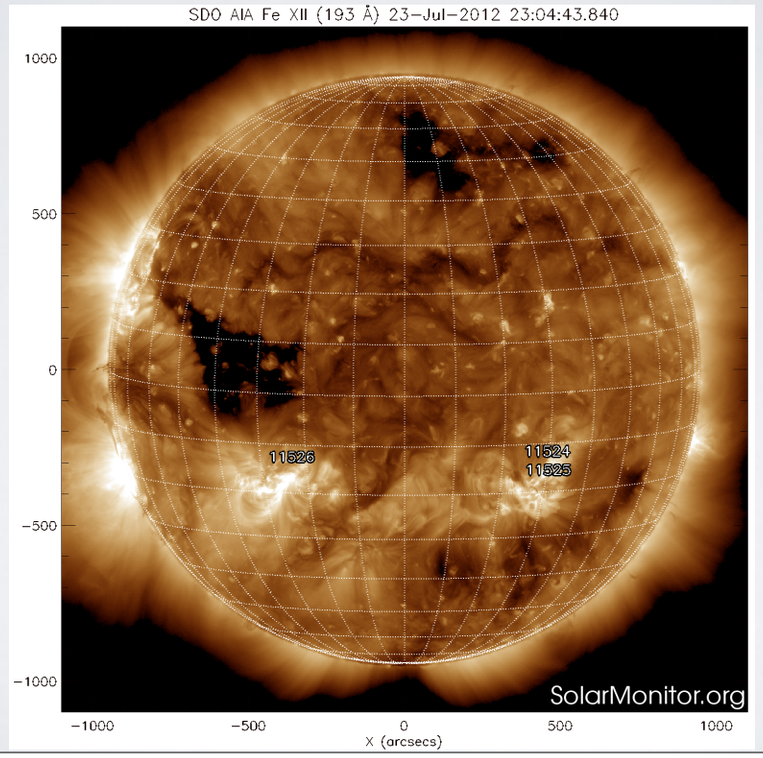
It is a speed difference between plasmas that causes shocks to be formed. In this case, there was no preceding shock formed because the solar wind and the CME had comparable speeds of around 500 km/s.


ACE RTSW (Estimated) MAG & SWEPAM
Begin: 2012-07-12 00:00:00UTC
Bt (nT)
Phi (deg)
Density (p/cm3)
Speed (km/s)
Temp (K)
UTC(days)
SUN
Electron Heat Flux
Magnetic Cloud
Shock
CME Plasma
Counterstreaming Electrons
Turbulent Sheath
Earth
(Courtesy of Deborah Eddy and Thomas Zurbuchen)

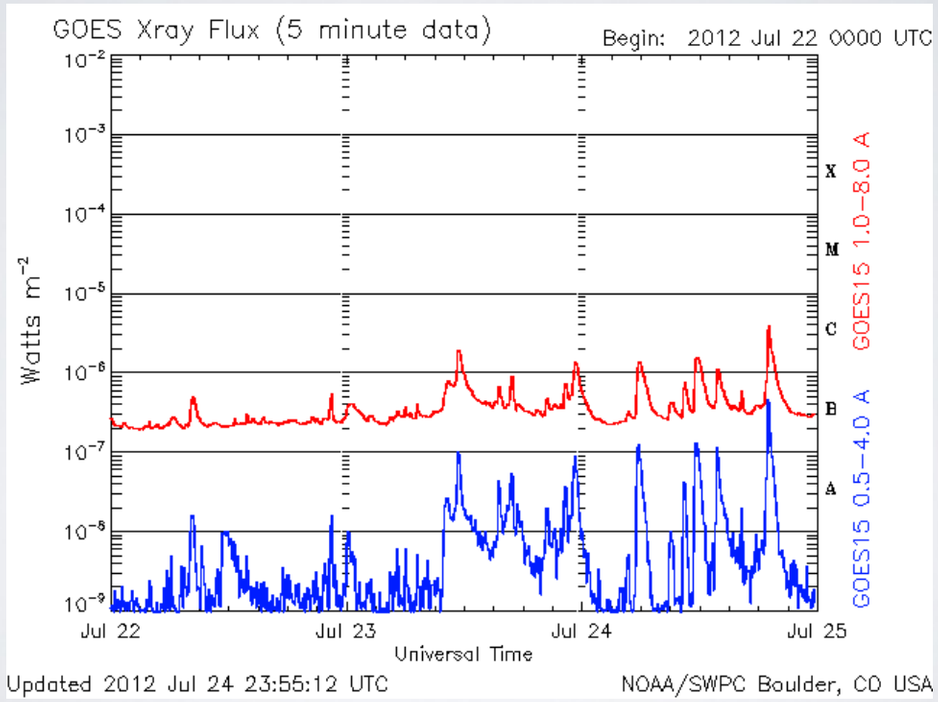

Sun
CME
sheath
shock
Earth
CIR
Earth
coronal hole
stream
Sun
stream interface
B
Bi
V
N
T
Dst
e-
a few days
a few days

EEN BIJNA HIT

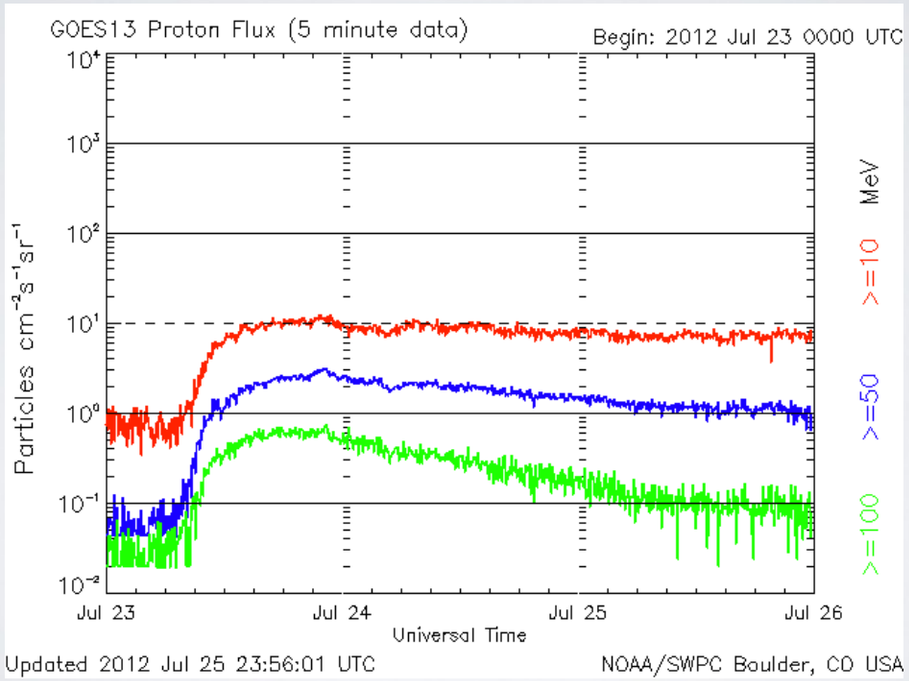
NEAR EVENT


SDO AIA Fe XII (193 Å) 23-Jul-2012 23:04:43.840
1000
500
0
−500
−1000
11526
11524
11525
SolarMonitor.org
−1000
−500
0
500
1000
X (arcsecs)

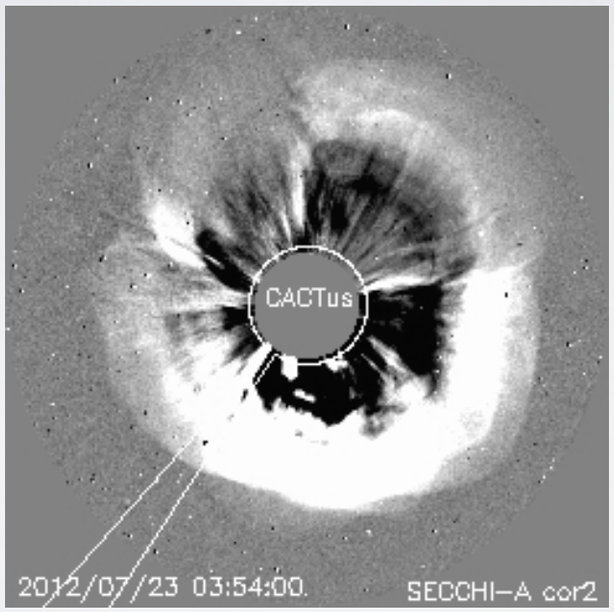
X-RAY FLUX


GOES Xray Flux (5 minute data)
Begin: 2012 Jul 22 0000 UTC
Watts m-2
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
X
M
C
B
A
GOES15 1.0–8.0 A
GOES15 0.5–4.0 A
Jul 22
Jul 23
Jul 24
Jul 25
Universal Time
Updated 2012 Jul 24 23:55:12 UTC
NOAA/SWPC Boulder, CO USA

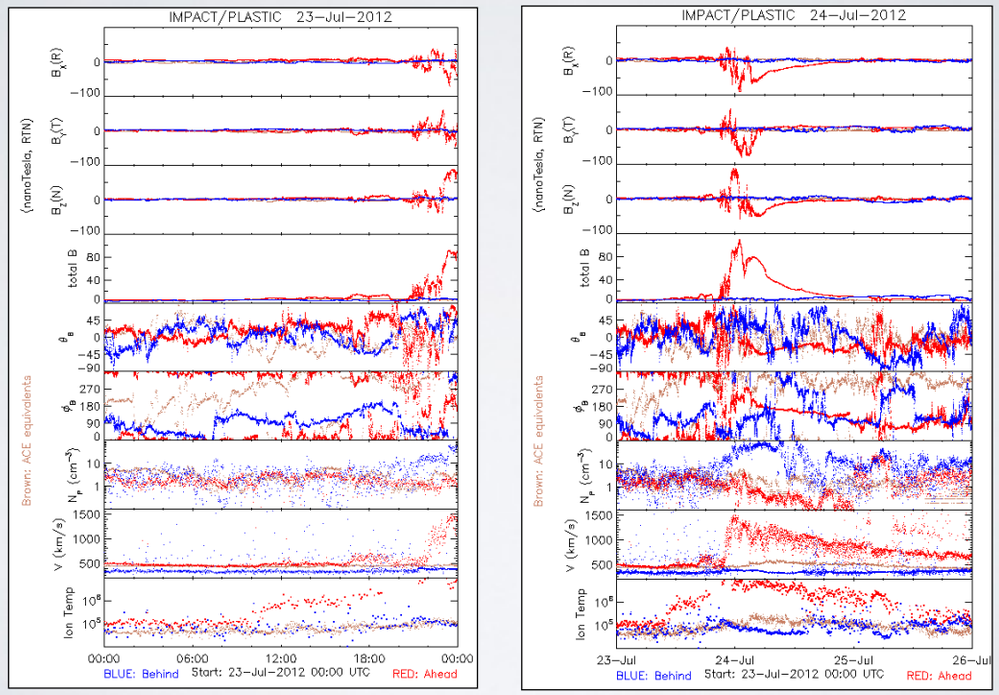
PROTON FLUX


GOES13 Proton Flux (5 minute data)
Begin: 2012 Jul 23 0000 UTC
Particles cm⁻²s⁻¹sr⁻¹
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
Jul 23
Jul 24
Jul 25
Jul 26
Universal Time
MeV
>=10
>=50
>=100
Updated 2012 Jul 25 23:56:01 UTC
NOAA/SWPC Boulder, CO USA

CORONAL MASS EJECTION



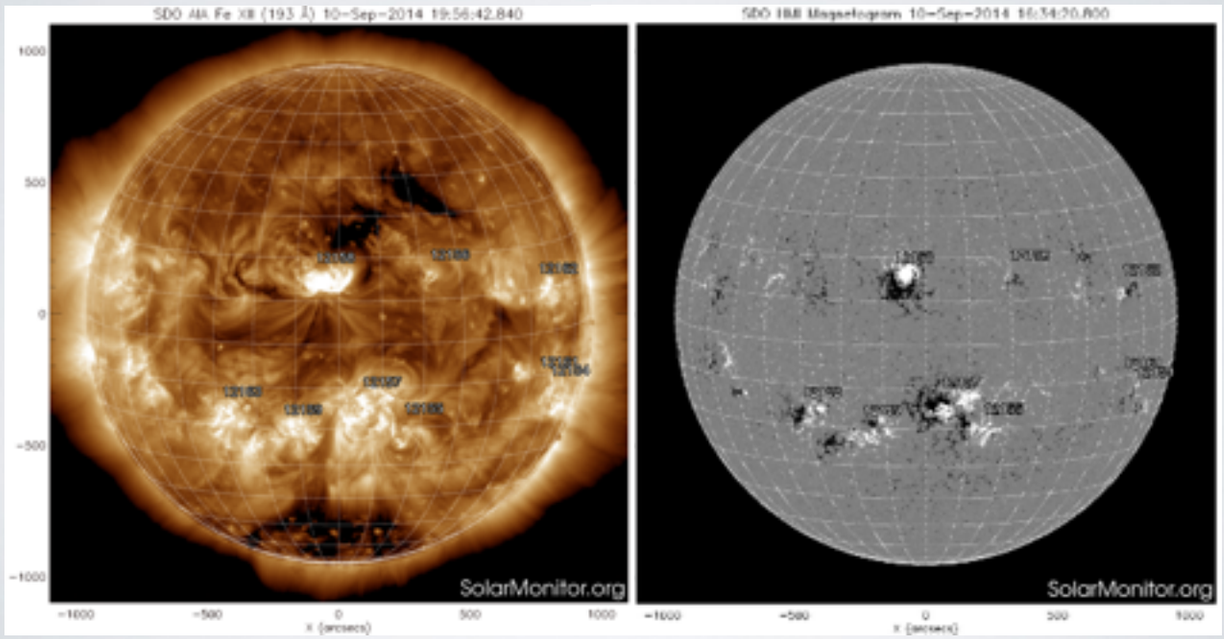
IN SITU


IMPACT/PLASTIC 23–Jul–2012
⟨nanoTesla, RTN⟩
Brown: ACE equivalents
00:00
06:00
12:00
18:00
00:00
BLUE: Behind
Start: 23–Jul–2012 00:00 UTC
RED: Ahead

IMPACT/PLASTIC 24–Jul–2012
⟨nanoTesla, RTN⟩
Brown: ACE equivalents
23–Jul
24–Jul
25–Jul
26–Jul
BLUE: Behind
Start: 23–Jul–2012 00:00 UTC
RED: Ahead

3 DAGEN UIT HET LEVEN VAN EEN VOORSPELLER

10 SEPTEMBER 2014
'S AVONDS



:Issued: **2014 Sep 10 1926 UTC**
:Product: documentation at http://www.sidc.be/products/flaremail
#---#
Large flare alerts from the SIDC (RWC-Belgium), detected in GOES
X-ray data
#---#

A class X1.6 solar X-ray flare occurred on 2014/09/10 with peak time 17:45 UT

#---#
Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium
Fax : 32 (0) 2 373 0 224
Tel.: 32 (0) 2 373 0 491

On 10 September at 17:45UT, NOAA 2158 produced the 35th X-class flare of the ongoing solar cycle. The X1.6 event was extensively covered in this news item. The images underneath show the sunspot region in white light and the corresponding magnetogram about 30 minutes prior to the flare's peak, and the flare at its maximum flux as observed in SDO/AIA 171. The flare took place along the borderline between negative (blue) and positive (red) magnetic polarity.

Graph underneath (Annotated version) shows the evolution of the flare in x-ray (GOES) and EUV (PROBA2/LYRA in W/m2; Solar Demon AIA 094 in counts). One can see that the EUV emissions peak 6-12 minutes later than those from x-ray. This is due to the cooling of the post-flare coronal loops, whose emissions become then better visible in the less energetic EUV passbands. The AIA 094 emissions also show a second peak about 30 minutes after its maximum. This second peak is not visible in x-ray. This "extra" EUV emission does not originate from the original flare site, but most probably from a volume of higher coronal loops. This may indicate there's additional post-flare loop reconnection, but at a lower temperature than during the flare's main peak. This is called the "EUV late phase". No doubt this flare will generate quite a few scientific papers!

The geomagnetic storm from the CME related to this X1 flare did not live up to the expectations, as the CME's magnetic field was directed mostly northward. This prevented a good connection with the Earth's magnetic field, and thus severe geomagnetic storming was not possible. Nice polar lights were observed, but they were confined to the usual places (Scandinavia, Canada, Alaska,...). Nonetheless, some aurora were photographed from Franeker, Friesland (northern part of the Netherlands), as picture underneath demonstrates. It was taken by Vincent van Leijen on 12 September at 23:05LT, when the storm was most intense. See also this web page. Can you see the Big Dipper constellation?

:Issued: **2014 Sep 10 1858 UTC**
:Product: documentation at http://www.sidc.be/products/presto
#---#
FAST WARNING '**PRESTO**' MESSAGE from the SIDC (RWC-Belgium)
#---#

An X1.6 flare took place in NOAA 2158. The flare peaked at 17:45UT. Coronal dimming and post-flare coronal loops have been observed. STEREO/WAVES show a type II burst. So, though there are currently no coronagraphic images available yet, it is very likely that a CME was associated to this event. There is also a good chance it has an Earth directed component, as the source region is located near disk center.

Further updates will be provided upon availability of data and images.
#---#
Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium
Fax : 32 (0) 2 373 0 224
Tel.: 32 (0) 2 373 0 491
#

20:58 BLT – terzake, films zijn dan al begonnen

:Issued: **2014 Sep 11 0149 UTC**
:Product: documentation at http://www.sidc.be/products/cactus
#---#
HALO CME ALERTS from the SIDC (RWC-Belgium), generated by CACTUS
#---#
A halo or partial-halo CME was detected with the following characteristics:

t0 |dt0| pa | da | v | dv | minv| maxv|
028|2014/09/10 18:00| 04 | 049| 360| 0637| 0237| 0206| 1302

Details can be found here: http://www.sidc.oma.be/cactus/out/latestCMEs.html

t0: onset time, earliest indication of liftoff
dt0: duration of liftoff (hours)
pa: principal angle, counterclockwise from North (degrees)
da: angular width of the CME (degrees),
v: median velocity (km/s)
dv: variation (1 sigma) of velocity over the width of the CME
mindv: lowest velocity detected within the CME
maxdv: highest velocity detected within the CME

03:49 BLT - nacht, dan slaap je

:Issued: **2014 Sep 11 0737 UTC**

:Product: documentation at http://www.sidc.be/products/presto

#----------#

FAST WARNING '**PRESTO**' MESSAGE from the SIDC (RWC-Belgium)

#----------#

The X1.6 flare from 10 September was associated with an asymmetric full halo coronal mass ejection (CME). It was first seen by SOHO/LASCO at 18:00UT and had an average plane-of-the-sky speed of about 800 km/s. The CME is expected to arrive at Earth on 12 September around 21:00UT (+/-12 hours). Major to severe geomagnetic storming is expected, pending the orientation of the magnetic field of the plasma cloud.

#----------#

Solar Influences Data analysis Center - RWC Belgium

Royal Observatory of Belgium

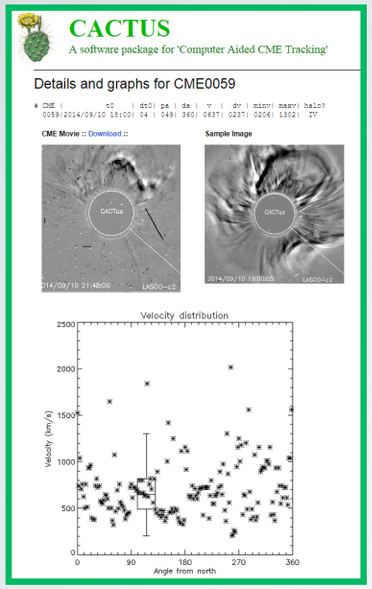
Fax : 32 (0) 2 373 0 224

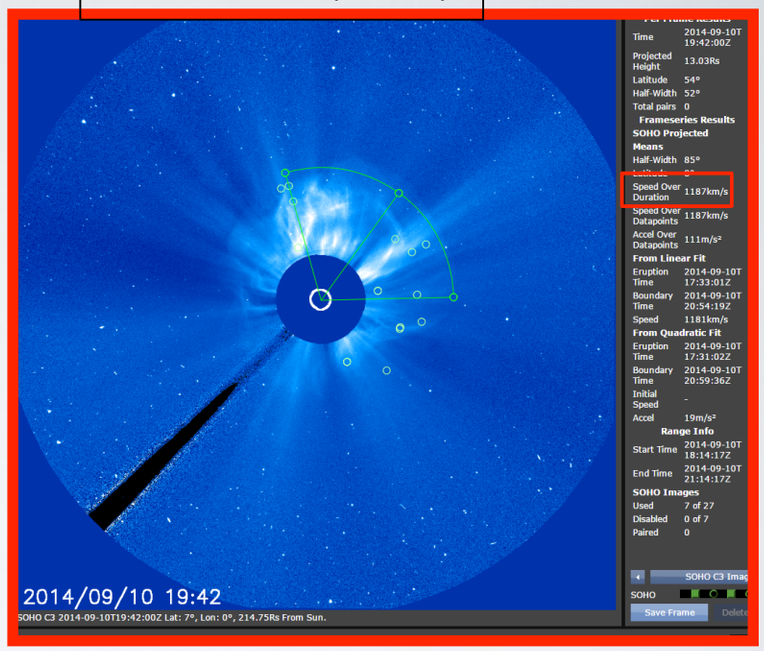
Tel.: 32 (0) 2 373 0 491

# #

09:37 BLT

STEREOCAT (NASA)





Manually (e.g. IDL, ~ 1200 km/s)

AANKOMST

- t=x/v
- modellen
- persoonlijke interpretatie

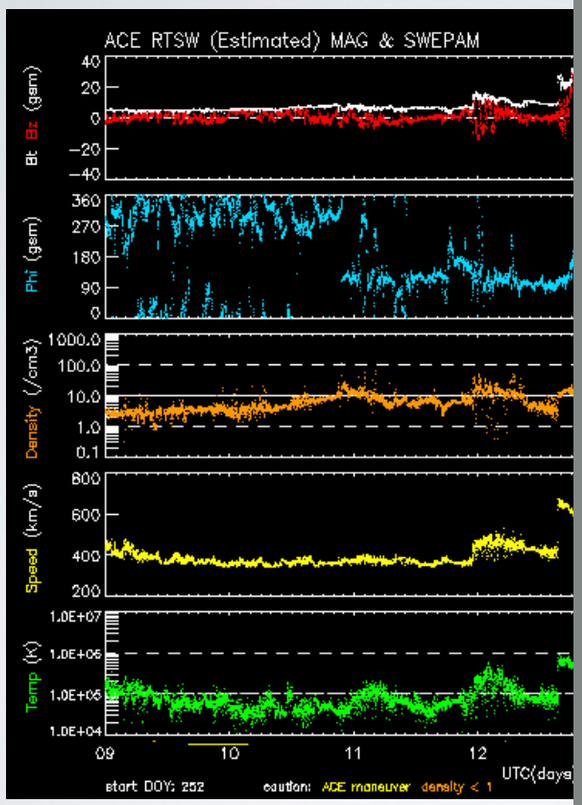
- Arrival predicted 12 Sep at 21:00UT +/- 12 hours

CME Arrival Alert
Issued **2014-09-11 09:50 UTC**

This mail contains the xml version of the CME arrival alert.
expected arrival time: 2014-09-12T21:00:00
time_uncertainty: 12
min_estimated_peak_K: 6
max_estimated_peak_K: 8
probability_of_arrival: 90

:Issued: **2014 Sep 11 1236 UTC**
:Product: documentation at http://www.sidc.be/products/meu
#---#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
(RWC Belgium)
#---#
SIDC URSIGRAM 40911
SIDC SOLAR BULLETIN 11 Sep 2014, 1209UT
SIDC FORECAST (valid from 1230UT, 11 Sep 2014 until 13 Sep 2014)
SOLAR FLARES : Active (M-class flares expected, probability >=50%)
GEOMAGNETISM : Active conditions expected (A>=20 or K=4)
SOLAR PROTONS : Proton event in progress (>10 MeV)
COMMENT:

On 10 September, NOAA 2158 produced an X1.6 flare peaking at 17:45UT. It was accompanied by an EIT wave, coronal dimming, and post-flare coronal loops. Associated to this strong flare was a full halo CME, first observed by SOHO/LASCO at 18:00UT. Estimated arrival time is 12 September at 21:00UT (+/- 12 hours). Pending the orientation of the CME's magnetic field, this may result in a major geomagnetic storm, with locally severe geomagnetic storming possible.

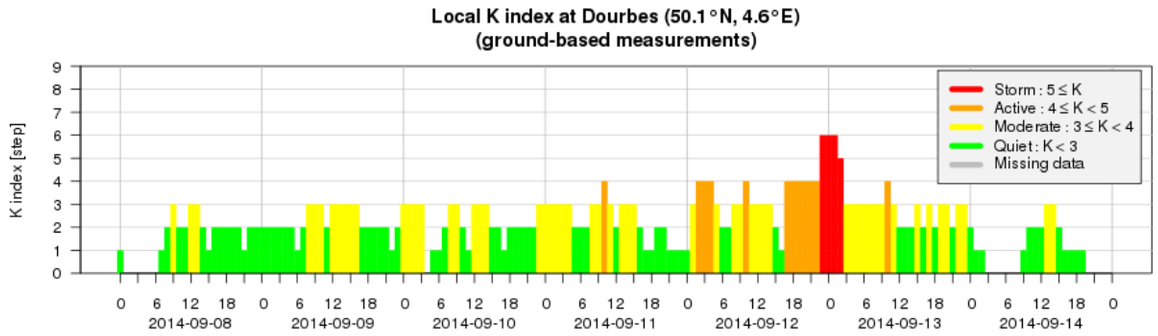

ACE RTSW (Estimated) MAG & SWEPAM
Bt Bz (gsm)
40
20
0
−20
−40
Phi (gsm)
360
270
180
90
0
Density (/cm3)
1000.0
100.0
10.0
1.0
0.1
Speed (km/s)
800
600
400
200
Temp (K)
1.0E+07
1.0E+06
1.0E+05
1.0E+04
09
10
11
12
UTC(days)
start DOY: 252
caution: ACE maneuver density < 1

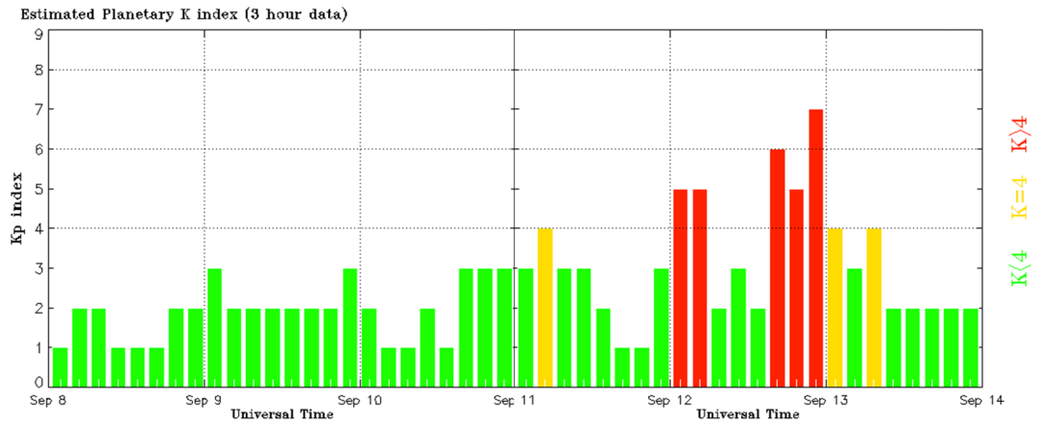
:Issued: **2014 Sep 12 1734 UTC**
:Product: documentation at http://www.sidc.be/products/presto
#---#
FAST WARNING '**PRESTO**' MESSAGE from the SIDC (RWC-Belgium)
#---#

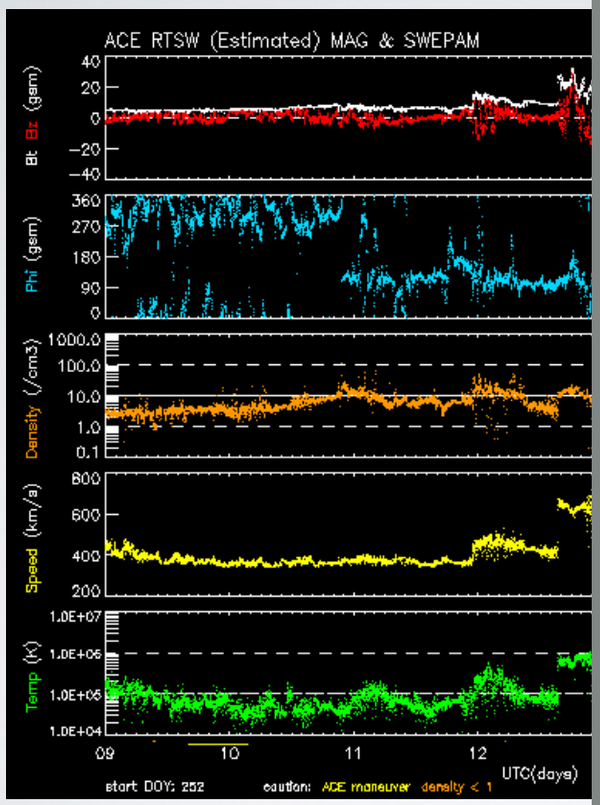
Just before 16:00UT, Earth's magnetic field was impacted by the shock from the halo CME related to the X1 flare from 10 September. Solar wind increased abruptly from about 410 to 650 km/s, as observed by ACE. Bt increased to a strong 28 nT, with the Bz-component currently oscillating between a moderate -13 and +20 nT. As the CME passes, there's a chance that Bz could turn more permanently southward and thus become more geo-effective.

The arrival of the CME also drove the proton flux briefly above the 100 pfu level.
#---#
Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium
Fax : 32 (0) 2 373 0 224
Tel.: 32 (0) 2 373 0 491

19:34BLT


Local K index at Dourbes (50.1°N, 4.6°E)
(ground-based measurements)
K index [step]
Storm : 5 ≤ K
Active : 4 ≤ K < 5
Moderate : 3 ≤ K < 4
Quiet : K < 3
Missing data
2014-09-08
2014-09-09
2014-09-10
2014-09-11
2014-09-12
2014-09-13
2014-09-14


Estimated Planetary K index (3 hour data)
Kp index
Universal Time
Universal Time
K<4
K=4
K>4
NOAA/SWPC Boulder, CO USA

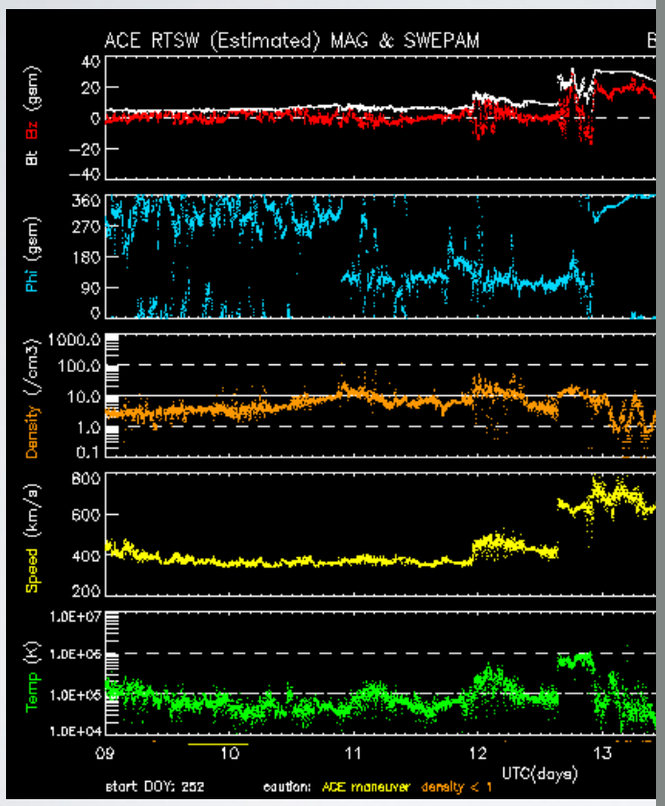

ACE RTSW (Estimated) MAG & SWEPAM
Bt Bz (gsm)
40
20
0
−20
−40
Phi (gsm)
360
270
180
90
0
Density (/cm3)
1000.0
100.0
10.0
1.0
0.1
Speed (km/s)
800
600
400
200
Temp (K)
1.0E+07
1.0E+06
1.0E+05
1.0E+04
09
10
11
12
UTC(days)
start DOY: 252
caution: ACE maneuver density < 1

:Issued: **2014 Sep 12 2229 UTC**
:Product: documentation at http://www.sidc.be/products/presto
#---#
FAST WARNING '**PRESTO**' MESSAGE from the SIDC (RWC-Belgium)
#---#

In response to the arrival of the 10 September halo CME, the Earth's magnetic field got disturbed. During the periods 15:00-18:00UT and 18:00-21:00UT, Kp values were resp. 6 and 5 (moderate and minor geomagnetic storming). Locally, the impact was even less impressive, with K-values in Potzdam resp. 5 and 4, and in Dourbes 4 and 4 (active conditions). This underperformance is due to the CME's magnetic field failing to develop a strong and persistent southward (negative Bz) component. However, the CME has not completely passed yet, with wind speed varying mostly between 600 and 700 km/s. Hence, there remains a chance that Bz could turn more permanently southward and the CME could become more geo-effective.

#---#
Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium
Fax : 32 (0) 2 373 0 224
Tel.: 32 (0) 2 373 0 491
# #

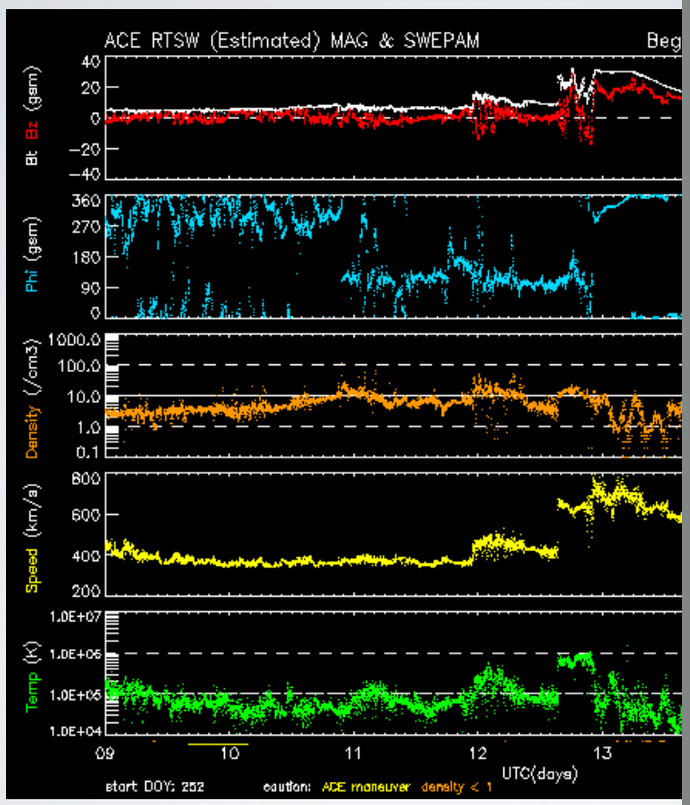
00:29 BLT


ACE RTSW (Estimated) MAG & SWEPAM
Bt Bz (gsm)
40
20
0
−20
−40
Phi (gsm)
360
270
180
90
0
Density (/cm3)
1000.0
100.0
10.0
1.0
0.1
Speed (km/s)
800
600
400
200
Temp (K)
1.0E+07
1.0E+06
1.0E+05
1.0E+04
09
10
11
12
13
UTC(days)
start DOY: 252
caution: ACE maneuver density < 1

:Issued: **2014 Sep 13 0518 UTC**
:Product: documentation at http://www.sidc.be/products/presto
#---#
FAST WARNING '**PRESTO**' MESSAGE from the SIDC (RWC-Belgium)
#---#

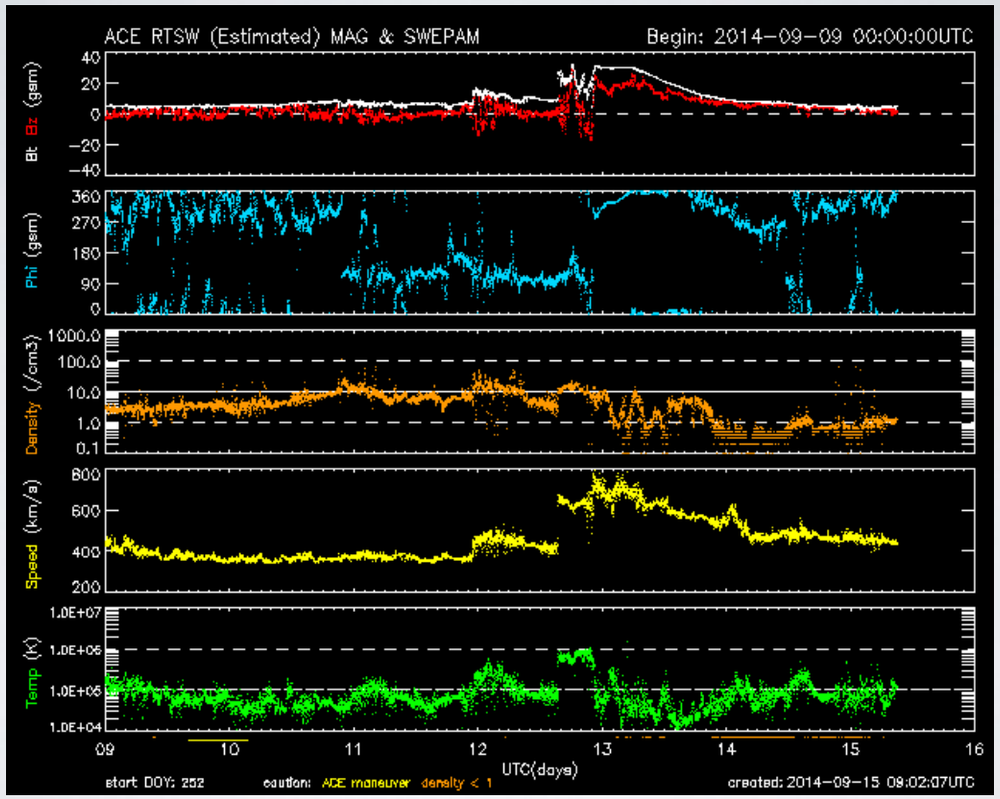
As the CME from the 10 September X1 flare is passing, a short period of negative Bz was observed between 20:30 and 22:00UT with maximum values near -17nT. Bz then abruptly turned northward to steady values around +20 nT. Kp reached strong geomagnetic storming levels (Kp = 7) between 21:00 and 24:00UT. Potzdam and Dourbes recorded moderate geomagnetic storming (K = 6). After that, geomagnetic activity seems to have decreased somewhat (active to unsettled conditions). Solar wind speed is still high, with values near 700 km/s.

#---#
Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium
Fax : 32 (0) 2 373 0 224
Tel.: 32 (0) 2 373 0 491
# #


ACE RTSW (Estimated) MAG & SWEPAM
Beg
Bt Bz (gsm)
40
20
0
−20
−40
Phi (gsm)
360
270
180
90
0
Density (/cm3)
1000.0
100.0
10.0
1.0
0.1
Speed (km/s)
800
600
400
200
Temp (K)
1.0E+07
1.0E+06
1.0E+05
1.0E+04
09
10
11
12
13
UTC(days)
start DOY: 252
caution: ACE maneuver density < 1

:Issued: **2014 Sep 13 1234 UTC**
:Product: documentation at http://www.sidc.be/products/meu
#---#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
(RWC Belgium)
#---#
SIDC URSIGRAM 40913
SIDC SOLAR BULLETIN 13 Sep 2014, 1209UT
SIDC FORECAST (valid from 1230UT, 13 Sep 2014 until 15 Sep 2014)
SOLAR FLARES : Eruptive (C-class flares expected, probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet
COMMENT:

The arrival of the halo CME related to the X1 flare from 10 September was observed on 12 September at 15:27UT. Wind speed increased abruptly from 430 to 670 km/s, and further increased to a maximum of nearly 800 km/s around 22:00UT. Bz was oriented southward between 20:30 and 22:00UT with maximum values near -17nT, then abruptly turned northward to steady values around +20 nT. The period between 21:00UT and 24:00UT was geomagnetically the most intense, with Kp reaching 7 (strong geomagnetic storm), and local K-indices at Dourbes and Potzdam reaching 6 (moderate storming).


ACE RTSW (Estimated) MAG & SWEPAM
Begin: 2014-09-09 00:00:00UTC
Bt Bz (gsm)
40
20
0
-20
-40
Phi (gsm)
360
270
180
90
0
Density (/cm3)
1000.0
100.0
10.0
1.0
0.1
Speed (km/s)
800
600
400
200
Temp (K)
1.0E+07
1.0E+06
1.0E+05
1.0E+04
09
10
11
12
13
14
15
16
UTC(days)
start DOY: 252
caution: ACE maneuver density < 1
created: 2014-09-15 09:02:07UTC

3 DAGEN

Human triggered

- 5 prestos
- 3 weerpraatjes
- 1 CME arrival alert

Software induced

- 1 automated CME alert
- 1 automated flare alert

ZONNEATMOSFEER

ZONNEATMOSFEER



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

The total solar eclipse of 1 August 2008, observed from Siberia.
What happens:
-visible light from the disc bounces off from plasma in the corona in our direction (Thompson scattering)
-the solar disc is a million times brighter than the corona, the light we see during eclipse is always there but swamped in the much brighter direct light

Seeing the corona ‘naturally’ is exceptional on astronomical scales:
- the apparent size of moon and star have to match the distance planet-star
- the moon should have no atmosphere
- the planets atmosphere should be transparant



corona is warm daardoor is die dik, heel de heliosfeer
De aardatmosfeer is een dunne schil.

Why is the atmosphere of the Earth, relatively speaking so much smaller?

The beginning of the wind is best "seen," said Parker, in pictures of a total solar eclipse. During a total solar eclipse the moon passes between the Earth and sun, blocking sunlight from reaching Earth. In pictures of the events, bits of the sun's corona—the outer edge of the sun—can be seen extending out into space.
"Around the 1930s scientists determined the temperature [of the corona] must be a million degrees [Celsius] because of the way it stood out into space," said Parker. "If it weren't so hot, it wouldn't be puffed out so much. Then some very clever spectroscopic detective work confirmed this extraordinary temperature."
The total solar eclipse of 1 August 2008, observed from Siberia. Equatorial streamers and polar plumes clearly map the corona's magnetic field. Earthshine illuminates the silhouetted lunar disk. (Images in from J.M.P., W. G. Wagner and H. Druckmüllerová, image processing by H. Druckmüllerová

Solar eclipses as an astrophysical laboratory
Jay M. Pasachoff
Nature 459, 789-795(11 June 2009)
doi:10.1038/nature07987

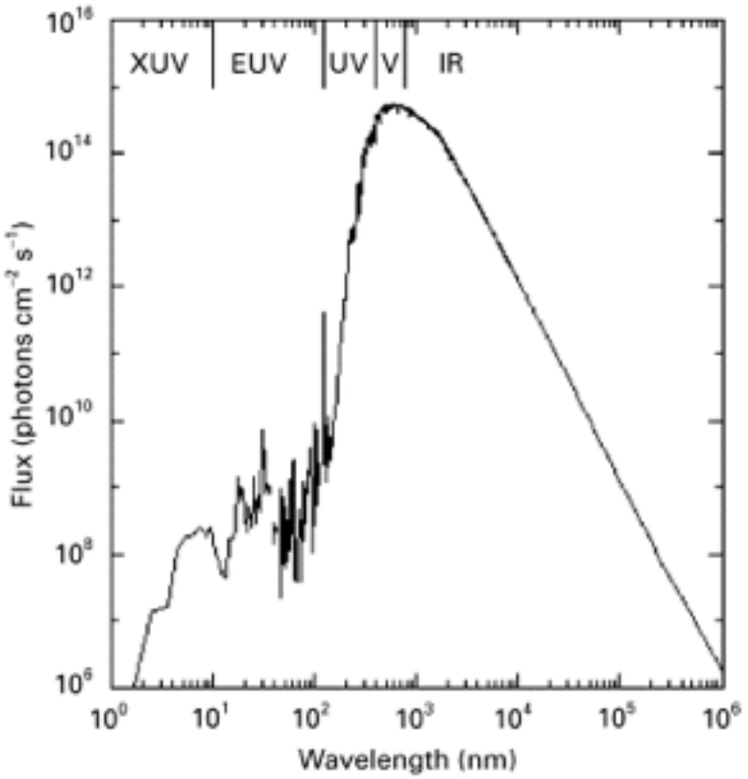
steek er hogere temperaturen in en ge komt tot een dikke atmosfeer
we zouden eigenlijk dus al heel lang moeten geweten hebben dat de corona heet is

OBSERVEREN VAN DE ZONNECORONA

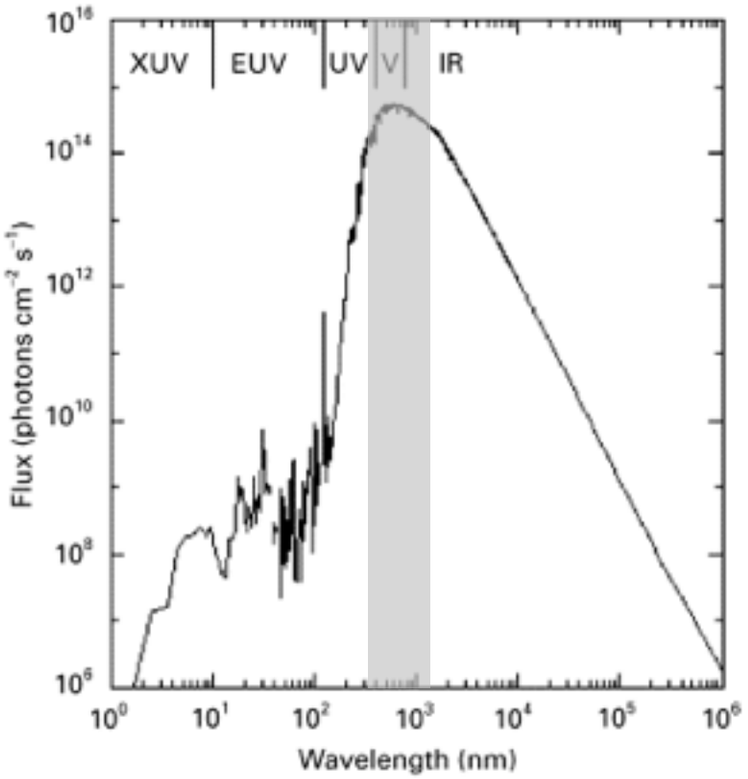
- wait for the next total solar eclipse
- get rid of the bright visible disk by blocking it off by an occultor
- get rid of the bright visible disk by looking at corona-only light (EUV & X-rays)
- fly into it and measure it locally

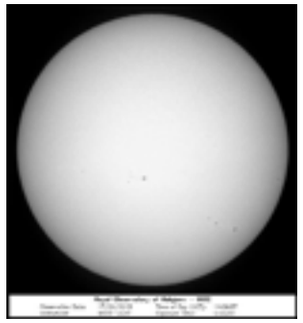
Alhoewel coronagrafen en EUV-telescopen allebei de corona tonen, zijn beide types van beelden erg verschillend. Dit heeft niet enkel met de andere telescoopopbouw en de verschillende beeldbewerking (oa kleuring) te maken maar ook met de intrinsieke andere processen in de atmosfeer van de zon die het licht veroorzaakt hebben.

EUV imagers



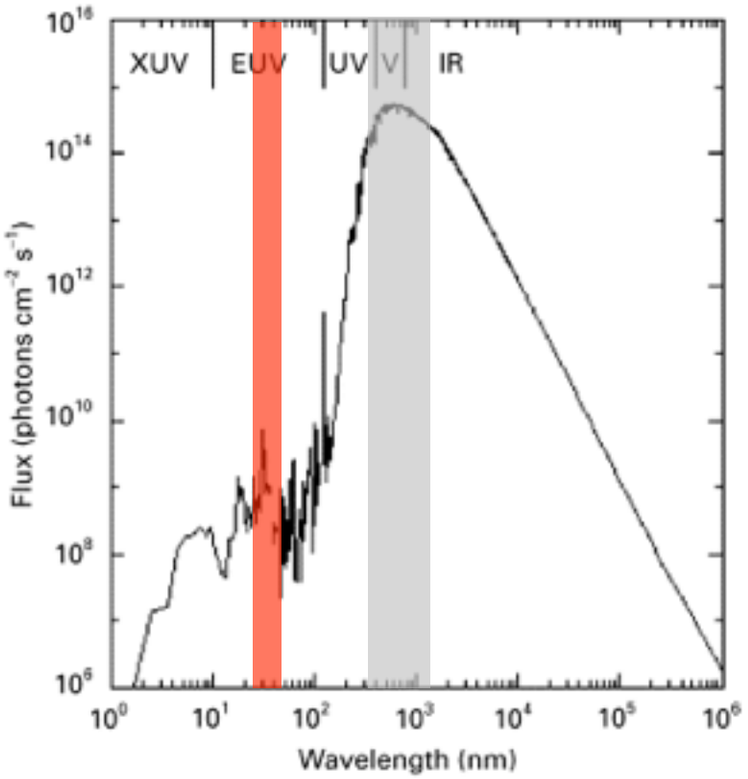
SOLAR2000, Tobiska 2000

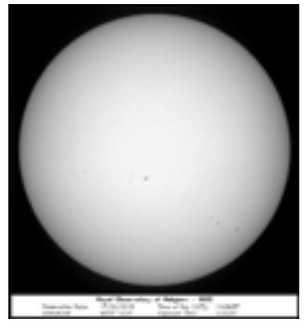




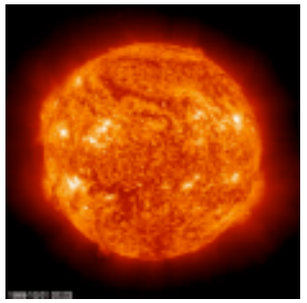
5700K

SOLAR2000, Tobiska 2000



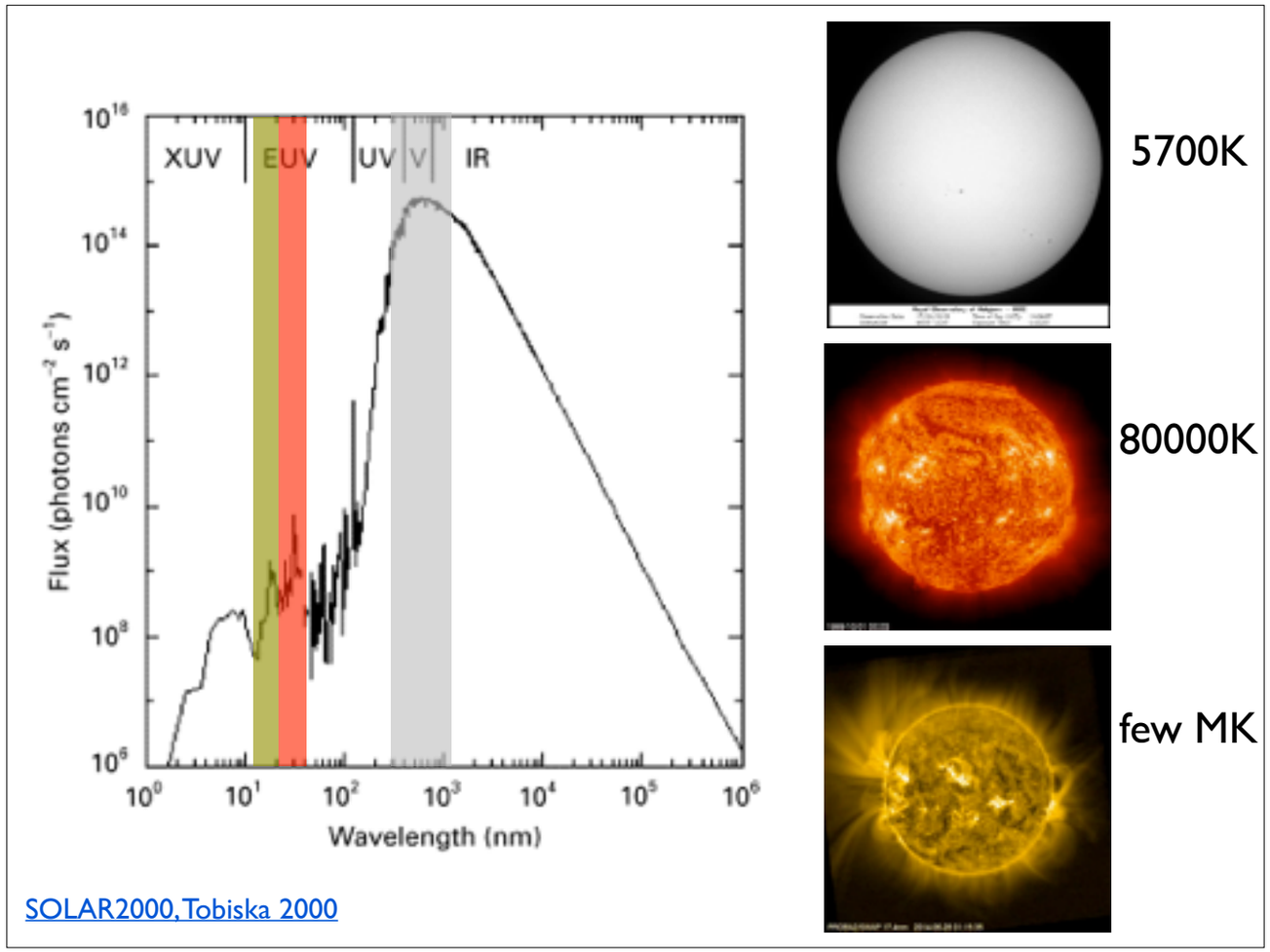


5700K



80000K

SOLAR2000, Tobiska 2000



SOLAR2000, Tobiska 2000

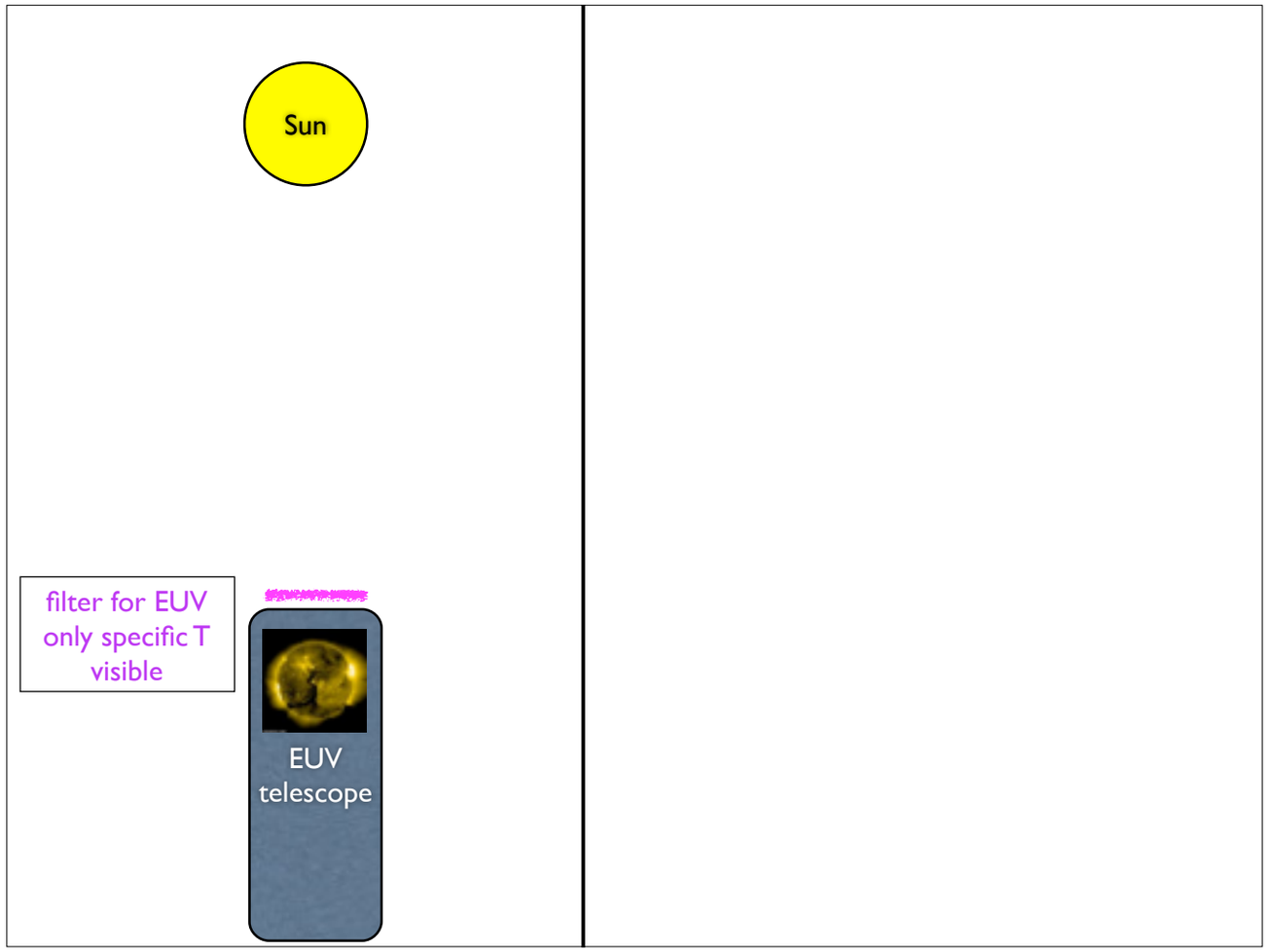
de tijd op de SWAP beelden is het tijdstip waarop de fotonen zijn aangekomen bij PROBA2. Die fotonen hebben 8 min eerder de zon verlaten en dus het beeld dat je ziet is hoe de zon was 8 minuten vroeger dan tijd die op de swap beelden staat.

Dit is de gebruikelijke conventie voor alle telescopen, je weet immers niet op voorhand naar wat je aan het kijken bent: een sterfoton zou er nog veel langer over gedaan hebben. **Omdat alle telescopen op aarde staan of in de buurt van de aarde hangen, kan je een beeld van 1 telescoop vergelijken met het beeld van een andere telescoop met hetzelfde tijdstip.**

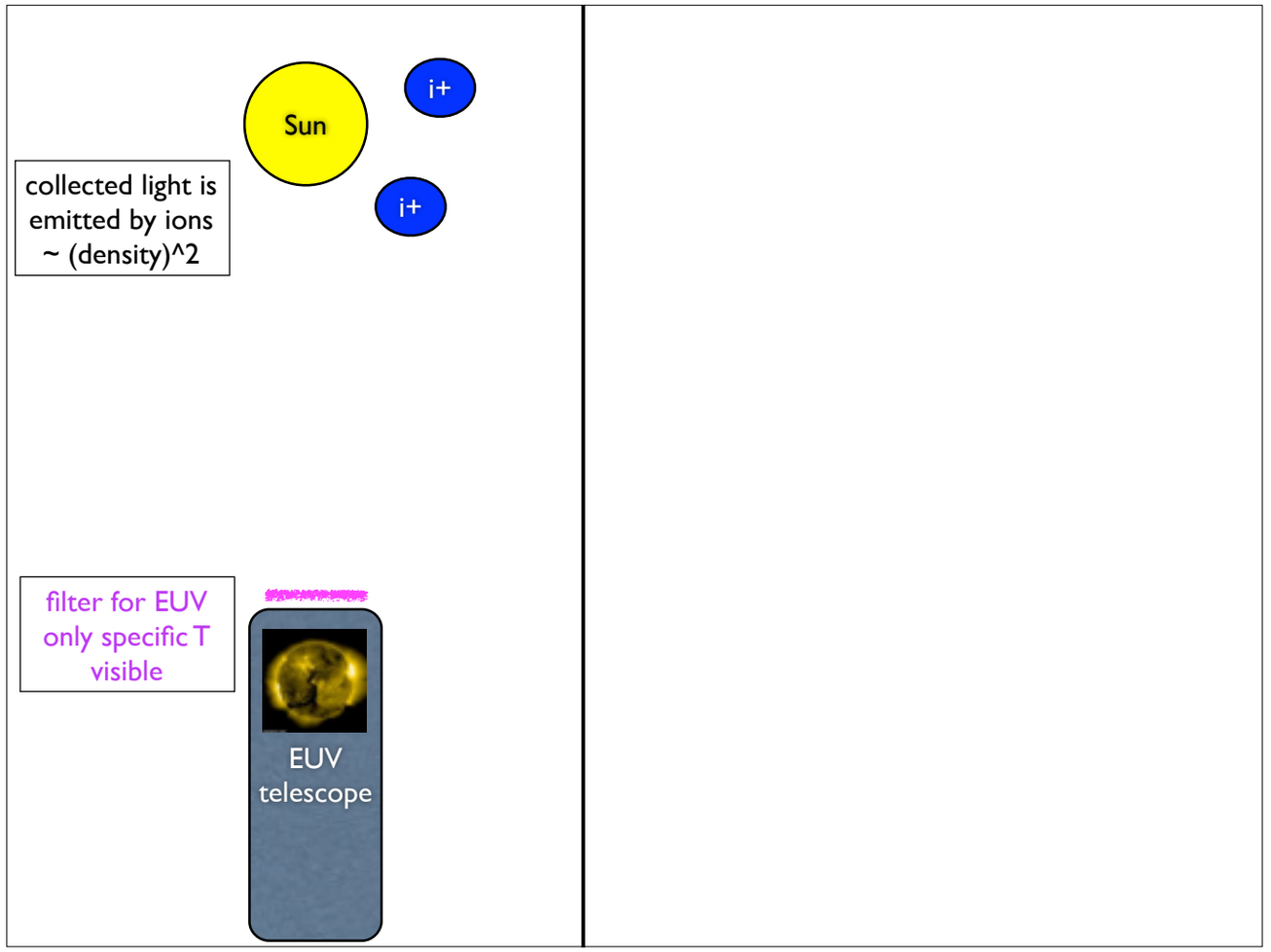
De STEREO telescopen hebben alle een kleine afwijking omdat 1 **STEREO op 1.1 AU** zit en de andere op **0.9 AU**. De tijdstippen op de STEREO beelden kunnen in de orde van een minuut ernaast zitten als je bvb een een flare vergelijkt in de STEREO beelden met dezelfde flare gezien vanaf de Aarde.

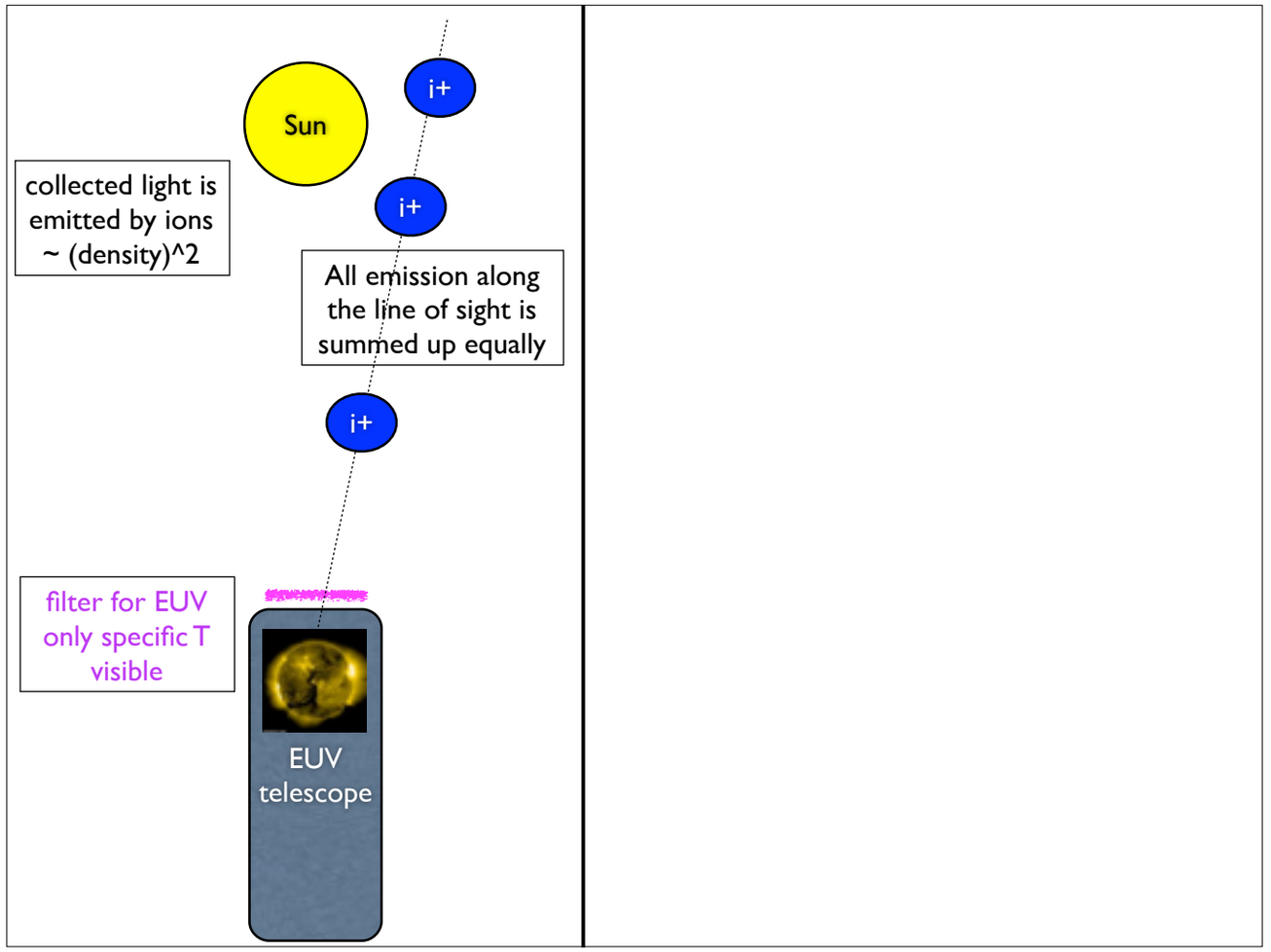
Met **Solar Orbiter** gaan we helemaal wild, dit gaat tot op **0.28AU** vliegen, en kan er dus 6 minuten naast zitten ten opzichte van de aarde.

Buiten dat zijn er nog wat exotischere probleempjes:
- op een aantal minuten tijd verplaatst Solar Orbiter zich toch al een flink eindje en dus staat de zon niet meer in dezelfde richting. Je moet dus de telescopen niet in de richting zetten waar de zon staat maar wel in de richting waar de zon enkele minuten geleden stond (uit die richting gaan de fotonen namelijk aankomen).
- klokken in de ruimte hebben het moeilijk om ‘juist’ te lopen (temperatuurschommelingen, vacuum, etc) en moeten dus regelmatig gelijkgezet worden met de atoomklokken op aarde. Als een signaal er echter vele minuten over doet is het niet simpel om de klokken gelijk te zetten, je moet al heel precies weten hoe ver de satelliet is.



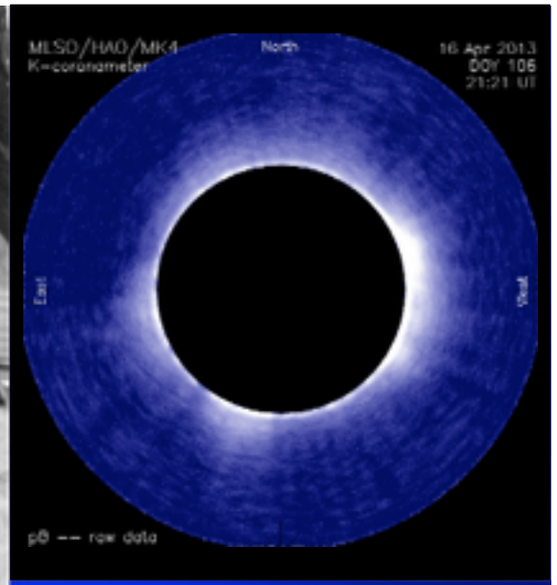
Een EUV-beeld daarentegen **toont licht dat door de corona zelf geproduceerd is**, door het verspringen van electronen rond sterk geïoniseerde atomen. Dit proces is sterk **temperatuursafhankelijk en evenredig met de dichtheid in het kwadraat**. Een gevolg hiervan is dat een EUV-telescoop, in tegenstelling tot een coronagraaf, slechts een beperkt temperatuursregime in de corona kan zien (1 millioen graden K voor SWAP). Aangezien de dichtheid van de corona zeer sterk afneemt op toenemende hoogten, en de EUV-emissie evenredig is met de dichtheid in het kwadraat, hebben EUV-telescopen moeite om ook maar iets te zien waardat coronagrafen op hun best zijn.


Sun
i+
i+
collected light is emitted by ions ~ (density)^2
filter for EUV only specific T visible
EUV telescope

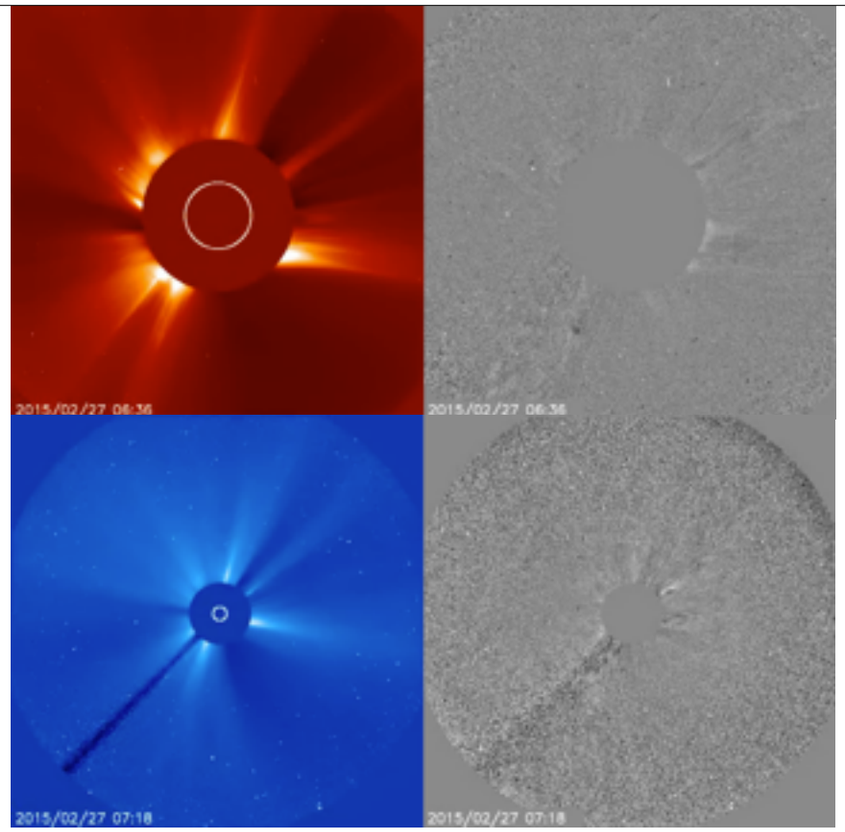

Sun
i+
i+
i+
collected light is emitted by ions ~ (density)^2
All emission along the line of sight is summed up equally
filter for EUV only specific T visible
EUV telescope

coronagraphs

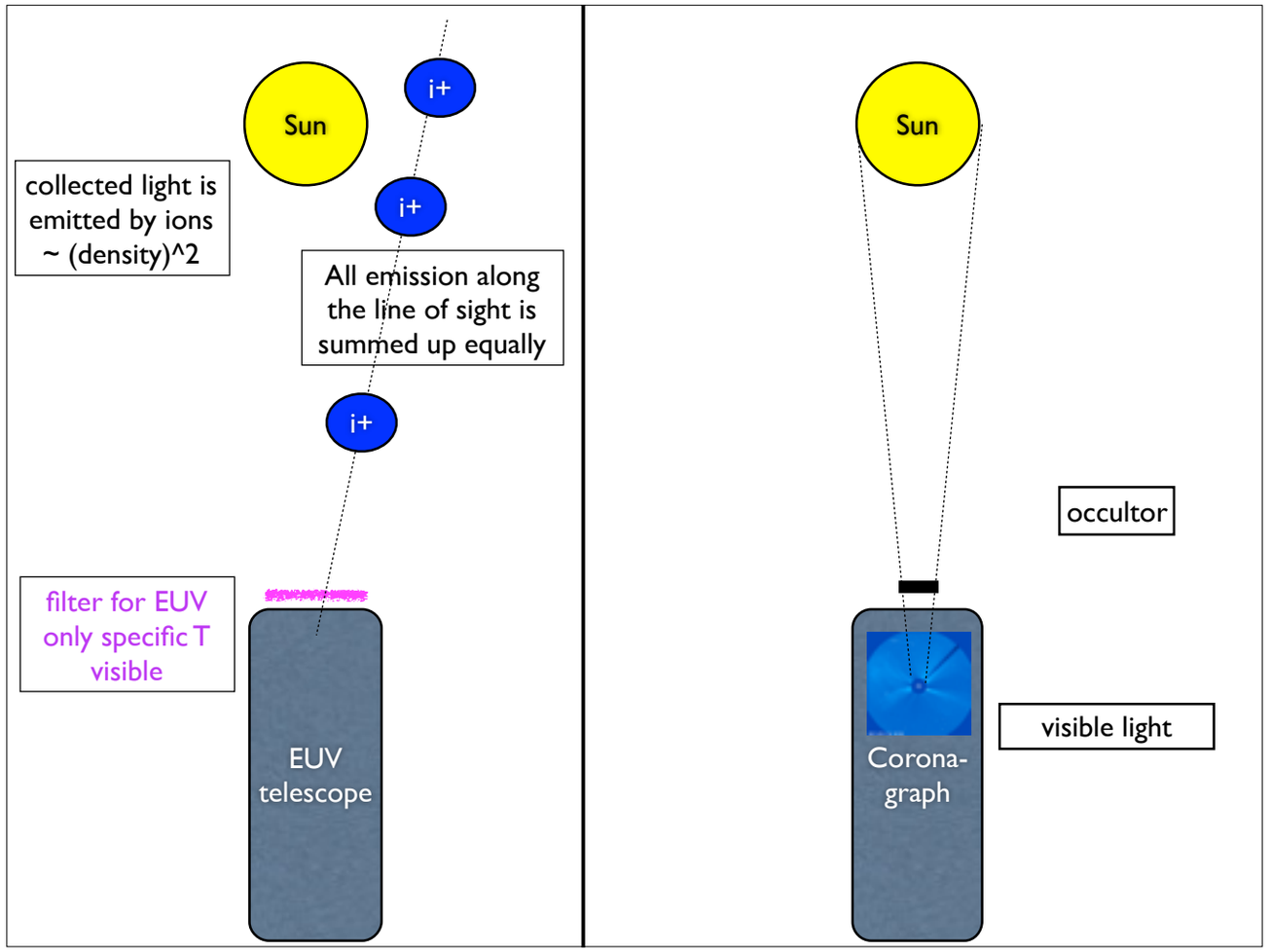




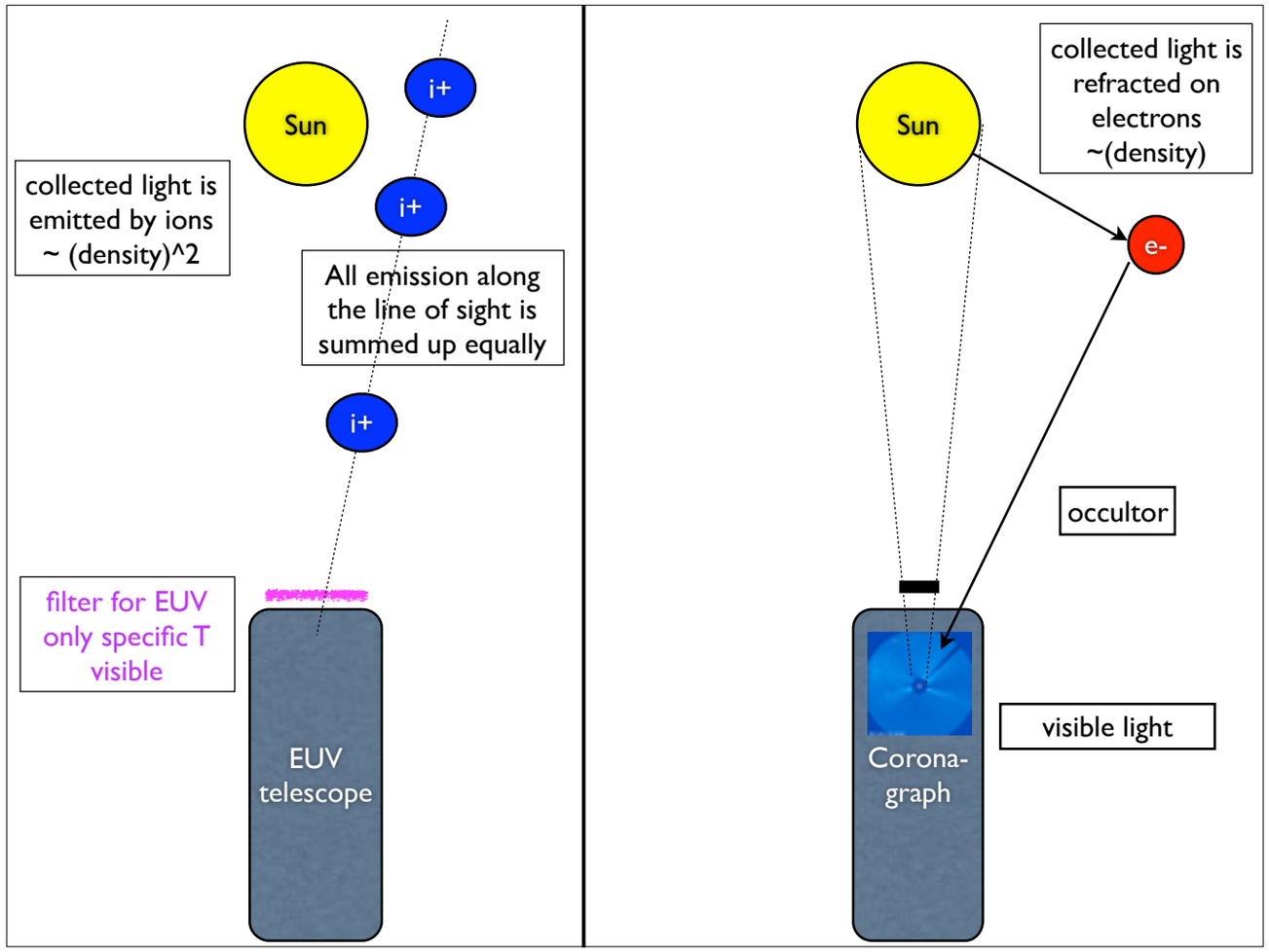
Bernard Lyot, 1939, at Pic du Midi
French Astronomer
Inventor of the Coronagraph



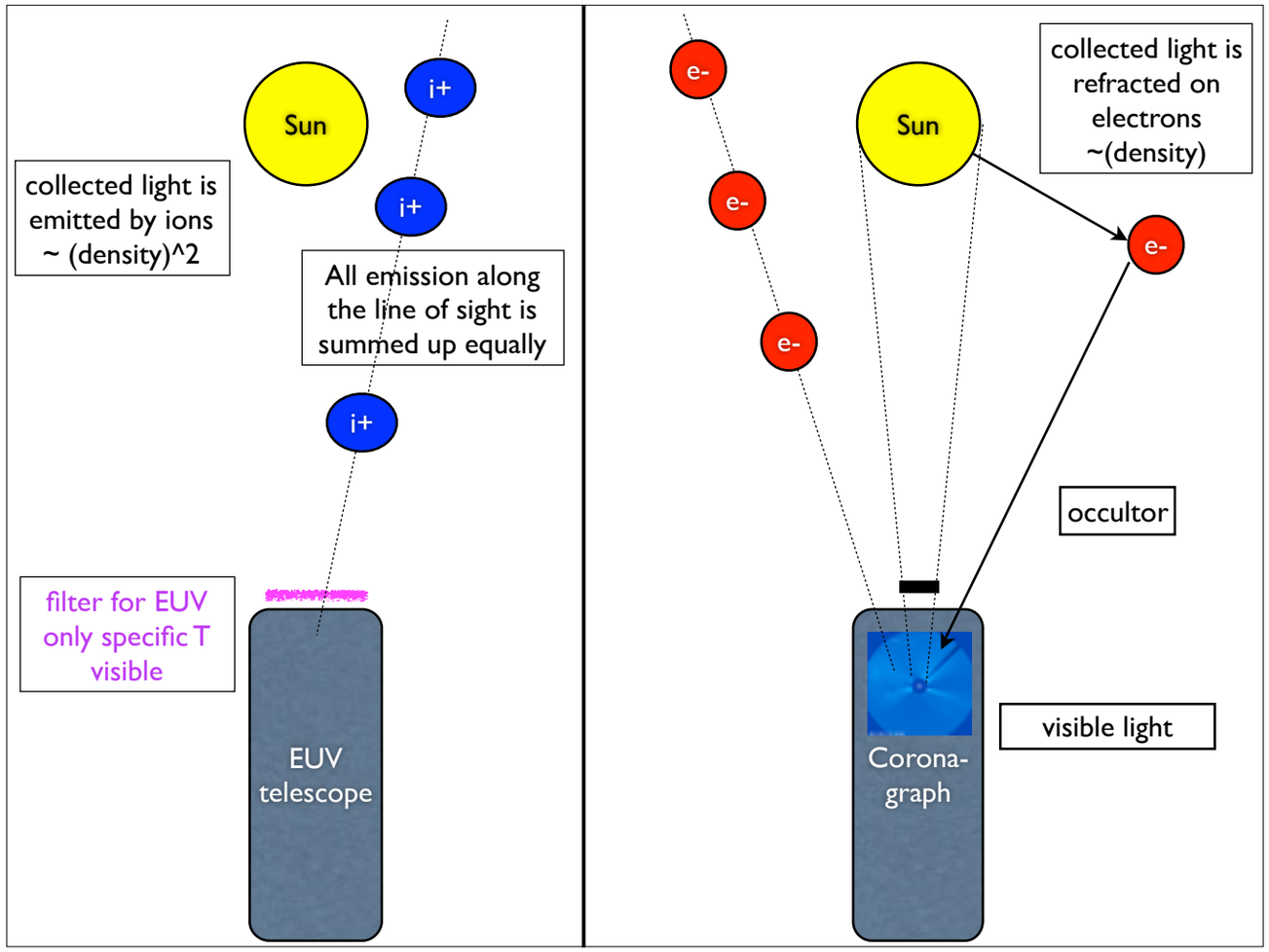
SOHO / LASCO c2&c3 running difference



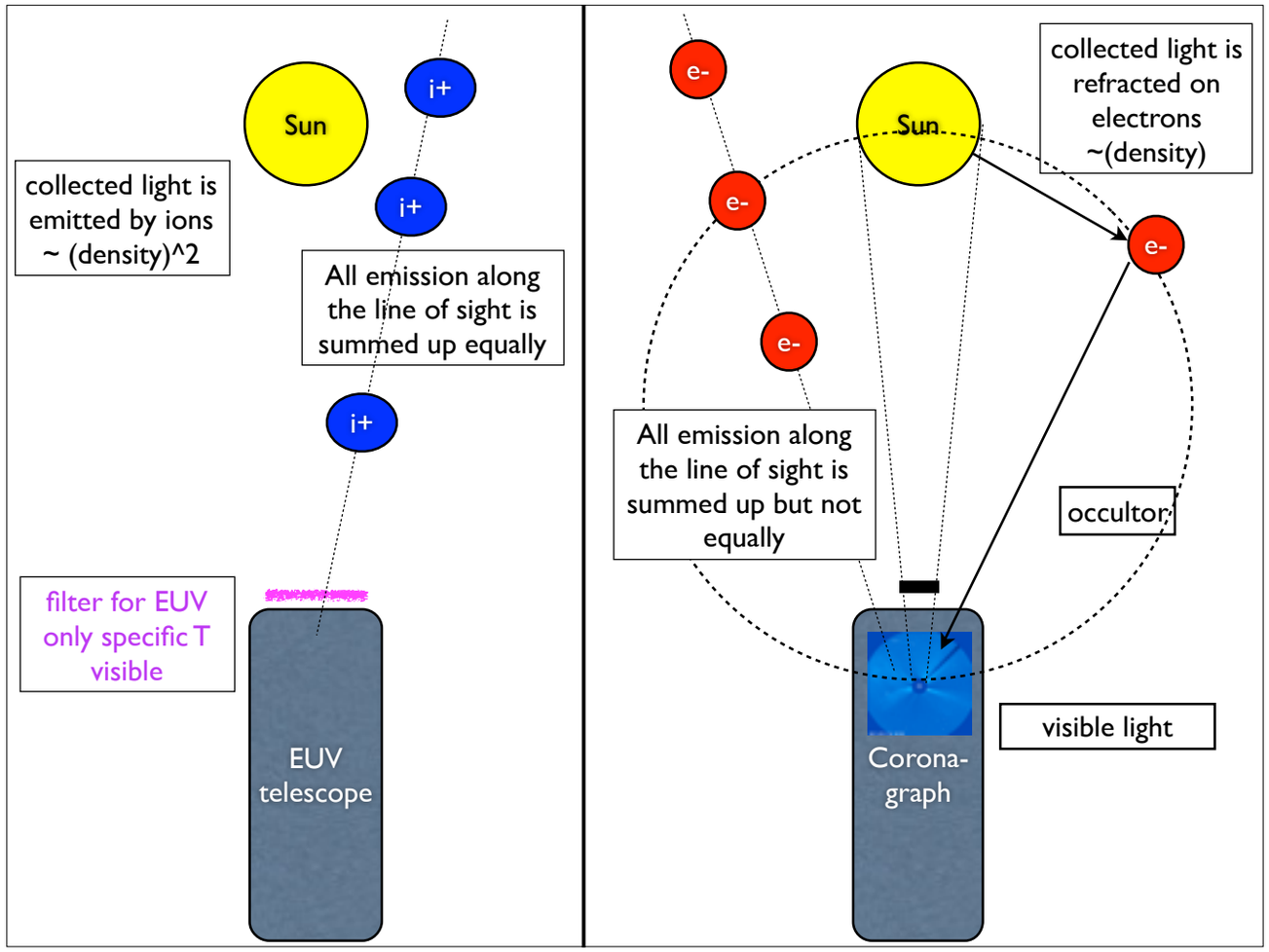
In coronagrafische beelden zien we in essentie zichtbaar licht uit de fotosfeer dat weerkaatst op het coronale plasma. Deze weerkaatsing is evenredig met de dichtheid van het plasma maar onafhankelijk van de temperatuur van het plasma. De weerkaatsing (“Thompson scattering” is de technische term) is het sterkst in een rechte hoek en de coronagrafisch beelden tonen dus niet de hele corona maar slechts het plasma dat zich op een bol bevindt met de afstand telescoop-zon als diameter.



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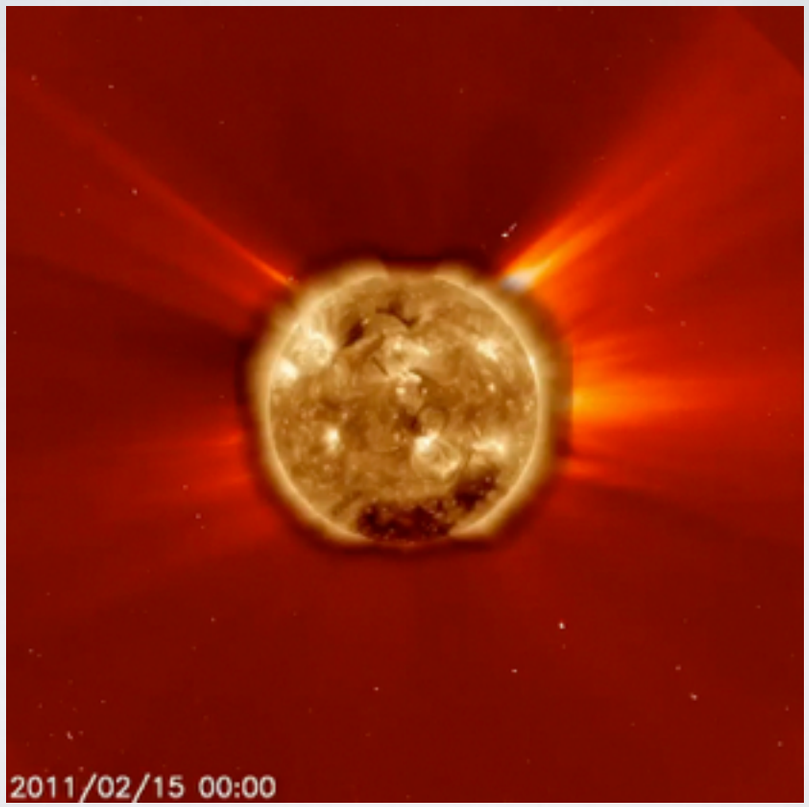
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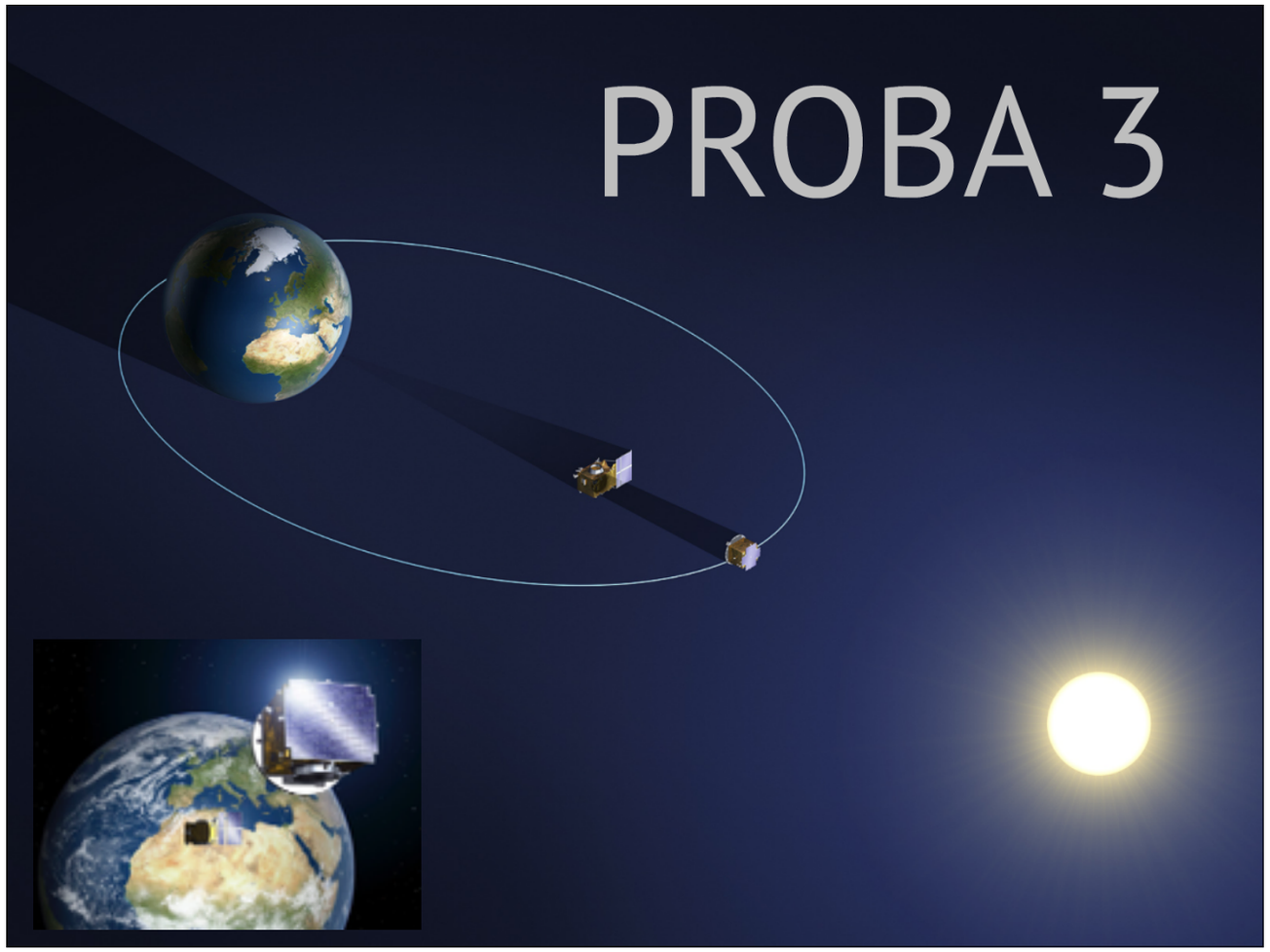
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HALO CME



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.

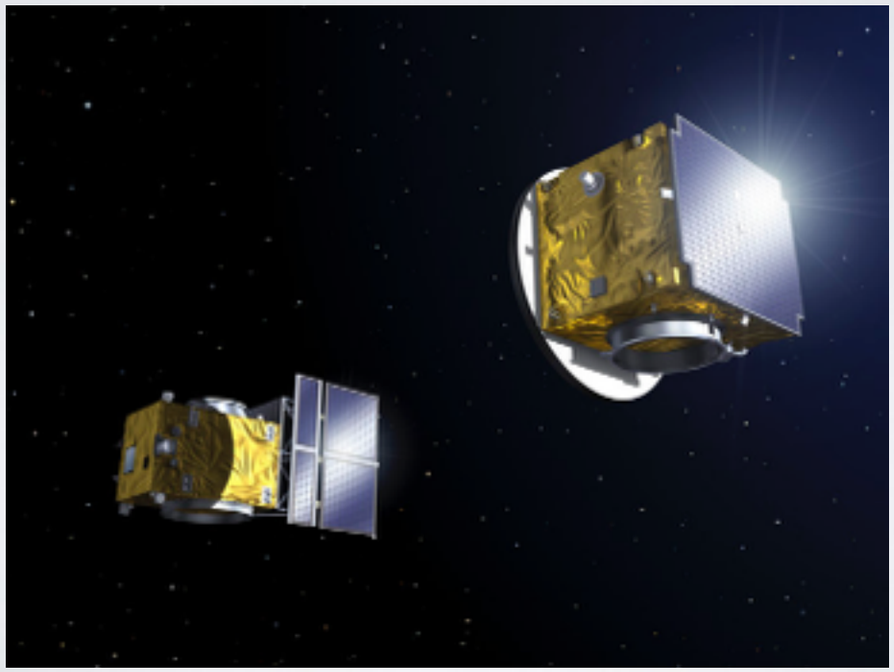


Coronagraph spacecraft 340 kg; Occulter spacecraft 200 kg

High Earth orbit, 19.7 hours orbital period, 60 530 km apogee, 600 km perigee

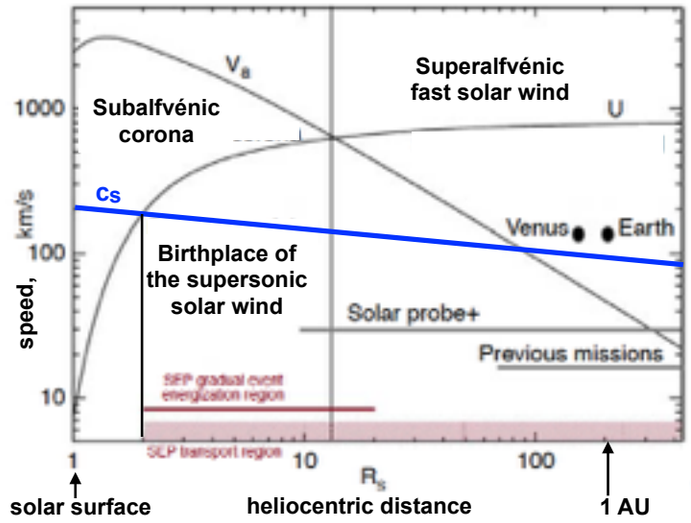
External coronagraph

FORMATIEVLUCHT



Proba-3 is ESA's – and the world's – first precision formation flying mission. A pair of satellites will fly together maintaining a fixed configuration as a 'large rigid structure' in space to prove formation flying technologies.
The mission will demonstrate formation flying in the context of a large-scale science experiment. The paired satellites will together form a 150-m long solar coronagraph to study the Sun's faint corona closer to the solar rim than has ever before been achieved. Beside its scientific interest, the experiment will be a perfect instrument to measure the achievement of the precise positioning of the two spacecraft.

INNER SOLAR CORONA

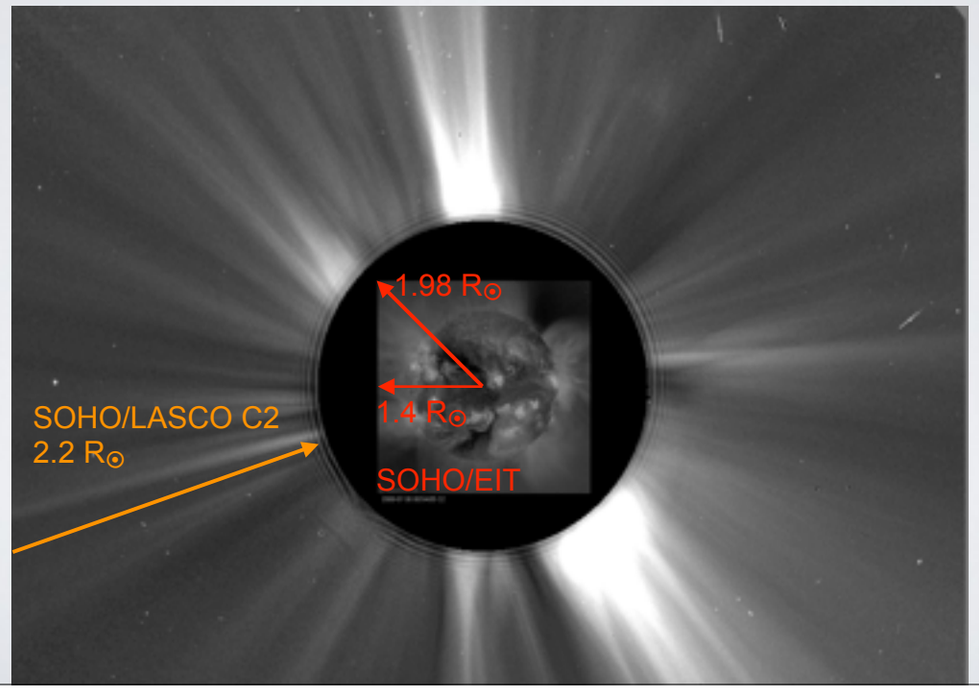


The solar wind becomes supersonic around 2-3 $R_\odot$ from the center of the Sun.

CMEs are also accelerated in this region.

The source of the solar wind is situated in the inner solar corona. This graph, with the heliocentric distance along the horizontal axis and the speed on the vertical axis, shows a typical solar wind acceleration profile. The solar surface is here, ten solar radii is here, and the Earth is here. We can see that the wind acceleration takes place very rapidly. Within the first **15 solar radii** the wind becomes **superalfvénic**, and the **sonic point** is reached even lower, within **two-three solar radii**. The inner corona, here loosely defined as the region within five solar radii, is also the place where coronal mass ejections, CMEs, accelerate.

MIND THE GAP

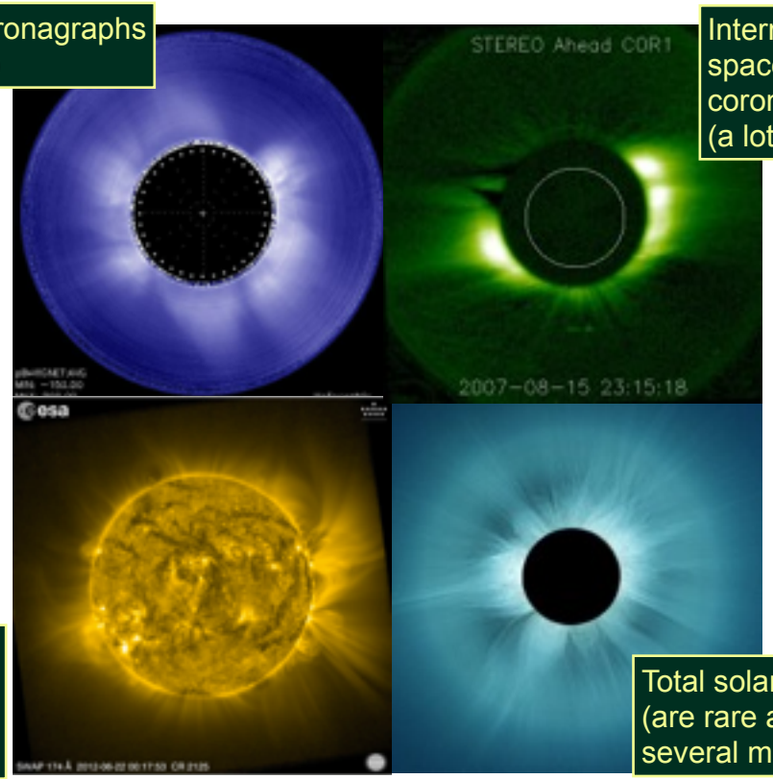


Between the low corona (typically observed by EUV imagers) and the high corona (typically observed by externally occulted coronagraphs), there is a region (“The Gap”) where observations are difficult to make.

An externally occulted coronagraph allows for a good straylight rejection - LASCO. However, the inner edge of its field of view is limited by the telescope length. Here you see the effect of diffraction

Given all the importance of this region for the coronal and heliospheric physics, it may be surprising that the inner corona is relatively badly observed. Here is a typical composite image showing the structure of the corona. The low corona is usually observed by extreme-ultraviolet imagers, showing also the solar disk, and the outer corona is best observed by **externally occulted coronagraphs like LASCO onboard SOHO**. But we can see that there is a gap between the fields of view of EUV imagers and coronagraphs, the gap between the low and high corona where observations are really difficult. Can we move this edge down? This is an externally occulted coronagraph, meaning that the solar light first meets the occulter before entering the telescope, so it has a good straylight rejection. **But the inner edge of its field of view is limited by the length of the telescope.**

BRIDGE THE GAP



Ground-based coronagraphs
(a lot of straylight)

Internally occulted
space-borne
coronagraphs
(a lot of straylight)

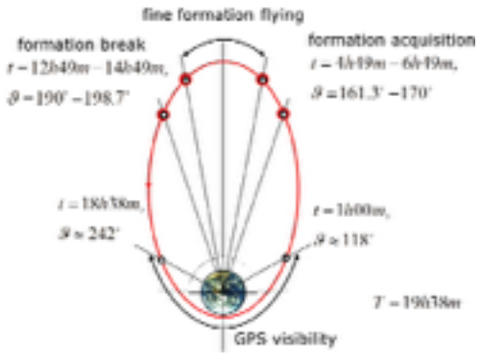
Wide field-of-view
EUV imagers
(very long
exposure times)

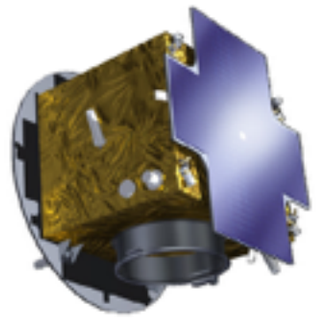
Total solar eclipses
(are rare and last only
several minutes)

Currently there are several ways to deal with this problem and to get access to The Gap, but none of them is totally satisfying. On the ground one can have a very long coronagraph, but the images are dominated by the **straylight produced by the Earth's atmosphere**. One can place the **occulter inside** the telescope – an internally occulted coronagraph – to diminish the inner edge without increasing the length of the instrument, but then one **allows the straylight to enter the telescope**. One can use an **EUV imager** with a wider field of view, but then one needs very **long exposure times**, of the order of several minutes, **so the coronal dynamics would be smeared out**. Finally, one can go to where all the coronal science started and to observe a total solar eclipse. This is actually a very good way, and the images have a great quality. The only problem is that total eclipses are too rare, one or two per year, and they are too short, several minutes at most.

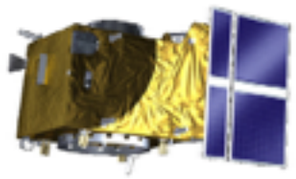
Bij toestellen die bediend worden van op de grond kan het plaatje ver van de telescoop geplaatst worden waardoor de binnenste waarnemingsrand dicht tegen het zonneoppervlak ligt, maar dan heb je last van verstrooid licht van de aardatmosfeer dat ongewild in de telescoop terecht komt. In de ruimte ben je beperkt door de lengte van de arm die de occulter voor de telescoop moet houden, je kan je telescoop niet te lang maken want de ruimte op een satelliet is beperkt. LASCO is een voorbeeld van een extern geocculteerde coronagraaf. Plaats je de occulter in de ruimtetelescoop – een intern geocculteerde coronagraaf, heb je weer last van het oorspronkelijke probleem: verstrooid licht. Al het licht valt in de telescoop, Het rechtstreekse zonlicht wordt tegengehouden door het plaatje, maar dit licht weerkaatst in de telescoop zelf en komt zo gedeeltelijk dan toch in het beeld terecht. Daarnaast hebben we de EUV-telescoop SWAP aan boord van de ESA missie PROBA2: deze brengt de lage corona zeer mooi in beeld. SWAP heeft zelfs een bredere kijk dan andere bekende EUV-telescopen zoals bv SDO/AIA, wat van onschatbare wetenschappelijke waarde is.

THE ULTIMATE CORONAGRAPH





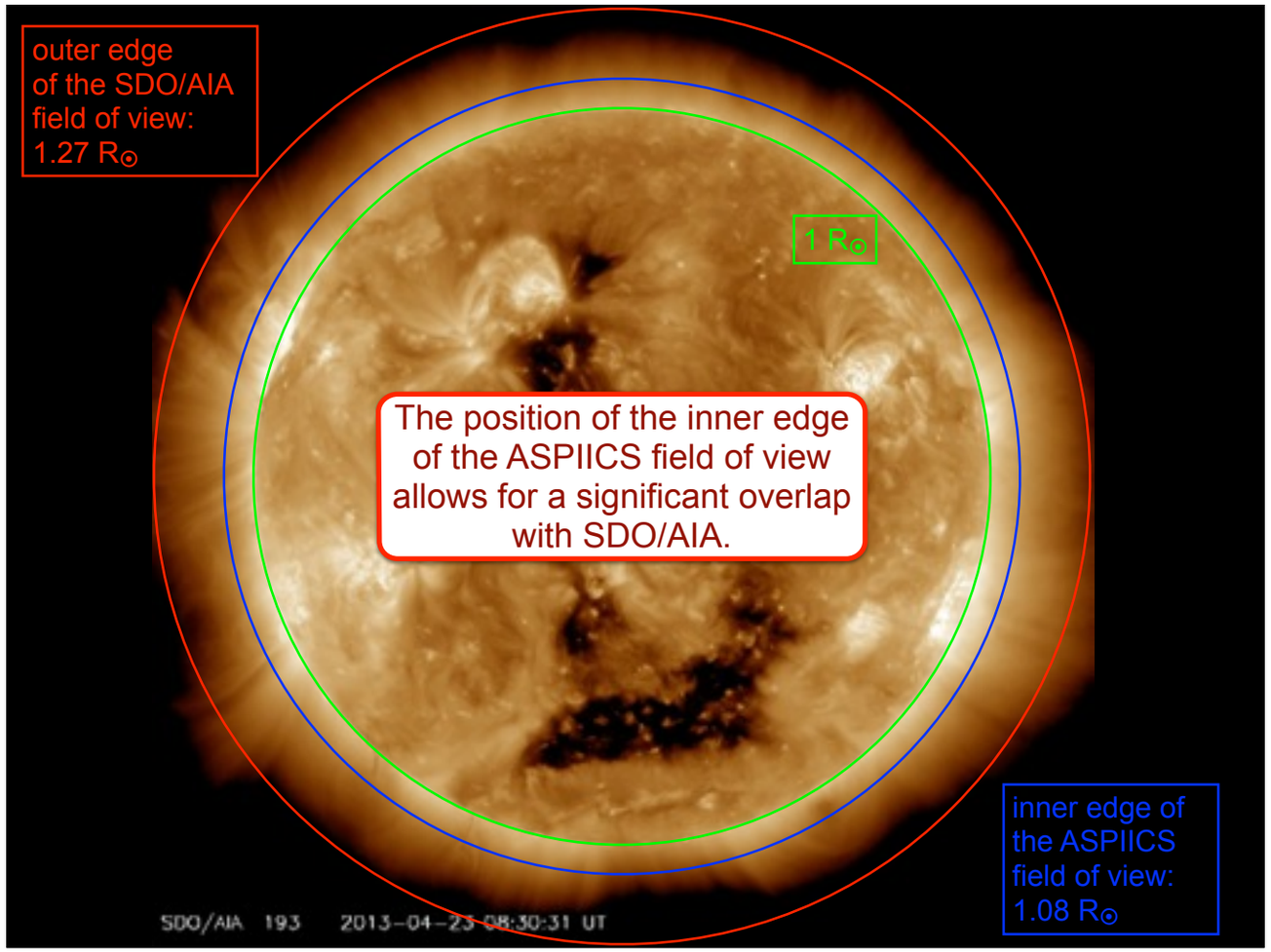
towards the Sun



- The formation flying is maintained over 6 hours in every 20-hour orbit: *around a factor 100 improvement* in the duration of uninterrupted observations in comparison with a total eclipse.
- A technological challenge: the distance between the spacecraft is 150 m, and the accuracy of their positioning should be around a few millimeters!

The ultimate coronagraph: artificial total eclipse created using two spacecraft in flight formation.

So what is the solution? The solution is to reproduce a total eclipse in space, using two spacecraft. One of them would carry a telescope, and the other would serve as the external occulter. The two spacecraft should move together in the so-called flight formation. So the PROBA-3 mission will do exactly that: place one spacecraft hundred and fifty meters away from the other, and try to keep the alignment towards the Sun with the precision of a few millimeters. This is a big technological challenge. The orbit of PROBA-3 is shown here, and the formation flying would be maintained only over a part of it. But this part would last for six hours, which is around a factor one hundred improvement in the duration of uninterrupted observations in comparison with a total eclipse.



The inner edge of the ASPIICS field of view is not only good enough to provide a unique coverage of the inner corona. It is also sufficiently low to allow for an overlap with a modern EUV imager, which should normally be still in operation when ASPIICS will fly. So we will be able to make synergies with other solar missions.

2018

