# Ontdekkingsreis naar de Zon

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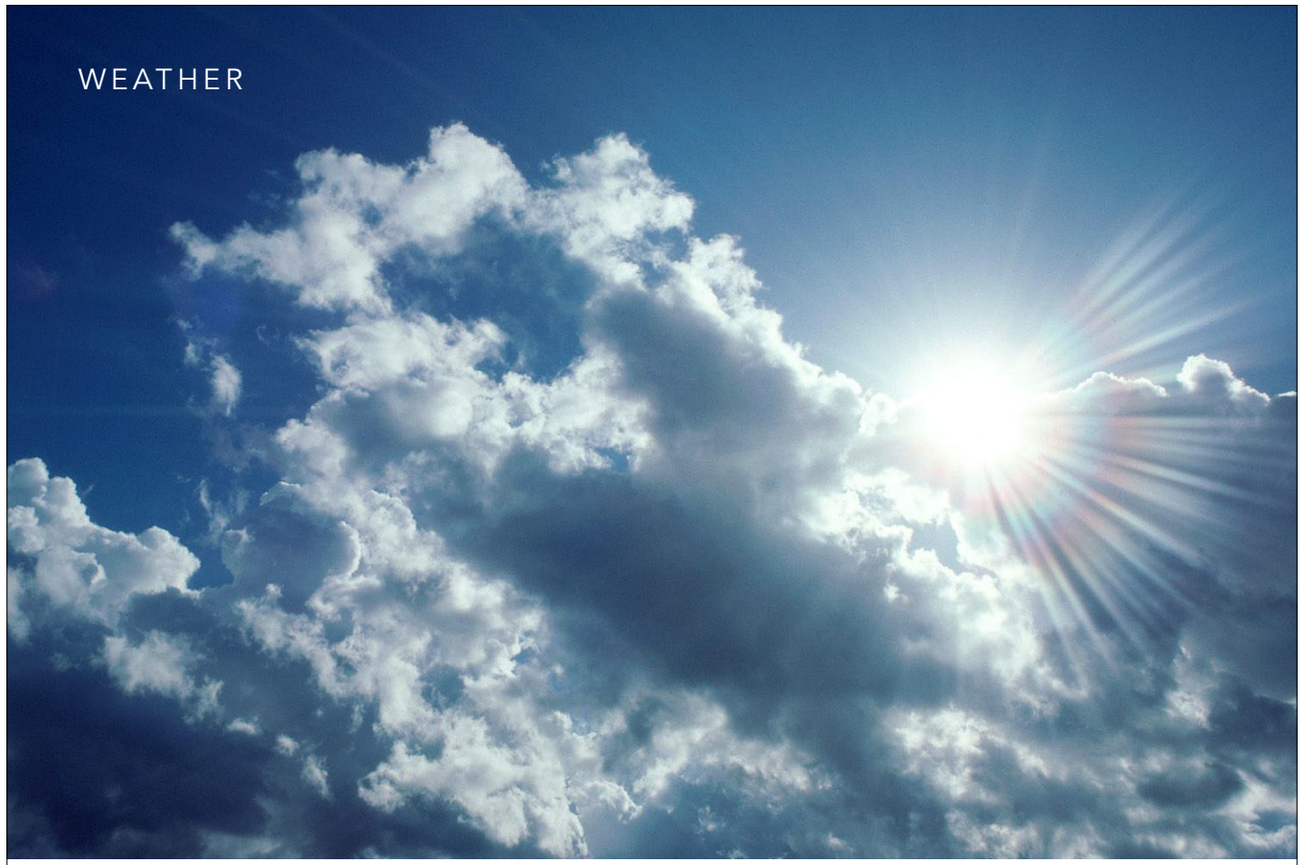
Solar-Terrestrial Centre of Excellence



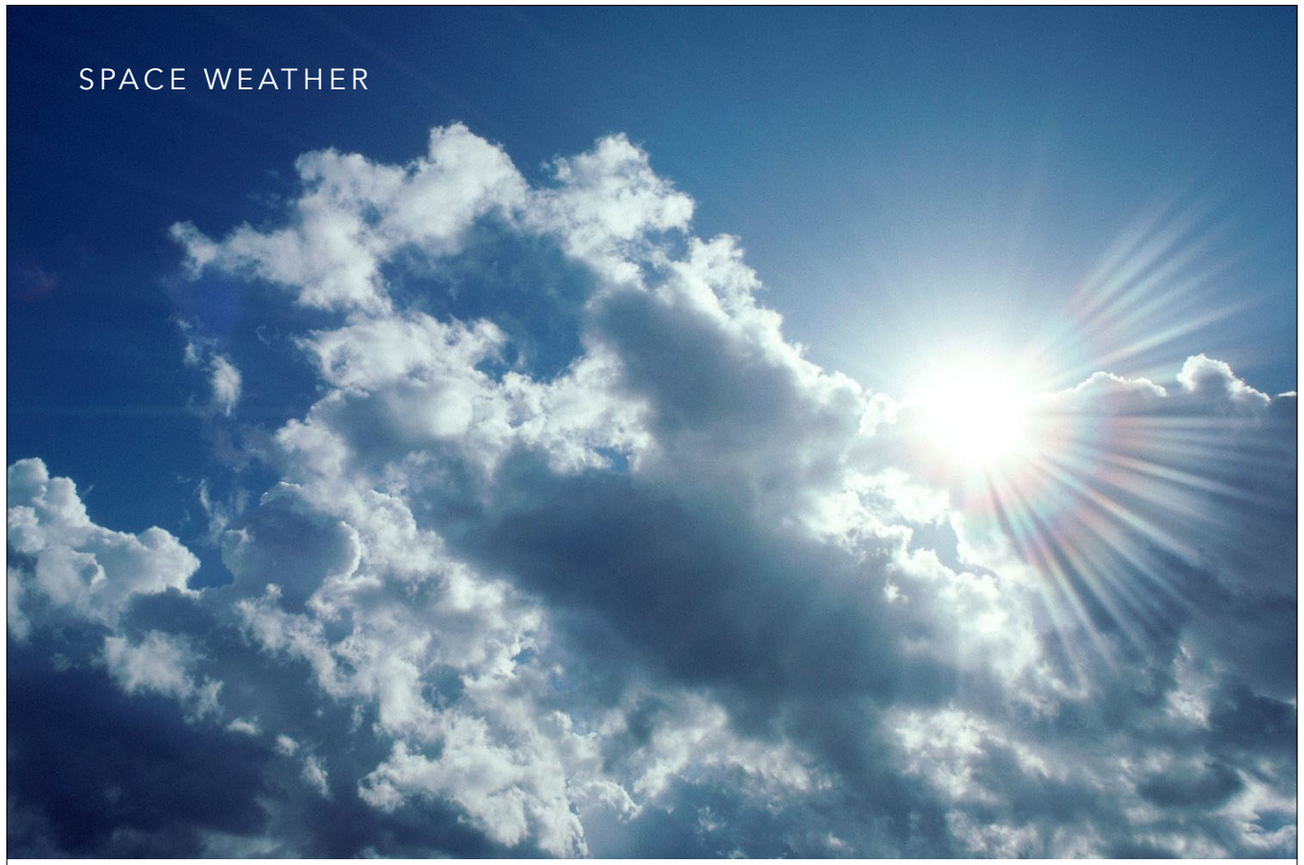



We are all familiar with terrestrial tropospheric weather. It is what we experience all around us; our atmospheric environment. It may be fine, cloudy, stormy or sunny. It may rain or hail. We know about temperature and pressure and humidity. This is all about weather in the lowest 10 km of our atmosphere.

Wikipedia
Weather is the **state of the atmosphere**, to the degree that it is hot or cold, wet or dry, calm or stormy, clear or cloudy.[1] Most weather phenomena occur in the lowest level of the atmosphere, the troposphere,[2][3] just below the stratosphere. Weather refers to day-to-day temperature and precipitation activity, whereas climate is the term for the averaging of atmospheric conditions over longer periods of time.[4]

Troposfeer 6-20 km
Stratosfeer 50 km
Mesosfeer 85 km
Thermosfeer 690 km oa poollicht
Exosfeer 10 000 km

Ionosphere: 60-1000 km




Energie die vanuit de ruimte komt binnengerold en wordt losgelaten op de aarde en alles dat daarrond vliegt.
We zien de impact van het ruimteweer via onze technologie waarmee we navigeren, communiceren, energie transporteren, ons verplaatsen  … Er is 1 natuurlijk ruimteweerfenomeen dat OK is, en dat is aurora.
Natuurlijk willen we hierover alles te weten komen, dit bestuderen.

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.**

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.

Definition of 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.




How can we study the Sun - simply by watching it. The Sun is a bright star with overwhelming direct light.




How can we study the Sun – simply by watching it.
in different circumstances, at special events, using a telescope – from 1609 – to magnify

Visible light

A special event: a solar eclipse. In the past, people thought it was a divine event: the gods interfered and made the sun disappear. Now we know it is the moon that occults the sun.
The moon appears to be as big as the Sun.

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) - **refracted light**
-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

De zon heeft ons altijd al gefascineerd. Waarnemingen gaan terug tot het begin van de mensheid.

Tijdens speciale gebeurtenissen - Vanaf 1609 met een telescoop

Wat gebeurt er:
Zichtbaar licht komt rechtstreeks in onze richting + zichtbaar licht weerkaatst op deeltjes in de ruimte in onze richting.

Tijdens een eclipse wordt het rechtstreeks licht tegengehouden en zien we het weerkaatste licht. We kunnen zo de deeltjes zien die zich in de zonneatmosfeer bevinden. Wat blijkt: er is daar ook van alles gaande - er zit structuur in de zonneatmosfeer.

STUDYING THE SUN

By watching it with a simple telescope from Earth in visible light .



The simplest way to study the sun is to watch it through a simple telescope from earth. A telescope can enlarge the image.

In de eerste plaats bestuderen we de zon door ernaar te kijken, op een simpele manier: door een eenvoudige telescoop.
Zichtbaar licht.

LOOKING AT AN OBJECT

A picture of a hand in visible light.



We study object by looking at them.

Solar visible light bounces back from the hand into our eyes.

You see the surface. Visible light can’t penetrate into the skin. The skin is not transparant for visible light.

LOOKING AT AN OBJECT

# ...in x-rays.



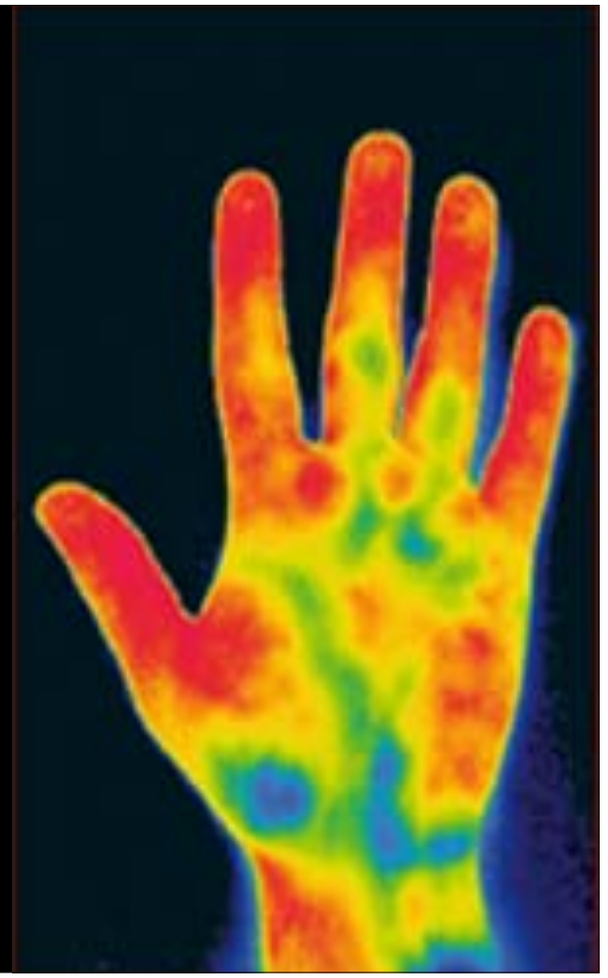
By looking at objects using another sort of light, we see different things.
X-rays are produced by a machine. The x-rays pass soft tissues, but bones for example are less opaque to x-rays.
Medical pictures: x-rays are sent through the body. It is the shadow of the x-ray light that you see in the image. Bones have more shadow than soft tissues.

Hard X-rays can traverse relatively thick objects without being much absorbed or scattered. For this reason, X-rays are widely used to image the inside of visually opaque objects. The most often seen applications are in medical radiography and airport security scanners, but similar techniques are also important in industry (e.g. industrial radiography and industrial CT scanning) and research (e.g. small animal CT). The penetration depth varies with several orders of magnitude over the X-ray spectrum. This allows the photon energy to be adjusted for the application so as to give sufficient transmission through the object and at the same time good contrast in the image.
X-rays have much shorter wavelengths than visible light, which makes it possible to probe structures much smaller than can be seen using a normal microscope. This property is used in X-ray microscopy to acquire high resolution images, and also in X-ray crystallography to determine the positions of atoms in crystals.

An X-ray generator is a device that produces X-rays. Together with an X-ray detector, it is commonly used in a variety of applications including medicine, fluorescence, electronic assembly inspection, and measurement of material thickness in manufacturing operations. In medical applications, X-ray generators are used by radiographers to acquire x-ray images of the internal structures (e.g., bones) of living organisms, and also in sterilization.

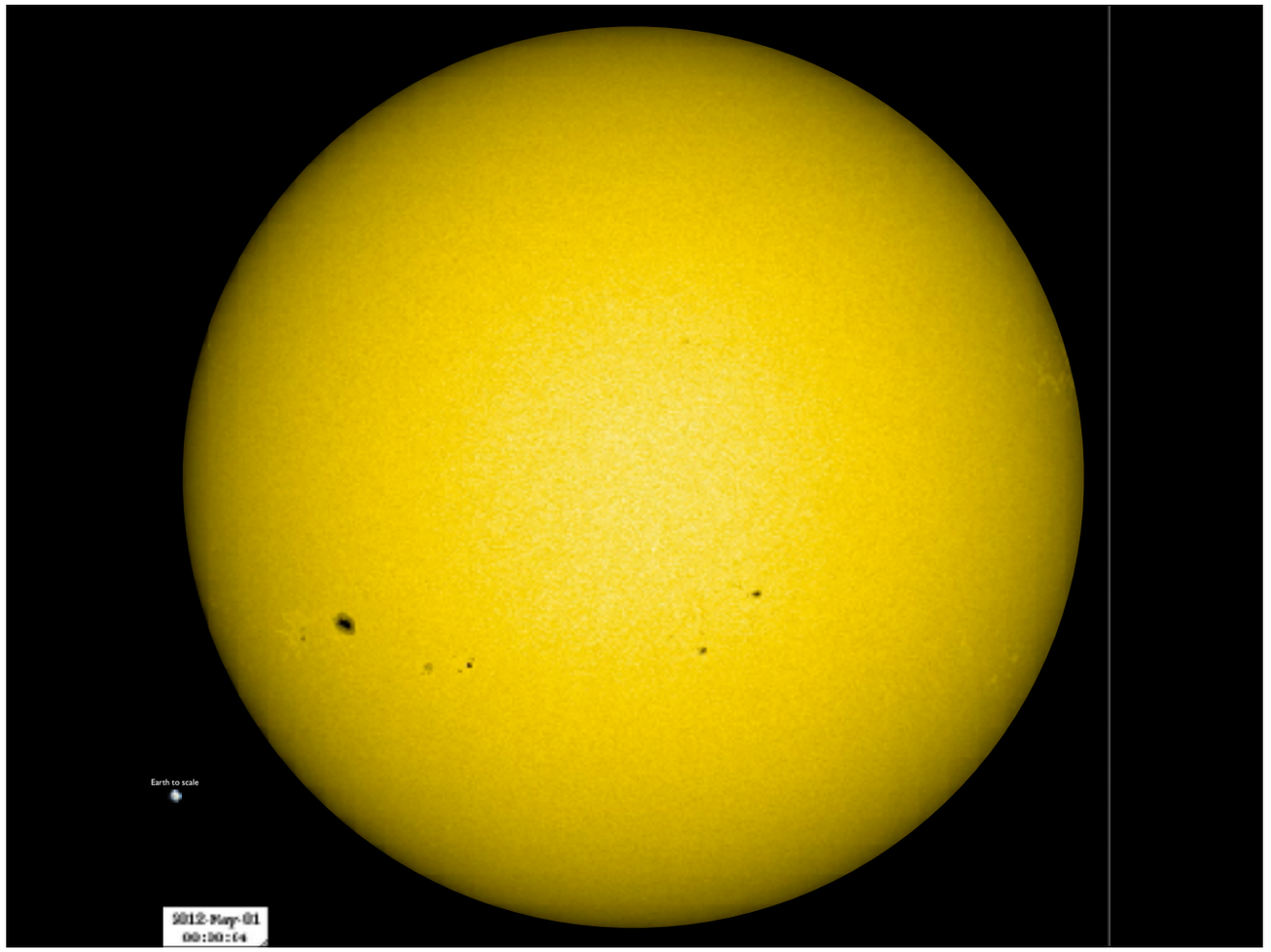
LOOKING AT AN OBJECT

…in infra-red.



Each body radiates infrared. When molecules are moving, there is heat and infrared.

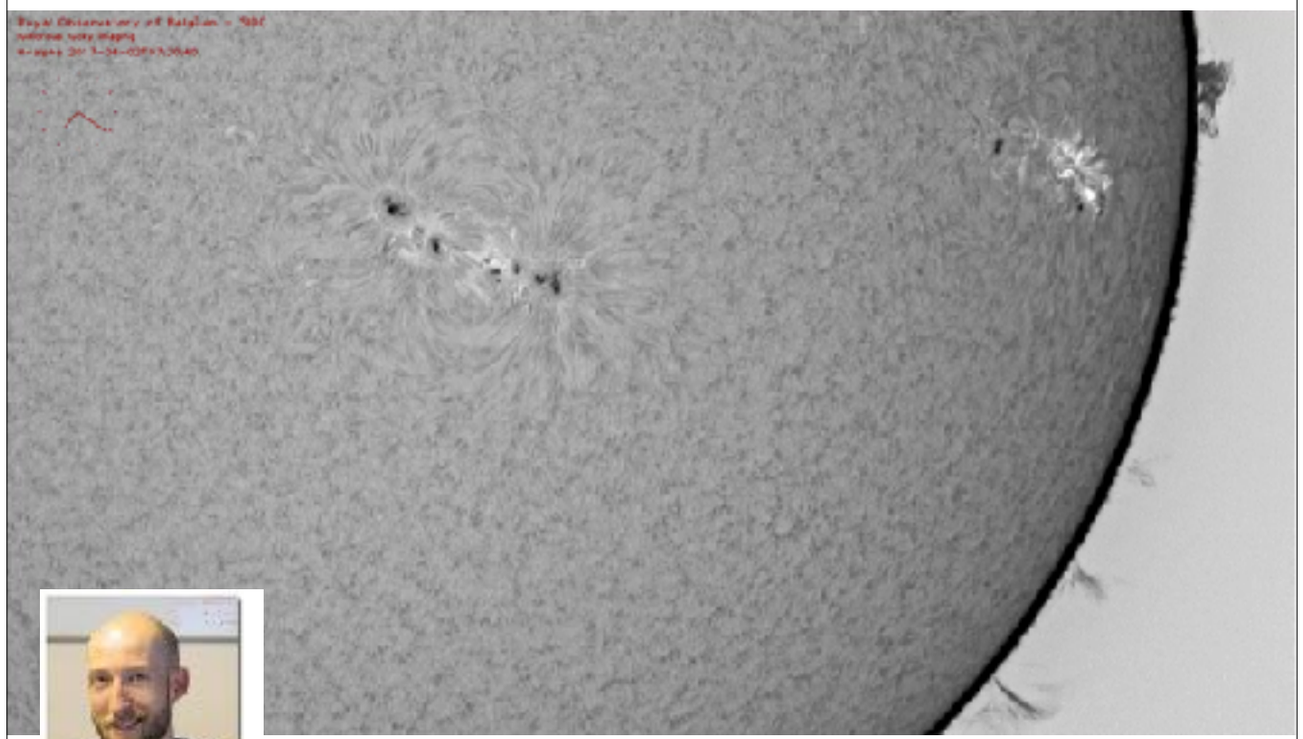
Infrared can be used as a way to measure the heat radiated by an object. This is the radiation produced by the motion of atoms and molecules in an object. The higher the temperature, the more the atoms and molecules move and the more infrared they produce. Any object which has a temperature i.e. anything above absolute zero (-459.67 degrees Fahrenheit or -273.15 degrees Celsius or 0 degrees Kelvin), radiates in the infrared. Absolute zero is the temperature at which all atomic and molecular motion ceases. Even objects that we think of as being very cold, such as an ice cube, emit infrared. When an object is not quite hot enough to radiate visible light, it will emit most of its energy in the infrared. For example, hot charcoal may not give off light but it does emit infrared which we feel as heat. The warmer the object, the more infrared it emits. We experience infrared radiation every day. The heat that we feel from sunlight, a fire, a radiator or a warm sidewalk is infrared. Although our eyes cannot see it, the nerves in our skin can feel it as heat. The temperature-sensitive nerve endings in your skin can detect the difference between your inside body temperature and your outside skin temperature. We also commonly use infrared rays when we operate a television remote.
What specifically do infrared images reveal?
Infrared is a type of light that we cannot see with our eyes. Our eyes can only see what we call visible light. Infrared light brings us special information that we do not get from visible light. It shows us how much heat something has and gives us information about an object's temperature. Everything has some heat and puts out infrared light. Even things that we think of as being very cold, like an ice cube, put out some heat. Cold objects just put out less heat than warm objects. The warmer something is the more heat it puts out and the colder something is the less heat it puts out. Hot objects glow more brightly in the infrared because they put out more heat and more infrared light. Cold objects put out less heat or infrared light and appear less bright in the infrared. Anything which has a temperature puts out infrared light. In the infrared images shown in these lesson plans, different colors are used to represent different temperatures. You can find out which temperature a color represents by using the color-temperature scale show to the right of most of the images. The temperatures are in degrees Fahrenheit.
http://coolcosmos.ipac.caltech.edu/image_galleries/ir_zoo/lessons/background.html




The sun emits visible light

# HOME MADE BY USET - EMIL









H-alpha 656.28 nm - rood - 9000 °K

C II K 3933.7Å - 393.37 nm - blauw -

H-alpha (Hα) is a specific deep-red visible spectral line in the Balmer series with a wavelength of 656.28 nm; it occurs when a hydrogen electron falls from its third to second lowest energy level. H-alpha light is important to astronomers as it is emitted by many emission nebulae and can be used to observe features in the Sun's atmosphere, including solar prominences and the chromosphere.

Emil Kraaikamp is a famous astrophotographer working as an IT specialist at the Royal Observatory of Belgium. A few years ago, he wrote the image processing software AutoStakkert!2, which is now used by astrophotographers worldwide and has been featured in the September 2016 issue of Sky and Telescope, one of the principal journals for the amateur astronomical society.
Two weeks ago, on 28 March, Emil was 'lucky' enough to capture a plane transit event during high cadence observations with the USET solar telescopes (Uccle Solar Equatorial Table). These observations were part of a joint solar observation campaign with satellites such as SOHO (SUMER ), IRIS and HINODE , and other groundbased instruments.

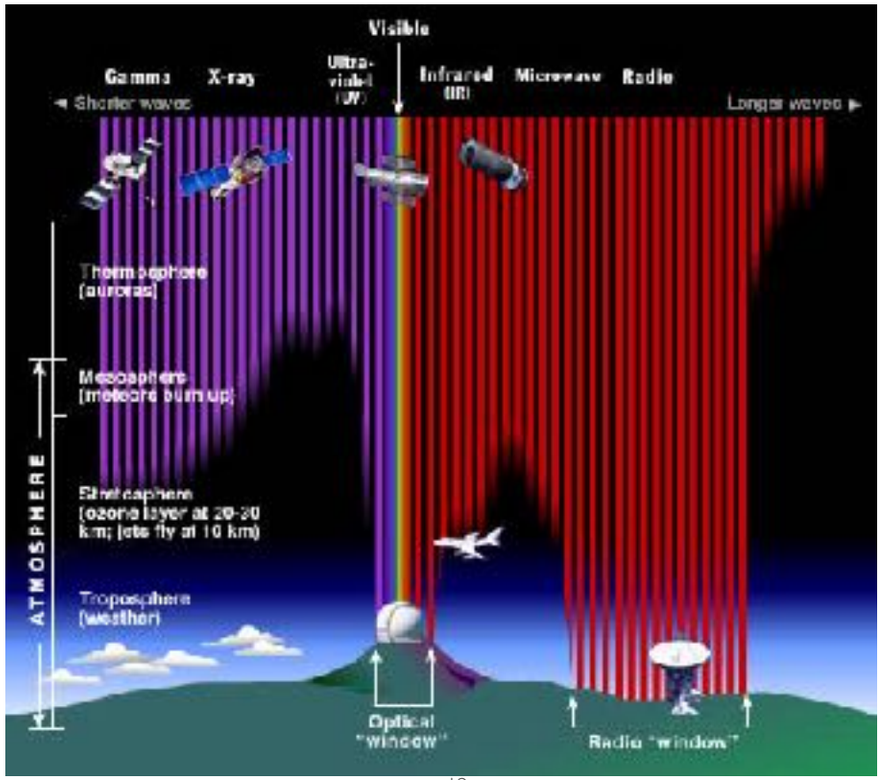
Emil explains that because of the longer exposure time in H-alpha (+/- 80ms), the airplane is a bit blurry there, but Ca-K was able to freeze the movement quite well with just 5 ms of exposure per frame. The two fuzzy stripes to the right of the airplane are condensation trails ("contrails") from the aircraft's exhaust (see the Contrailscience website for more info). As can be seen in the Ca-K clip underneath, the airplanes can also be tracked, although not for very long and they obviously need to exactly pass the solar disc.

zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGeGrBIV

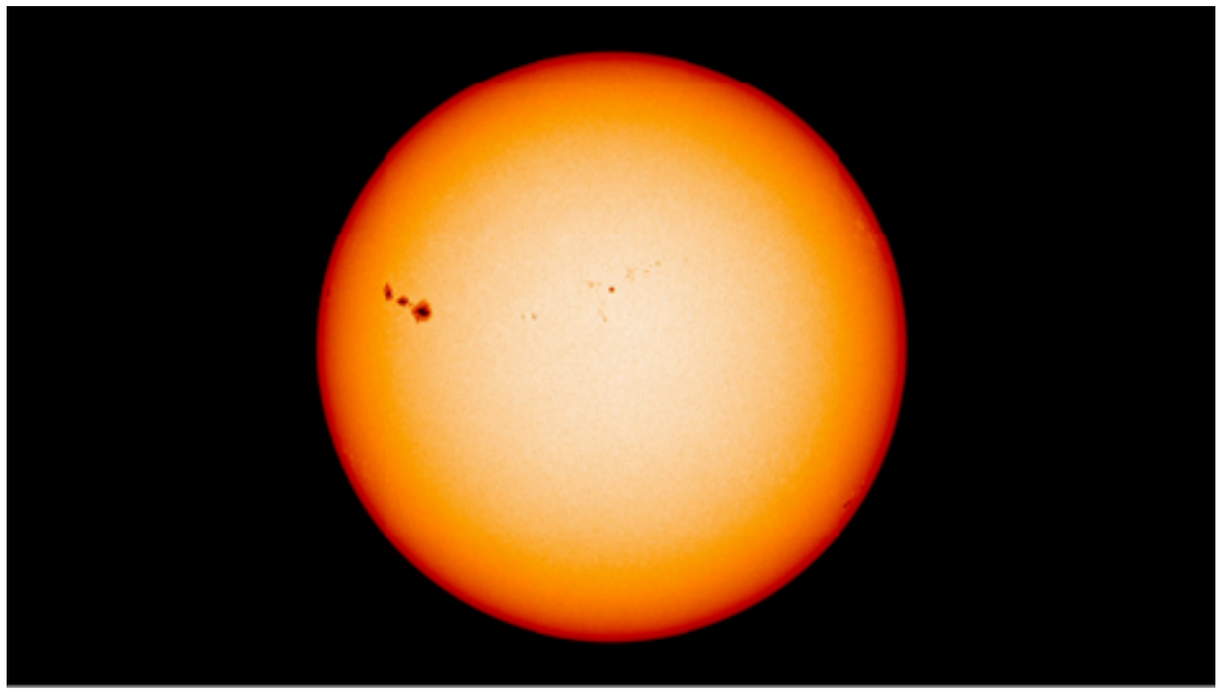
UV: 380 - 10 nm / 3800 - 100 Angstrom

EUV: 100 - 10 nm / 1000 - 100 Angstrom

# TRANSPARENCY OF OUR ATMOSPHERE



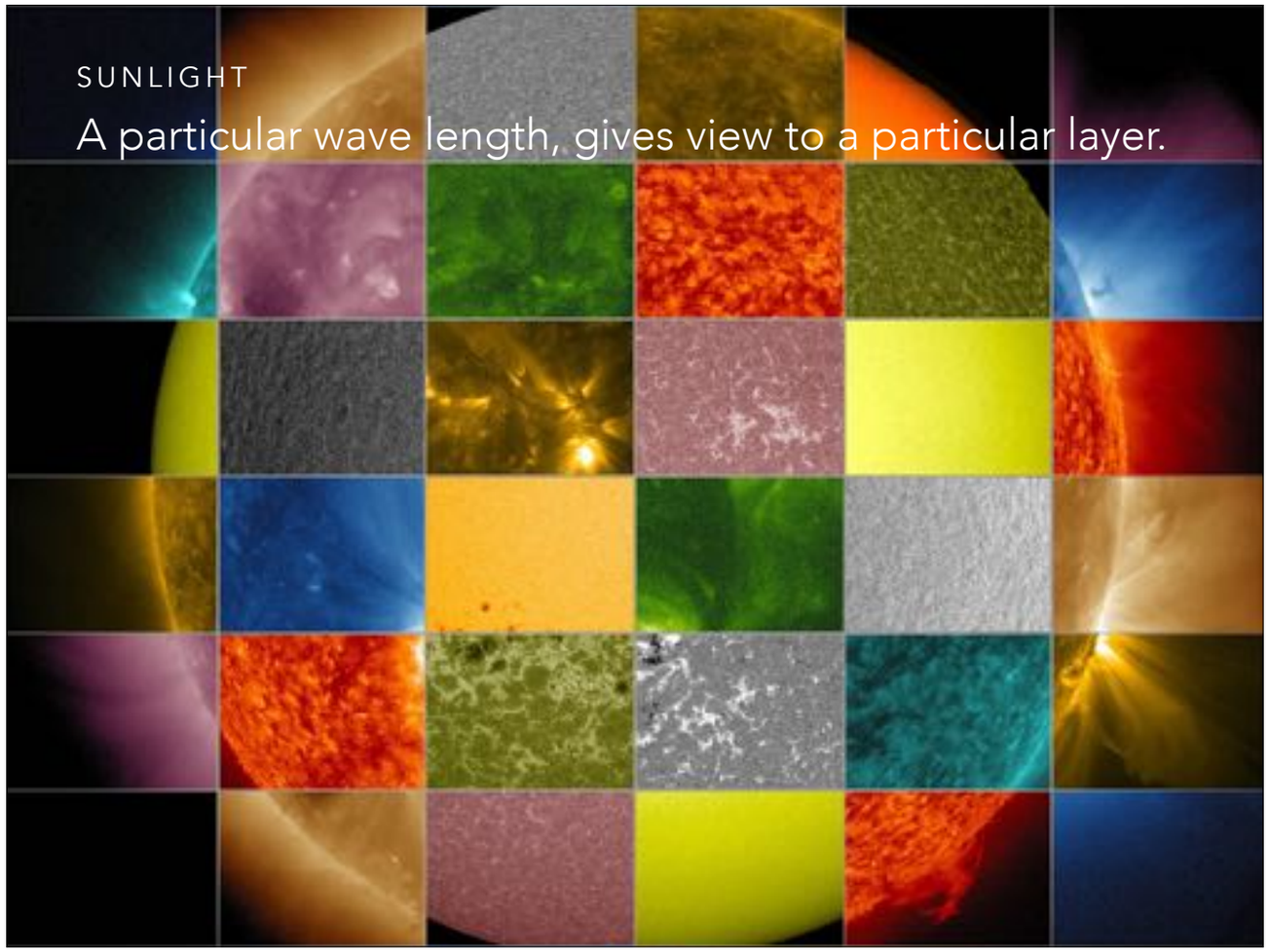
# LOOKING AT AN OBJECT IN ALL SORTS OF LIGHT



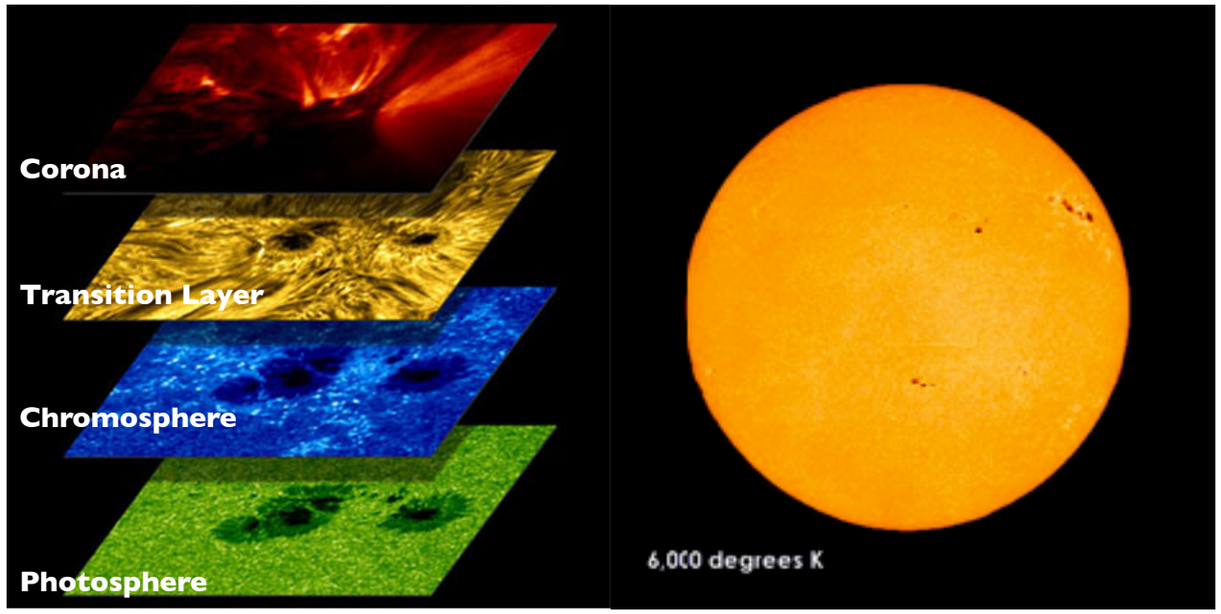
But the sun is so hot that emits even more energetic light, with much shorter wavelengths than visible light. If you catch this light, the sun looks very different.
To catch this light, we have to go to space. So, it was only since the start of the space age that we were able to make such recordings.
In een andere golflengte zien we telkens iets anders. 1 bepaalde structuur ziet er compleet anders uit in een andere golflengte. We zien dat de zon een magnetische persoonlijkheid heeft.

The Sun has a hidden part that became only visible at the start of the space age. From the moment, we could inspect the Sun in other wavelengths, the Sun showed its dynamic, explosive and magnetic personality.

We use many tricks to observe the Sun and its activity. One of them is to look at the Sun using different parts of the light spectrum, thus in different wavelengths. From Earth, with the naked eye, we see the surface of the Sun in white light like this. However, now that I start the movie, you can see how looking at the Sun in other wavelengths from space reveals very different structures and complexity. For this we mainly use extreme ultraviolet wavelengths because we are studying the hot outer region of the Sun, the corona. We see active regions, these are the bright patches, that show up in EUV wavelengths where the sunspots were first seen in white light. We also see the effects of the sun's magnetic field in the many loops above these sunspots. Each wavelength shows us different aspects and different layers of the solar atmosphere and by combining them, we try to build a complete picture of the solar activity.
Therefore, we have many instruments in space to observe the solar atmosphere. This movie was made combining different observations from the AIA telescope on board the Solar Dynamics Observatory.


SUNLIGHT
A particular wave length, gives view to a particular layer.

# TRANSPARANT OUTER LAYERS - THE SOLAR ATMOSPHERE




The plasma seems to be layered. In each layer, the plasma is at a different temperature.
At the surface, it is ‘cold’, only 6000°K but hot enough to emit visible light.
If we go further away from the Sun, the plasma emits predominantly in shorter wavelengths. This is because the plasma is much hotter.

The huge coronal magnetic loops, don’t put a shadow in visible light pictures. This is because the plasma in that layer is not dense. It doesn’t block the visible light.
But there is enough plasma that radiates in the EUV making the invisible magnetic loops visible.

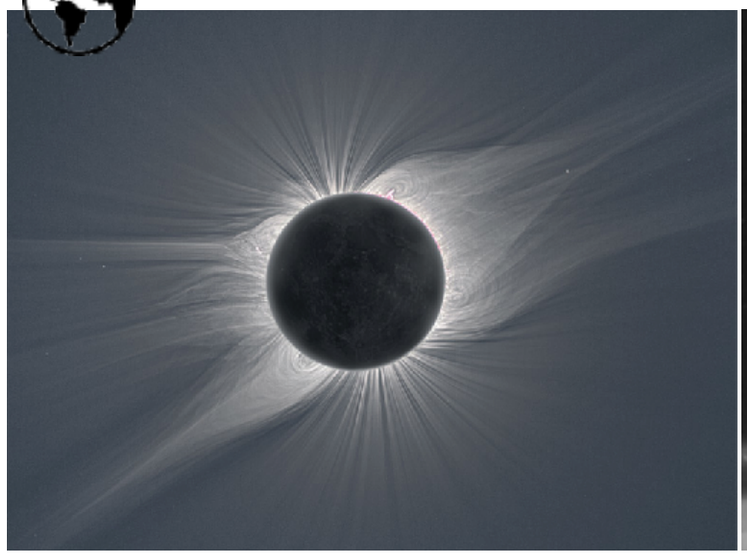
The solar atmosphere are the most outer layers of the Sun from where the sunlight can escape freely, in contrast to the un-transparant inner layers.
The solar atmosphere has 4 basic layers
Photosphere - chromosphere - transition layer - corona

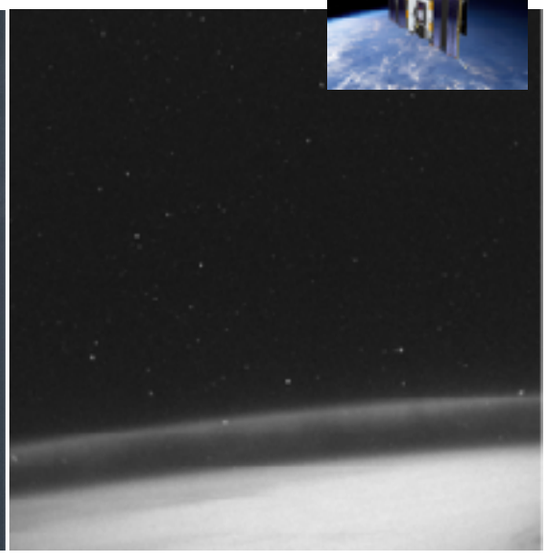
Temperature increases which is sort of strange. Normally you would think that the temperature decreases if you go further away from the heat source. Why is the corona so hot? There is not a clear answer yet.

The name photosphere comes from the greek work photon which means ‘light’. The photosphere radiates mostly in visible light which we can see.
While the corona radiates in (E)UV and X-rays, all wavelengths which we can’t see with our eyes. That’s why we see the sun as a non-dynamic structure. The coronal loops and dynamic structures in the corona are invisible for us unless we watch it in the EUV using special filters translating the EUV into a picture which we can see.

https://www.nasa.gov/feature/goddard/2017/studying-the-sun-s-atmosphere-with-the-total-solar-eclipse-of-2017
The answer to another mystery also lies in the lower corona: It is thought to hold the secrets to a longstanding question of how the solar atmosphere reaches such unexpectedly high temperatures. The Sun’s corona is much hotter than its surface, which is counterintuitive, as the Sun’s energy is generated by nuclear fusion at its core. Usually temperatures go down consistently as you move away from that heat source, the same way that it gets cooler as you move away from a fire – but not so in the case of the Sun’s atmosphere. Scientists suspect that detailed measurements of the way particles move in the lower corona could help them uncover the mechanism that produces this enormous heating.

# ONZE EERSTE ONTDEKKING







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?

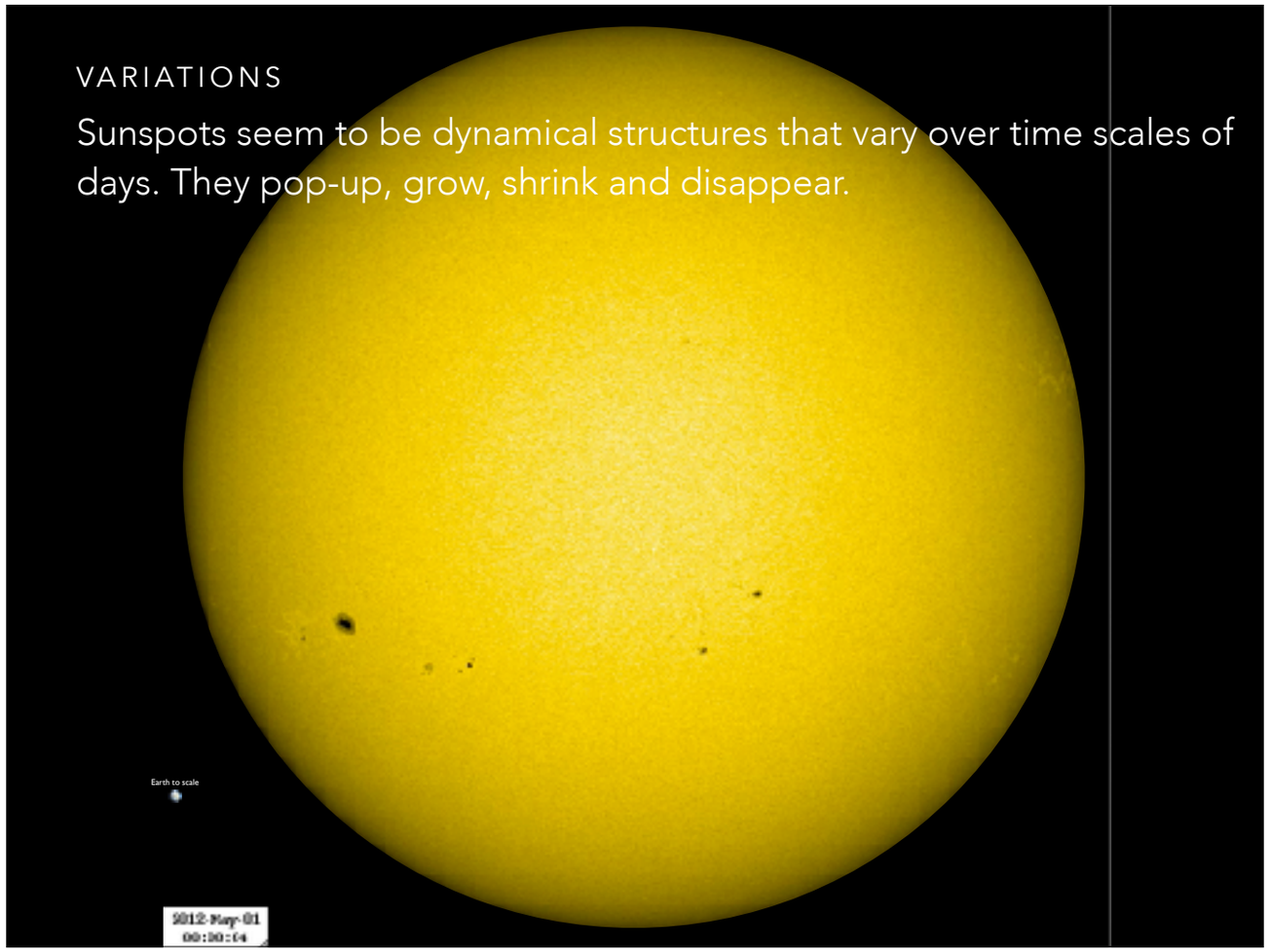
The beginning of the wind is best "seen," said Parker, in pictures of a total solar eclipse. During a total solar eclipse the moon passes between the Earth and sun, blocking sunlight from reaching Earth. In pictures of the events, bits of the sun's corona—the outer edge of the sun—can be seen extending 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

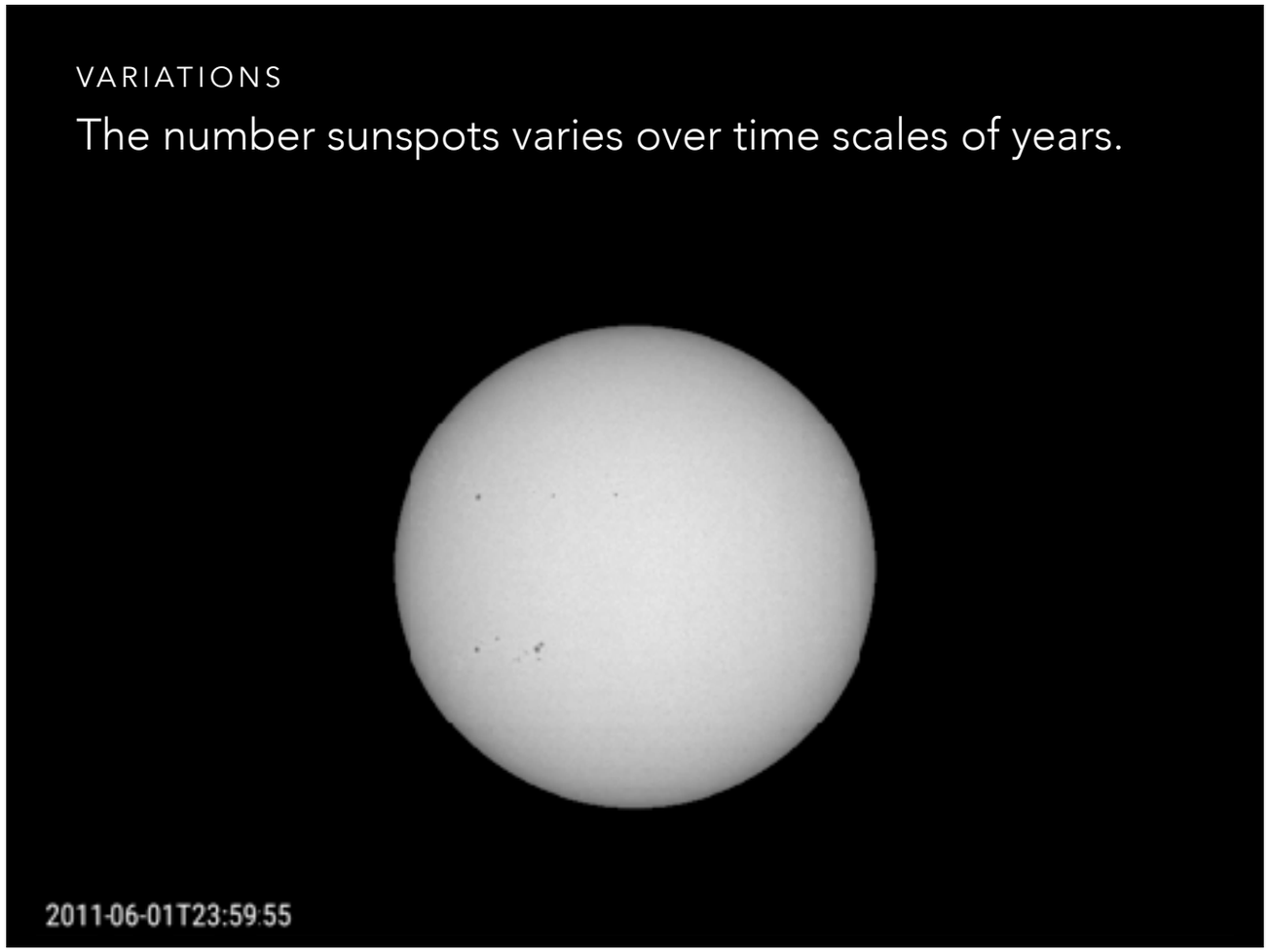
Foto genomen door de star tracker-cameras: hiermee kan PROBA2 zich autonoom oriënteren.
In deze foto zie je de aardatmosfeer en, het belangrijkste, de sterren. Deze worden gebruikt om zich te oriënteren.

Per toeval staat de aarde erop.
Er zitten sterrenkaarten in de computer van PROBA2.




Kijken wordt pas interessant als er iets veranderd.

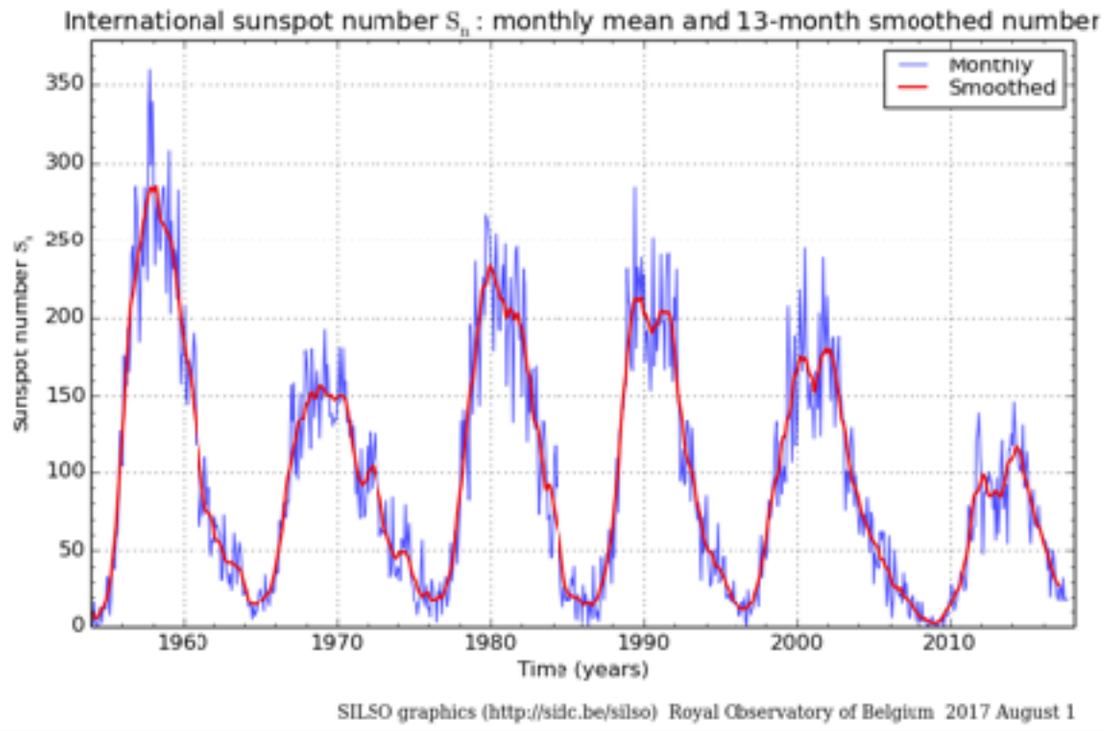
Even terug naar zichtbaar licht.
Variatie over dagen - week




Variatie over jaren

## COUNTING SUNSPOTS

Stations worldwide count sunspots and calculate their Wolf number:
R = k ( 10 x Ng + Ns). The WDC calculates the daily ISN.

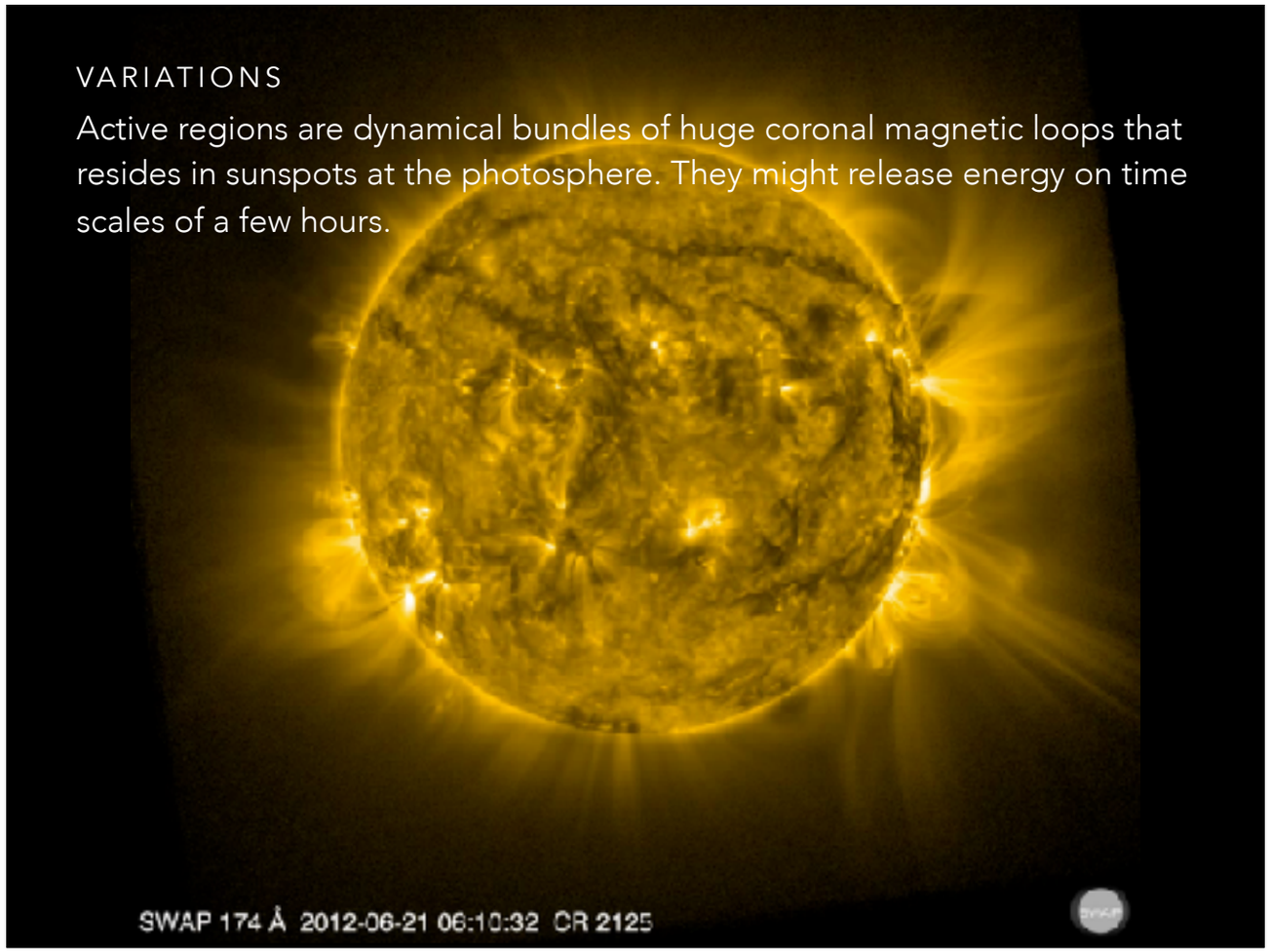



K - reduction coefficient, scaling factor, quality index — ingevoerd door Wolfer. Wolf, de vorige directeur heeft k = 1.

hangt af van hoe
goed een waarnemer kleine zonnevlekken kan waarnemen : persoonlijke ervaring, lokale zichtbaarheid, sterkte telescoop, zicht van de ogen, …

waarnemer groepen opsplitst

hierdoor kan het zonnevlekkengetal van 1 waarnemer verschillen van een geheel getal.

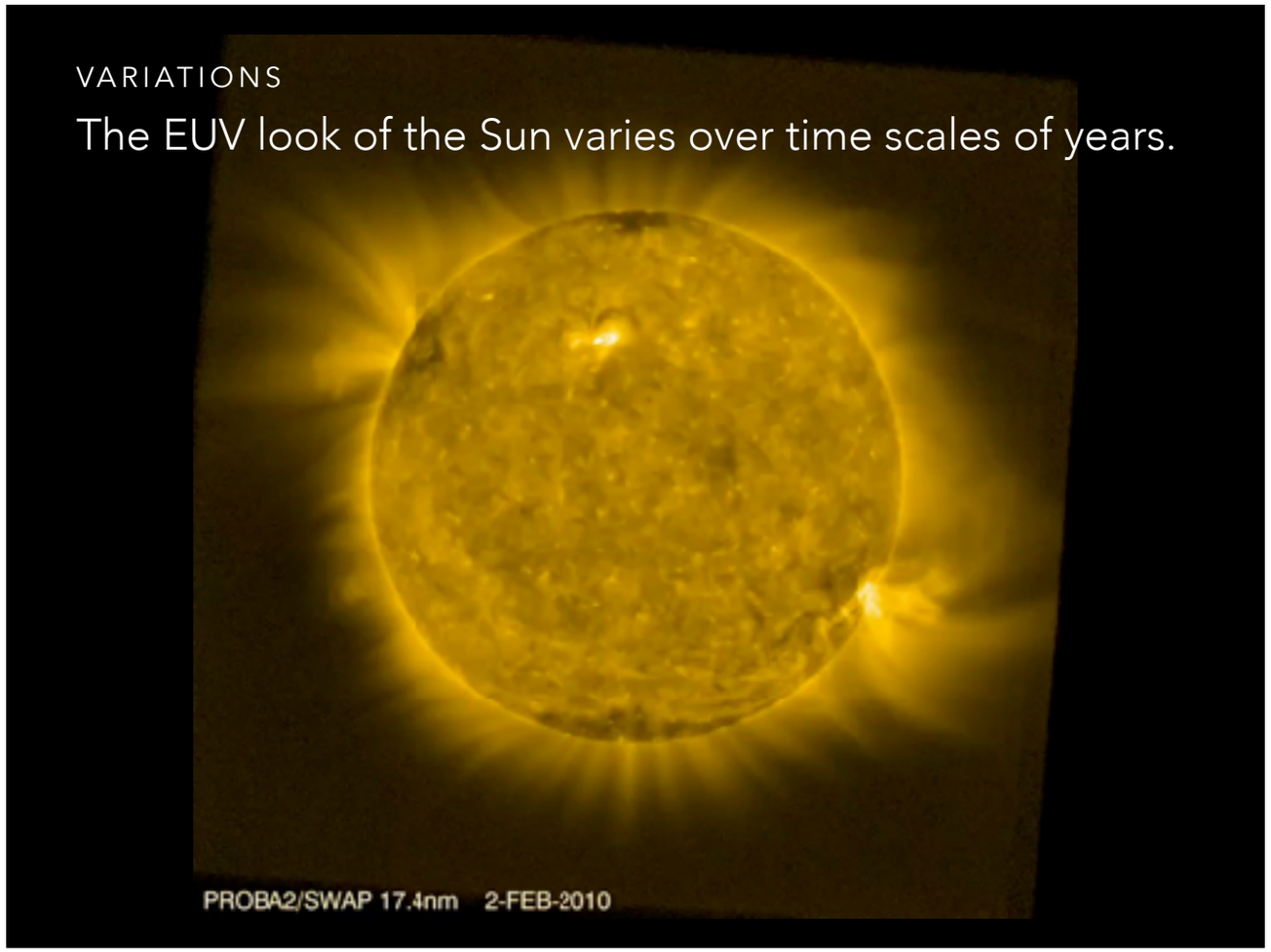



In het EUV zien we dat die structuren erg dynamisch en beweeglijk zijn. Dit is een filmpje over enkele zonnerotaties.

De zon varieert
Film over een paar zonnerotaties
Actieve gebieden kunnen net zoals zonnevlekken ontstaan, groeien, verdwijnen.

VARIATIONS

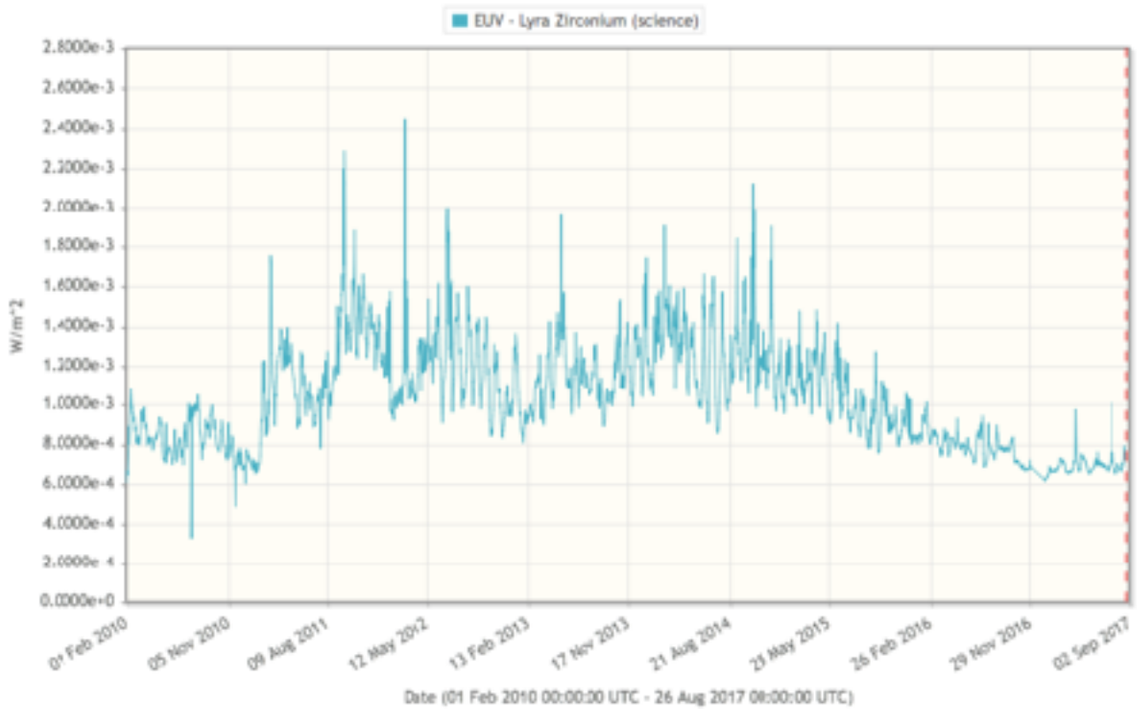
The EUV look of the Sun varies over time scales of years.




EUV variatie over 5 jaar

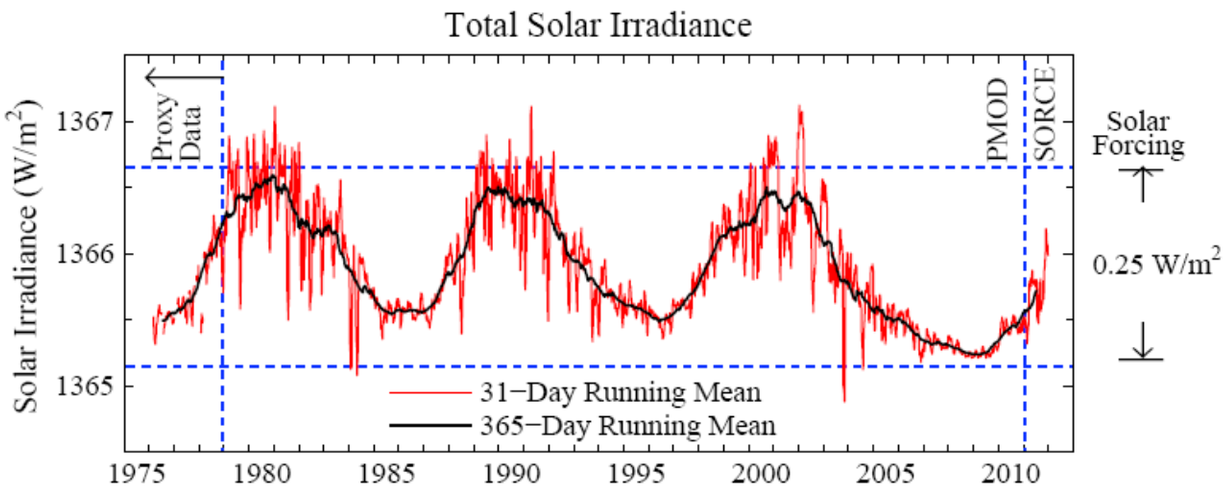
MEASURING 1 EUV WAVELENGTH

The radiometer LYRA onboard PROBA2 measures the EUV radiation in 4 wavelengths. The intensity varies over years.




We pikken er 1 golflengte uit en maken een tijdsserie.

VARIATIONS




De stralingsenergie die de aarde bereikt per seconde, bedraagt ongeveer 1365 Watt per vierkante manier aan de top van de atmosfeer. Dit is de “total solar irradiance” (TSI) en wordt gebruikt in klimaatstudies
Vermogen is watt

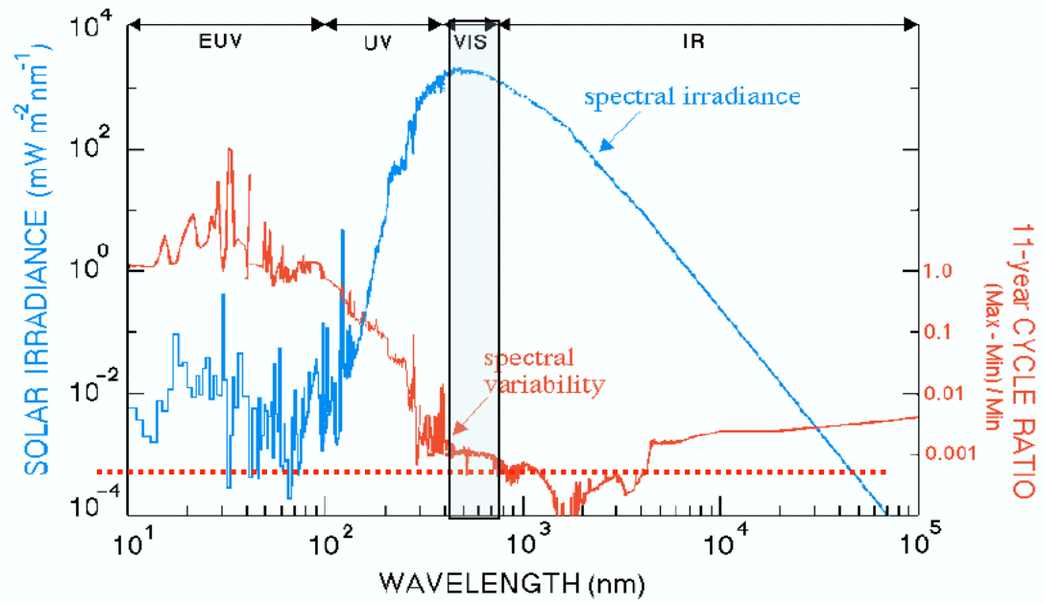
This represents a fraction of the total amount of electromagnetic radiation emanating from the Sun in all directions.

In de astronomie wordt onder de lichtkracht (luminositeit, helderheid) van een ster verstaan het totaal uitgezonden vermogen (watt, energie/tijd) in de vorm van elektromagnetische straling. De lichtkracht is afhankelijk van de effectieve temperatuur van de ster en z'n omvang. De lichtkracht wordt uitgedrukt in Watt of in eenheden van de lichtkracht van de zon (L☉).
De lichtkracht van de zon kan direct gemeten worden door de bepaling van de zonneconstante. De lichtkracht van een ander ster bepaalt men door z'n absolute helderheid te vergelijken met die van de zon of van een andere ster met reeds bekende lichtkracht.

als je de TSI vermenigvuldigd met het oppervlak van een bol met straal 1AU,
4*Pi*R^2*1367 met R=1,496 10^8 km dan bekom je de lichtkracht van de zon, 3,839 10^26 Watt

VARIATION PER WAVELENGTH

## The variation is the strongest is the short wavelengths.




Logaritmische schaal

als je alles integreert onder de blauwe curve, bekom je de TSI

Het zichtbare en infrarode spectrum, voortgebracht ter hoogte van de fotosfeer, varieert bijzonder weinig (<1%).
De variaties zijn veel hoger (een factor 10 tot 1000), bij golflengtes onder de 320 nm, in het ultraviolet. **Deze straling, die echter van de andere lagen komt (chromosfeer, corona) komt slechts overeen met 2% van de totale straling**. Ze heeft niettemin een belangrijk effect op de hogere aardatmosfeer

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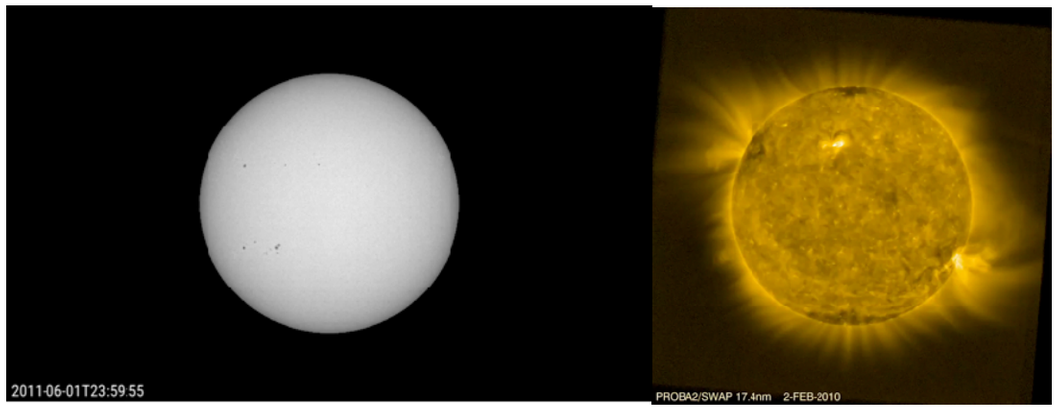
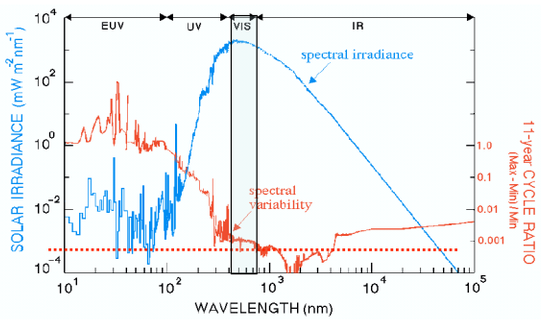


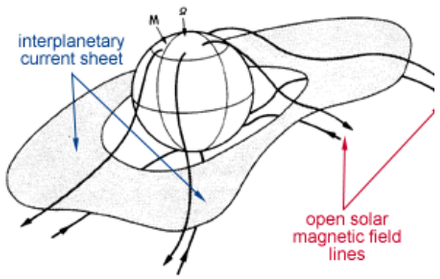



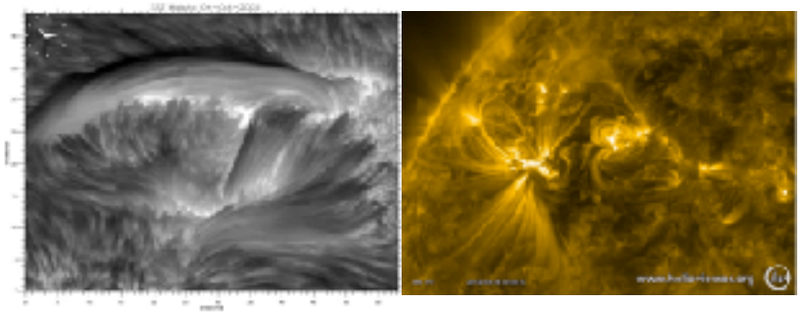

Logaritmische schaal

In zichtbaar licht wordt de zon of stukken van het oppervlak niet helderder - terwijl in het EUV er duidelijk een variatie is -

## VARIATIONS IN MAGNETISM

Magnetic fields are the driving force behind solar activity. You have different spatial and time scales.



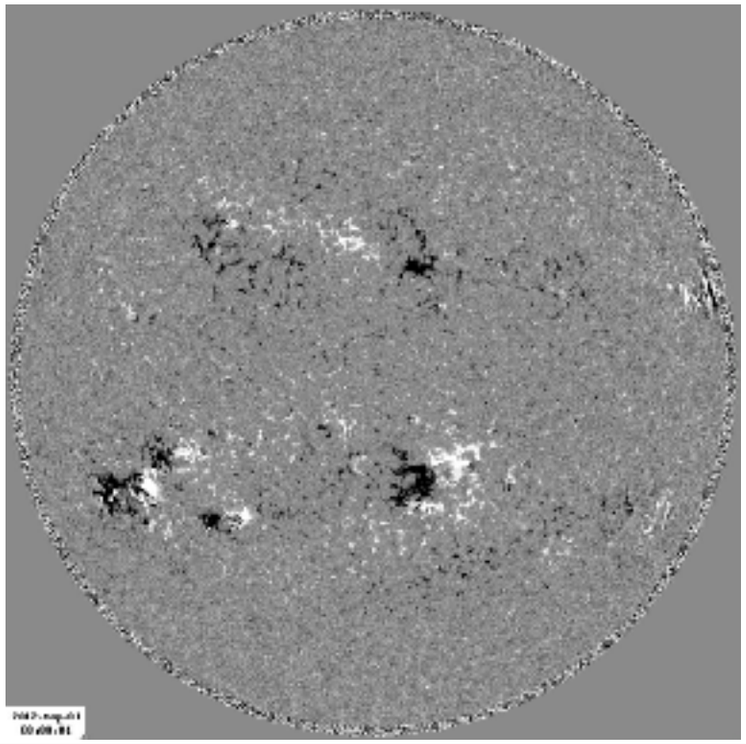
Het weer en klimaat wordt gestuurd door magnetische velden. Je hebt deze op alle mogelijke schalen.

spicules, AR, June 2004

Swedish Solar Telescope; hydrogen “alpha”

## THE PHOTOSPHERIC MAGNETIC FIELD

Similar like sunspots and magnetic coronal loops, the photospheric magnetic field varies over time scale of days.



variatie over een maand

THE SOLAR ATMOSPHERE CHANGES OVER TIME



2008 2015 2017

De zonneatmosfeer verandert op hetzelfde ritme van de zonnecyclus.

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.

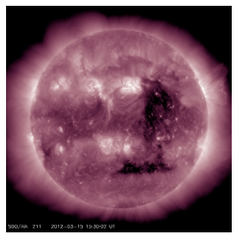
SPACE CLIMATE

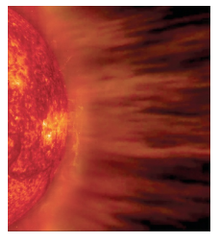
The sun looses energy in different forms in a continuous way.

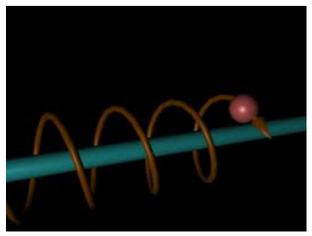
Light

Mass - wind

Particles







Variaties op lange termijn maken het ruimteklimaat.

Van het blauwe en rode hebben we nog niet concreet gesproken.

energievormen
De uitstoot varieert over een periode van 11 jaar - klimaat

Klimaat
algemene toestand in de ruimte
verschillende vormen van energie die in de ruimte ‘rond dwalen’

Rood - Beweging en gedrag wordt per deeltje beschreven.
Blauw - wordt als een geheel bekeken, MHD

Blauw en rood zijn nauw verbonden met magnetisme.

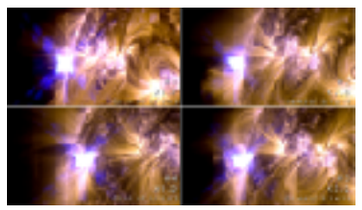
SPACE WEATHER

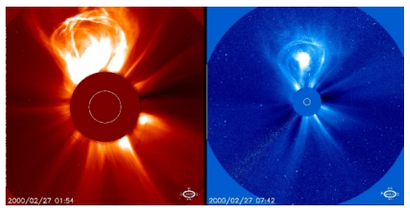
The sun looses energy in different forms in an abrupt, impulsive and brutal way.

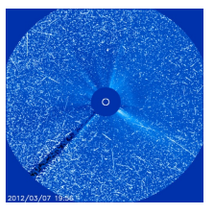
Zonnevlammen

Wolken

Proton storm












Variaties op korte termijn maken het ruimteweer.

**Plotse veranderingen** van de energietoestand

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

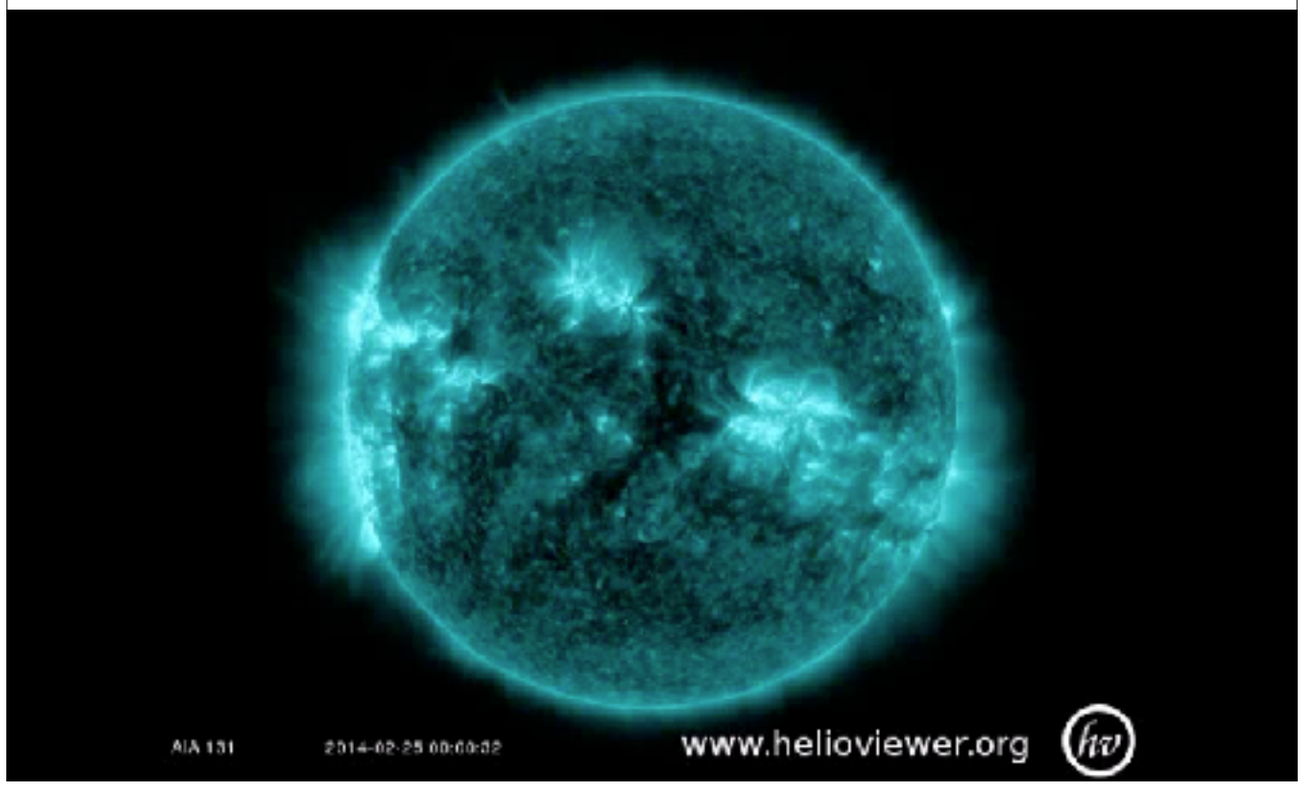
The "solar wind" from the Sun streams past the Earth and is mostly deflected by the Earth's magnetic field. But variations in the solar wind cause changes in the Earth's magnetic field.

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.

SOLAR STORMS

From time to time, we see light flashes. These are solar flares.



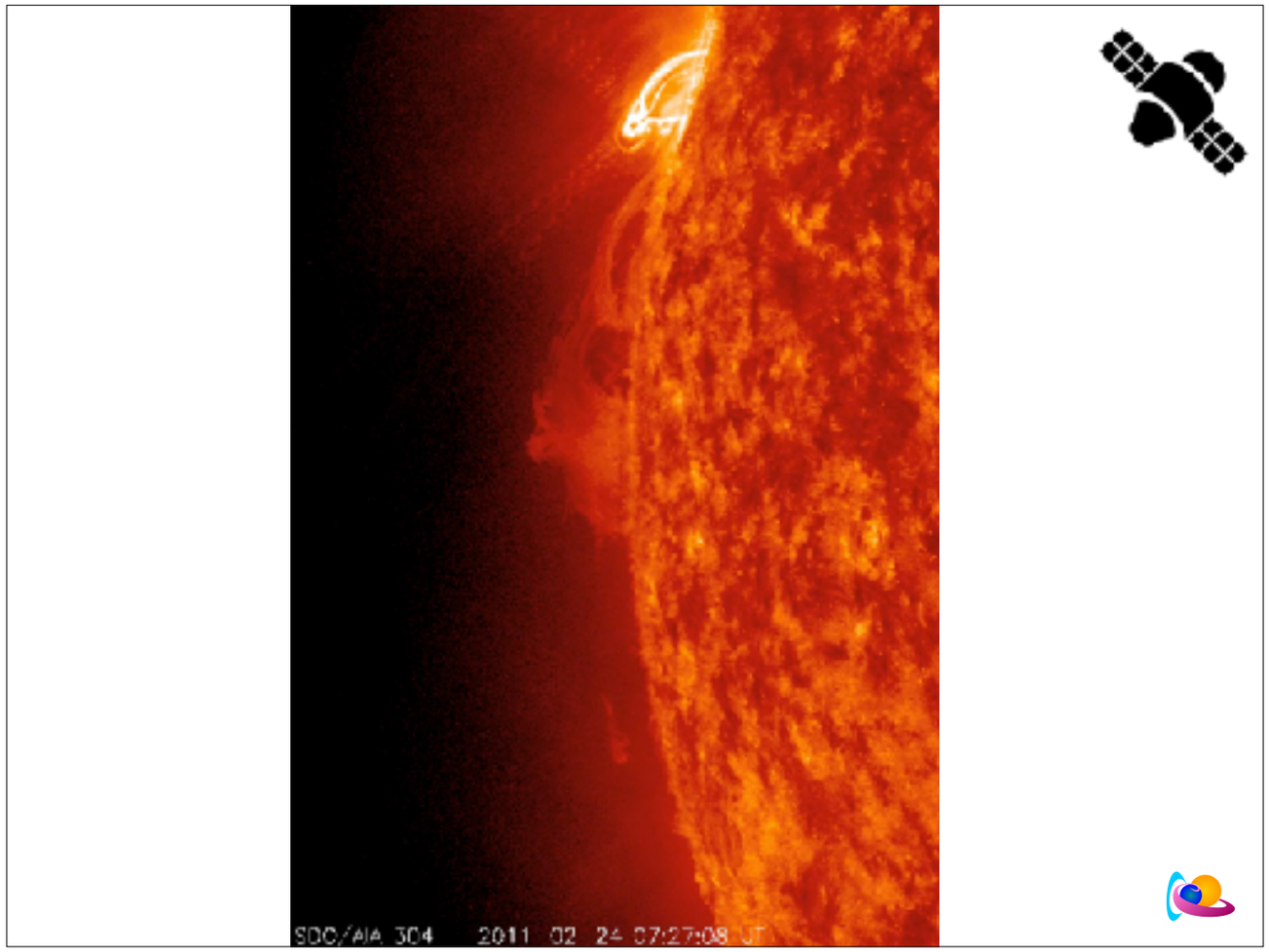

131 angstrom
of 13,1 nm

1700 Angstrom

zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGBIV

UV: 380 - 10 nm / 3800 - 100 Angstrom

EUV: 100 - 10 nm / 1000 - 100 Angstrom



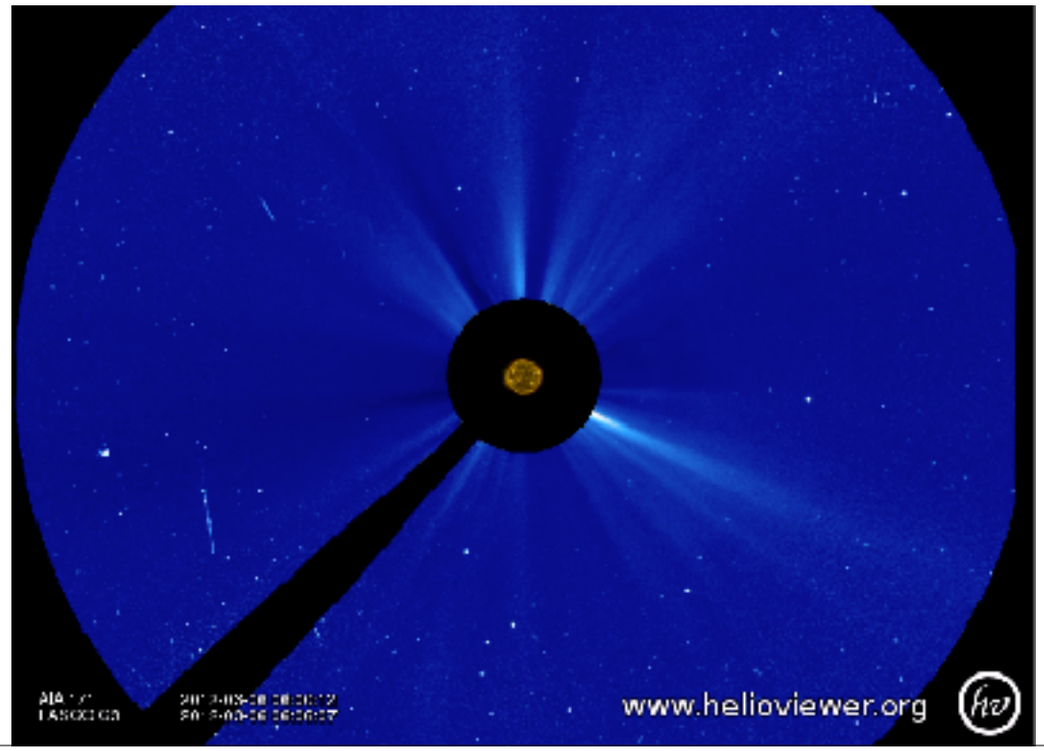

zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGBIV

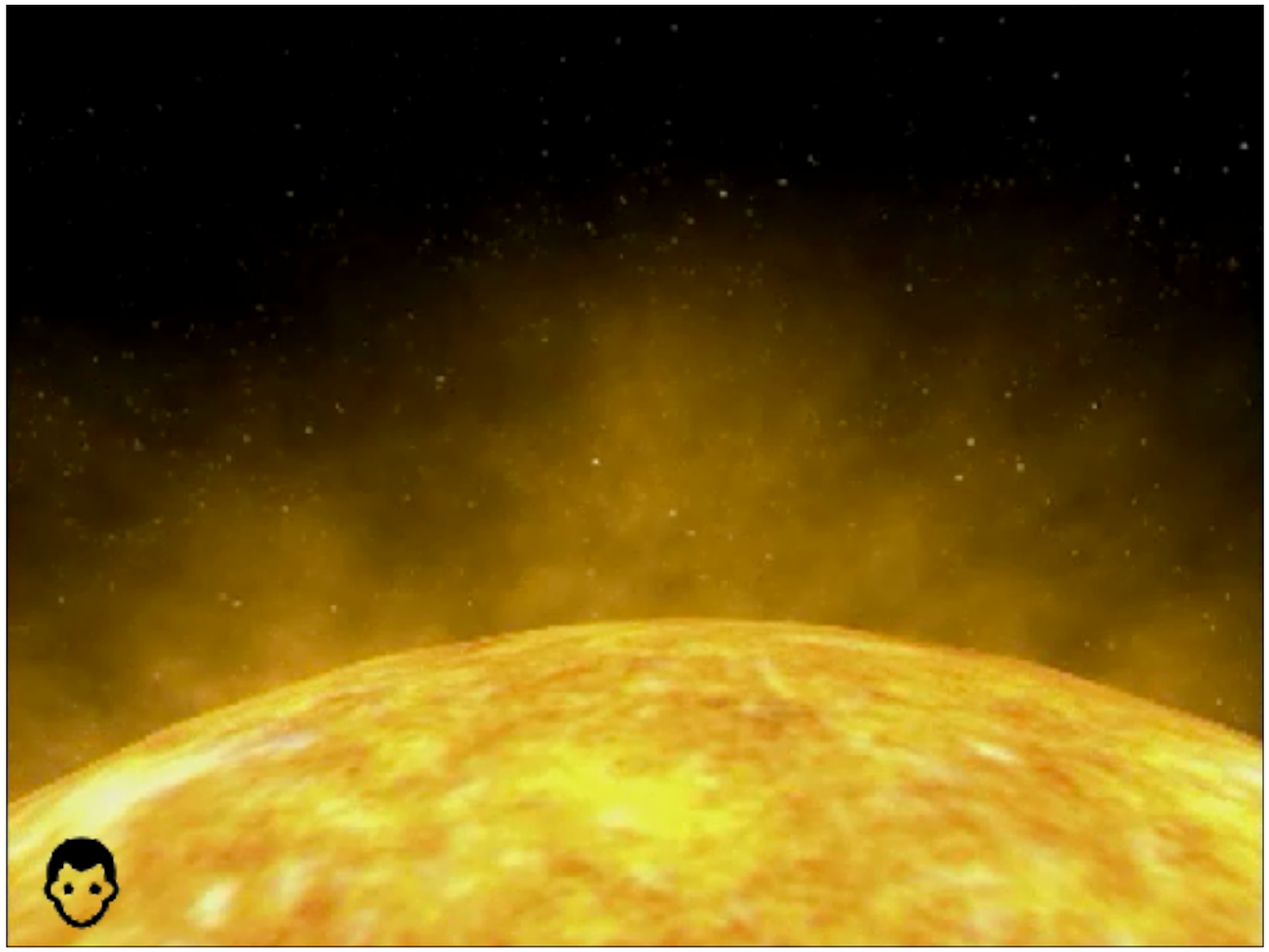
UV: 380 - 10 nm / 3800 - 100 Angstrom

EUV: 100 - 10 nm / 1000 - 100 Angstrom

SOLAR STORMS

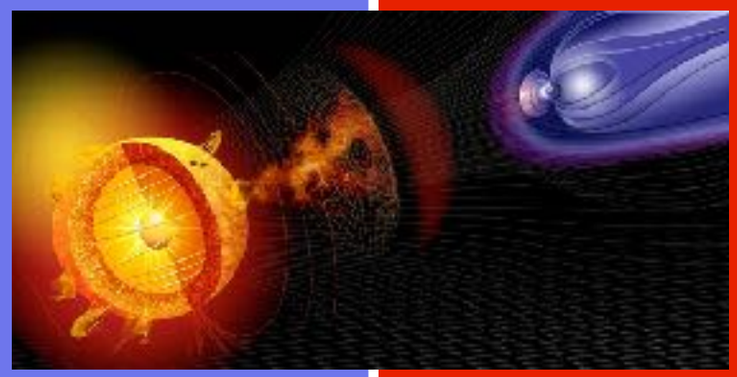
A solar cloud hurling through space. Solar particles hit the coronagraph.





The earth's atmosphere protects us against solar flares.
The earth's magnetic shield protects us against solar clouds and particles.



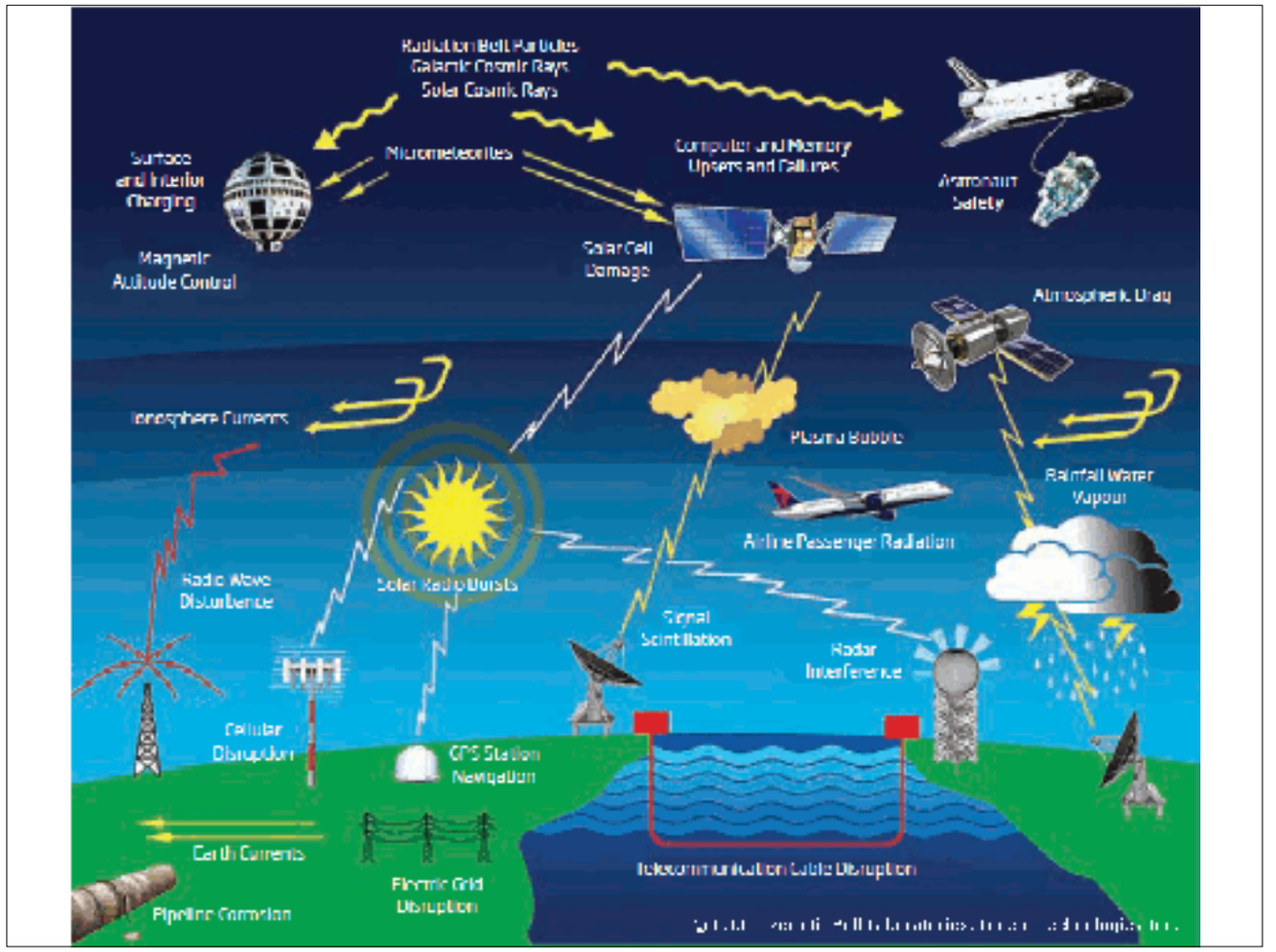






De magnetosfeer en de atmosfeer **beschermen het leven op aarde** tegen de schadelijke invloed van de Zon (zonneklimaat en zonneweer): de aardatmosfeer wordt niet weggeblazen dankzij de magnetosfeer, hoogenergetische deeltjes worden gereflecteerd, X-straling wordt tegengehouden door de atmosfeer. Het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

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




aurora - drag on satellites - GNSS, Global navigation satellite system - GIC

Polar flights  - astronauten - aan boord electronica

radio-communicatie

De zon schijnt al sinds mensenheugen. Sinds we bestaan is nog geen enkele zonnestorm geweest die de mensen van de aardbol heeft geveegd. We worden beschermd door de magnetosfeer en door de atmosfeer tegen de energie die de zon continue uitstoot of tegen de plotse energiepieken (zonnestorm).

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 hoogtechnoligische 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.

# Studie van de zonneatmosfeer



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

De zon is ons lievelingsstudieobject.
In het bijzonder de zonneatmosfeer.




We gaan even zelf ‘onderzoeker’ spelen.

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

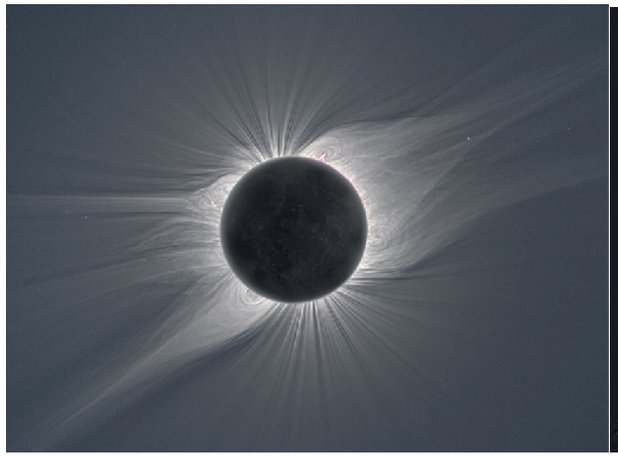
Why is the atmosphere of the Earth, relatively speaking so much smaller?

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

# De atmosfeer van de zon is ongelooflijk interessant.



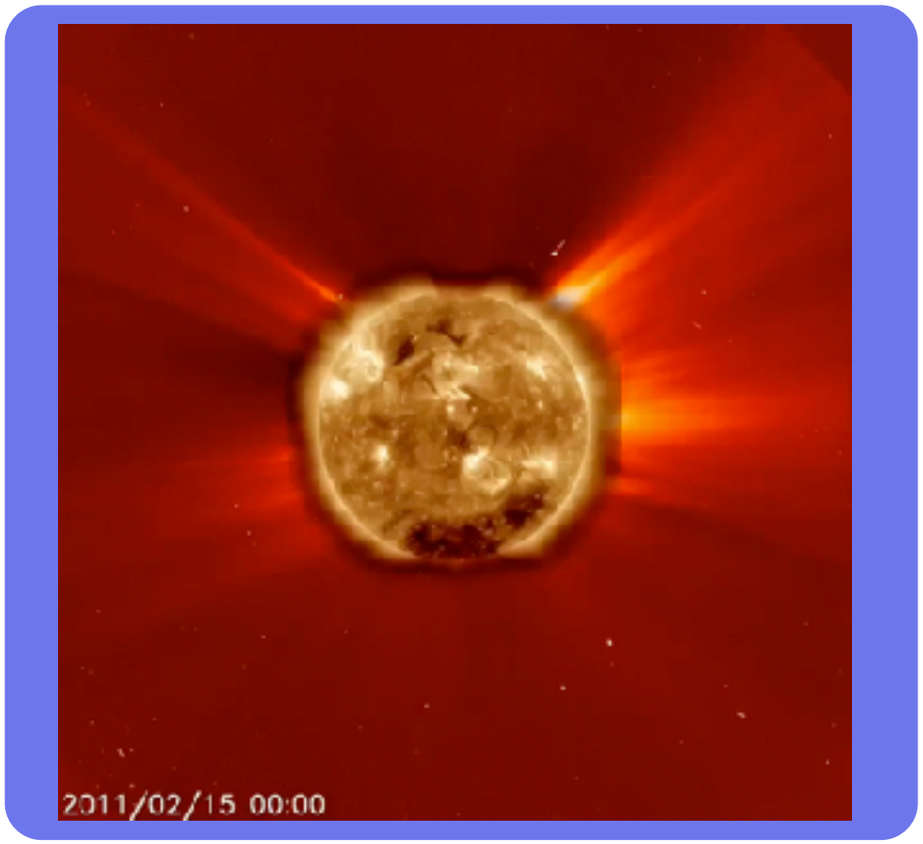




## Daar gebeurt veel.

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.

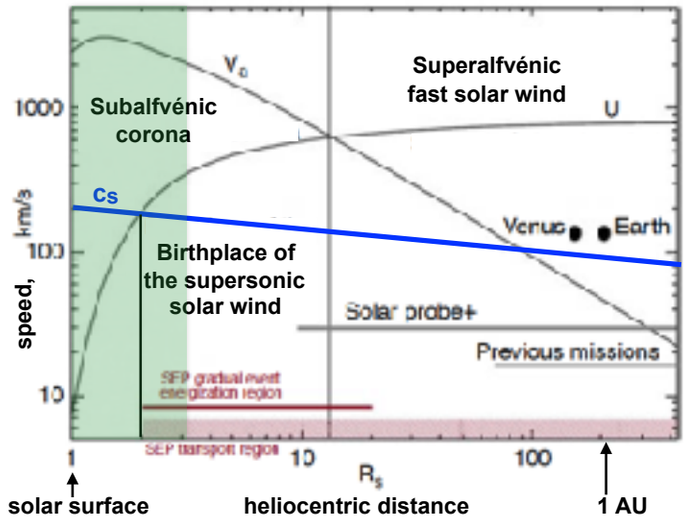
# HALO CME




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.

## INNER SOLAR CORONA

That's the place where it all happens: the solar wind is generated, CME's are accelerated …

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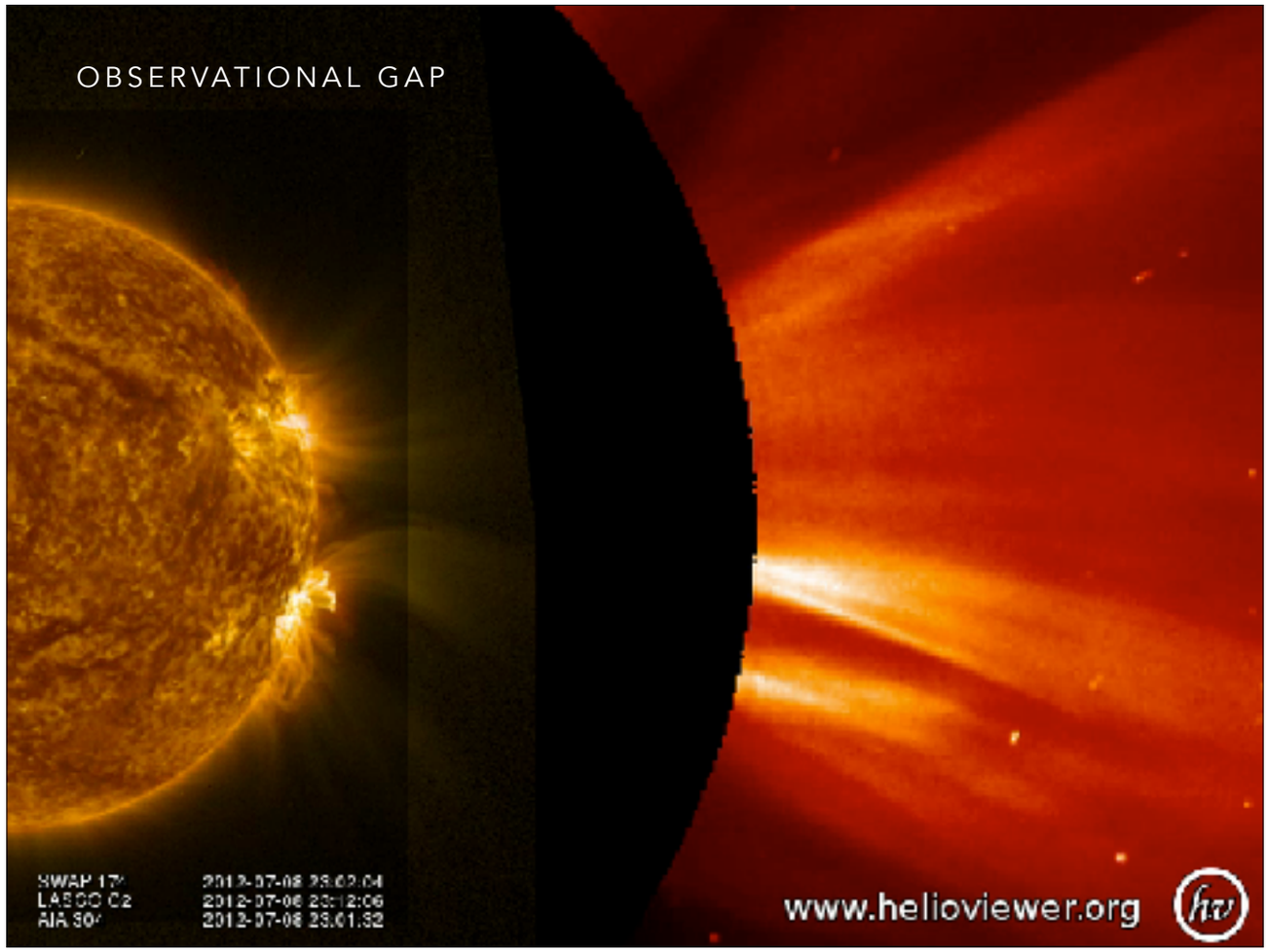
De zonnewind, een continue maar variabele stroom van zonneplasma, is een fysieke brug tussen de zon en de aarde en kan de aardatmosfeer grondig verstoren. De zonnewind ontstaat en versnelt tot super-sonische en super-alfvén snelheden in de lage corona. De alfvén snelheid is een typische golfsnelheid in een magnetisch medium (Magneto-Hydrodynamica). Dit is de reden waarom wetenschappers erop uit zijn om deze lage corona te observeren,



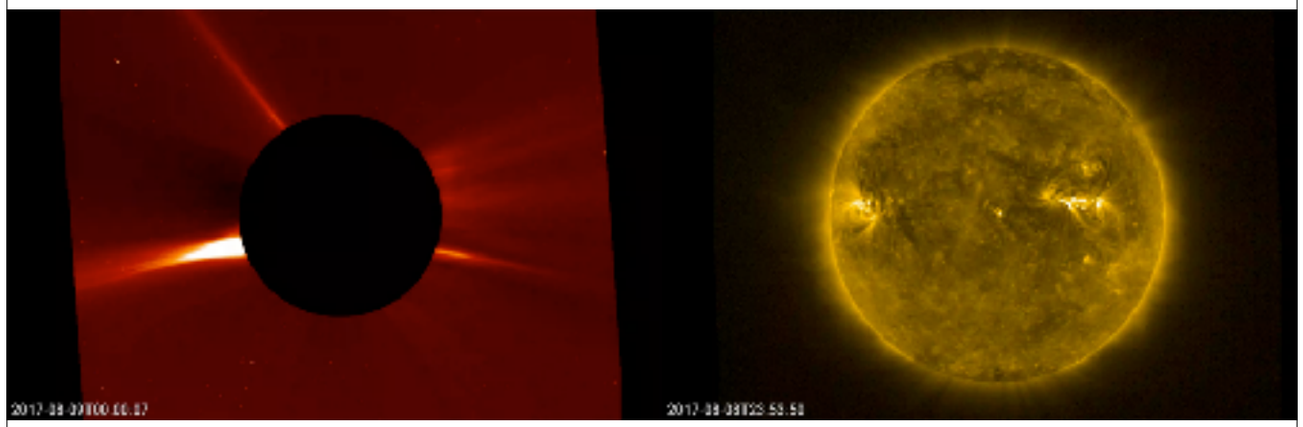

Net daar waar het leuk begint te worden:

- Ground-based radio observations of type II bursts show that shocks often form in the inner corona, namelijk in het gat!
- Waar versnelt de zonnewind: in het gat !
- CME initiatie mechanisme is nog steeds niet goed begrepen. Verschillende mechanismen werden voorgesteld, maar om te zien wie het bij het rechte eind heeft moeten we het gat kunnen waarnemen.

Hoe gaan we dit gat dichten?

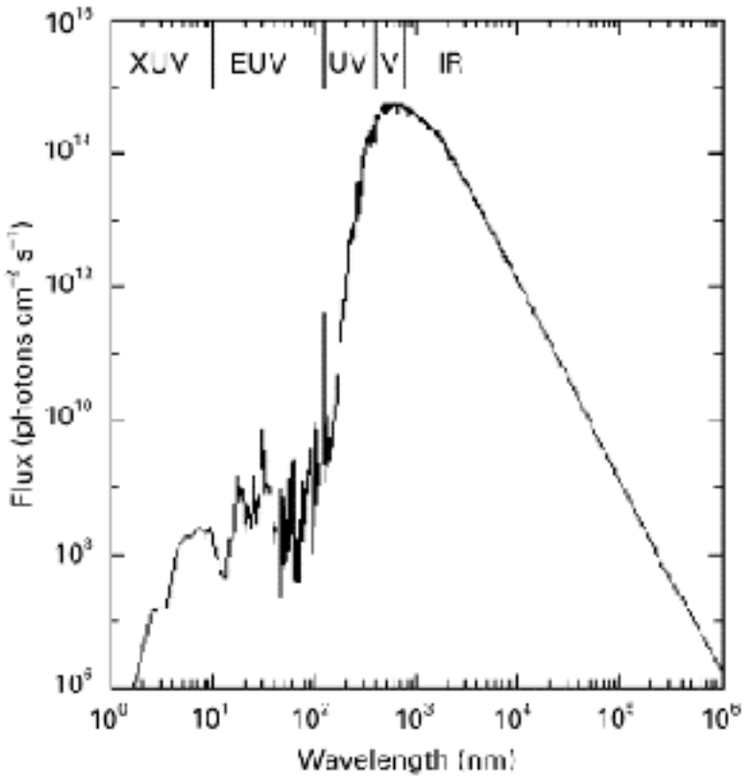
OBSERVATIONAL GAP

To close the gap, we could use coronagraphs and EUV imagers. Both show the corona. But how they work, is completely different.



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

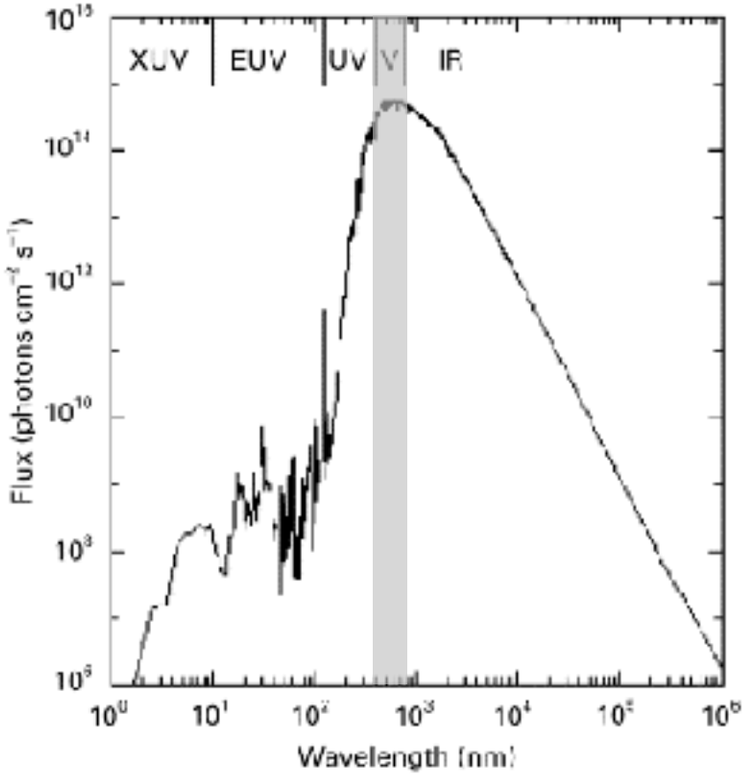
H-alpha 656.28 nm - rood - 9000 °K

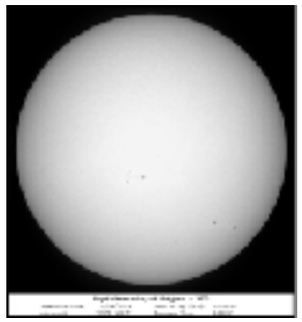
C II K 3933.7Å - 393.37 nm - blauw -

zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGeGrBIV

UV: 380 - 10 nm / 3800 - 100 Angstrom

EUV: 100 - 10 nm / 1000 - 100 Angstrom



5700K

SOLAR2000, Tobiska 2000

H-alpha 656.28 nm - rood - 9000 °K

C II K 3933.7Å - 393.37 nm - blauw -

**zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGeGrBIV**

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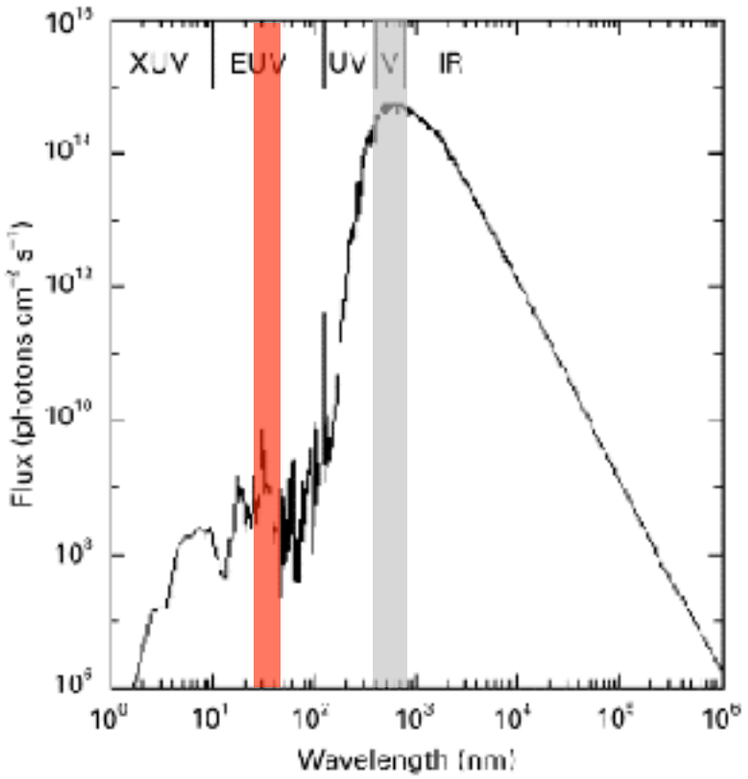
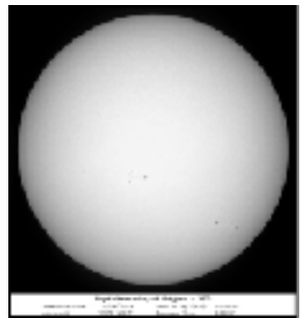
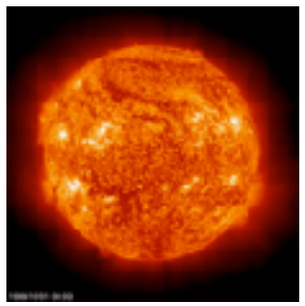


5700K



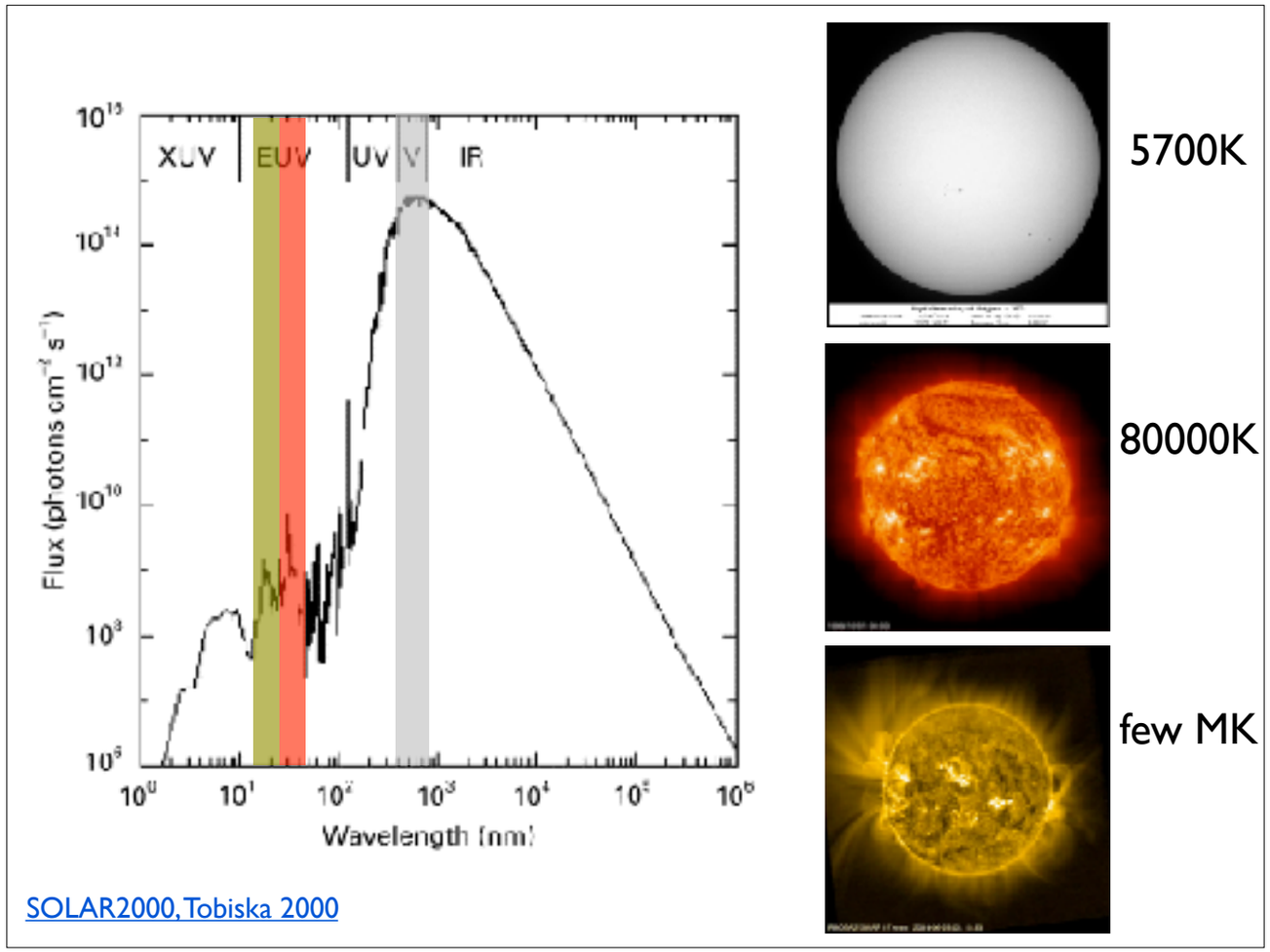
80000K

SOLAR2000, Tobiska 2000

H-alpha 656.28 nm - rood - 9000 °K
C II K 3933.7Å - 393.37 nm - blauw -
zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGeGrBIV
**UV: 380 - 10 nm / 3800 - 100 Angstrom**
EUV: 100 - 10 nm / 1000 - 100 Angstrom

AIA304 angstrom, 30,4 nm This channel is especially good at **showing areas where cooler dense plumes of plasma (filaments and prominences) are located above the visible surface of the Sun**. Many of these features either can't be seen or appear as dark lines in the other channels. The bright areas show places where the plasma has a high density.

Where: Upper chromosphere and lower transition region
Wavelength: 304 angstroms (0.0000000304 m) = Extreme Ultraviolet
Primary ions seen: singly ionized helium (He II)
Characteristic temperature: 50,000 K (90,000 F)




SOLAR2000, Tobiska 2000

H-alpha 656.28 nm - rood - 9000 °K
C II K 3933.7Å - 393.37 nm - blauw -
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**EUV: 100 - 10 nm / 1000 - 100 Angstrom**

SWAP 174 angstrom, 17,1 nm: This channel is especially good at showing **coronal loops** – the arcs extending off of the Sun where plasma moves along magnetic field lines. The brightest spots seen here are locations where the magnetic field near the surface is exceptionally strong.
Where: Quiet corona and upper transition region
Wavelength: 171 angstroms (0.0000000171 m) = Extreme Ultraviolet
Primary ions seen: 8 times ionized iron (Fe IX)
Characteristic temperature: 1 million K (1.8 million F)

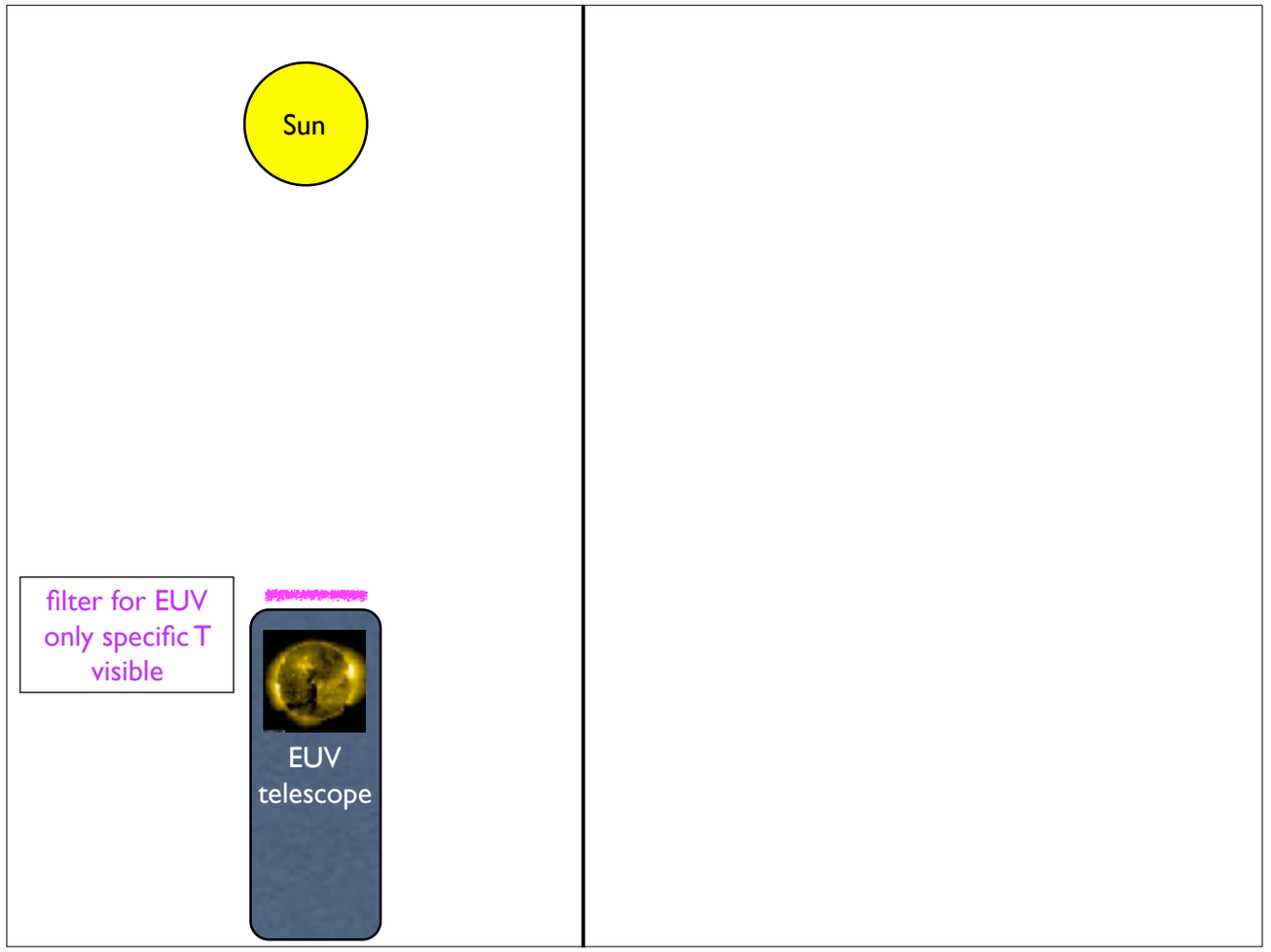
de tijd op de SWAP beelden is het tijdstip waarop de fotonen zijn aangekomen bij PROBA2. Die fotonen hebben 8 min eerder de zon verlaten en dus het beeld dat je ziet is hoe de zon was 8 minuten vroeger dan tijd die op de swap beelden staat.

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.**

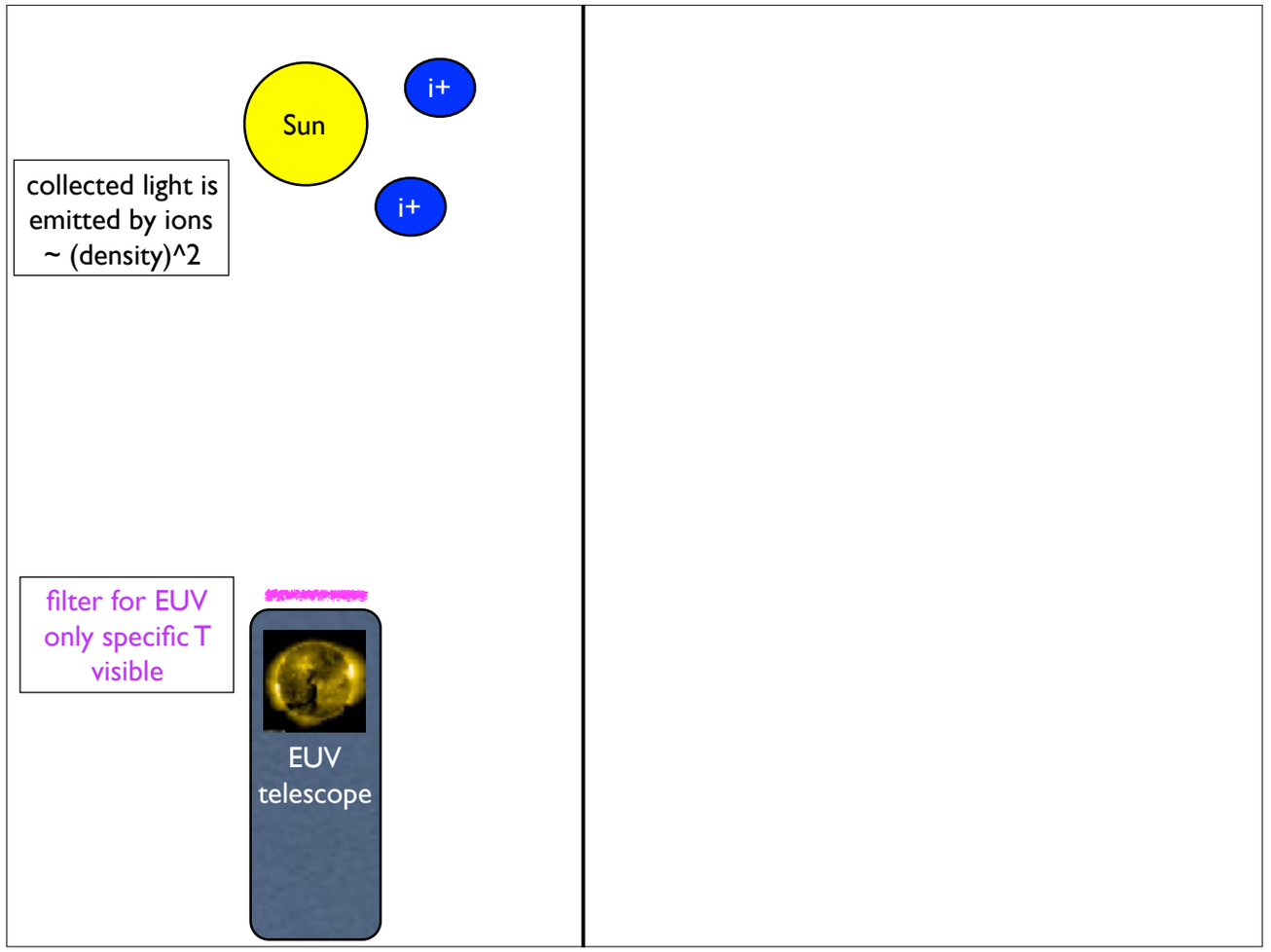
De STEREO telescopen hebben alle een kleine afwijking omdat 1 **STEREO op 1.1 AU** zit en de andere op **0.9 AU**. De tijdstippen op de STEREO beelden kunnen in de orde van een minuut ernaast zitten als je bvb een een flare vergelijkt in de STEREO beelden met dezelfde flare gezien vanaf de Aarde.

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. EUV emissie 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.

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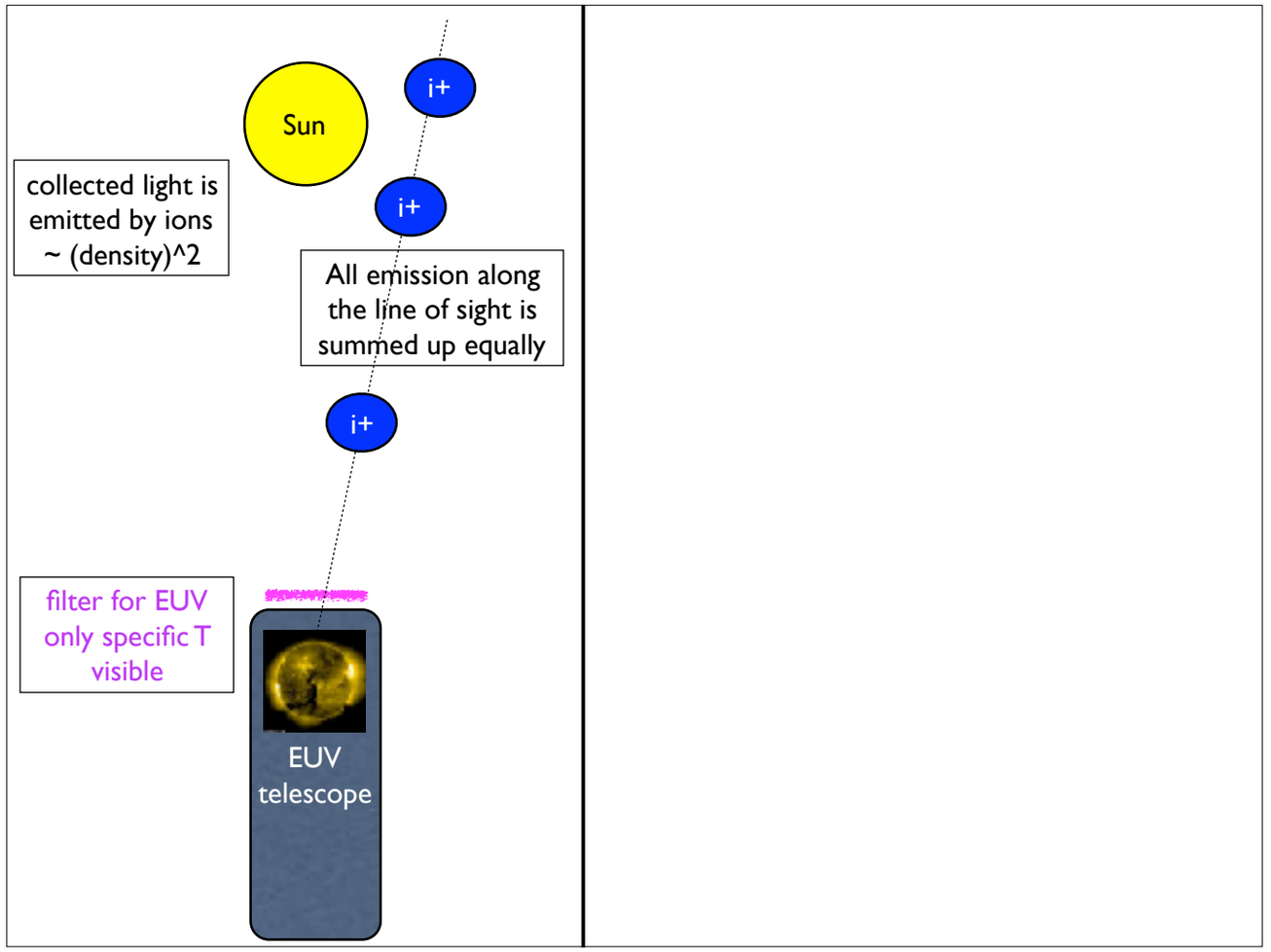


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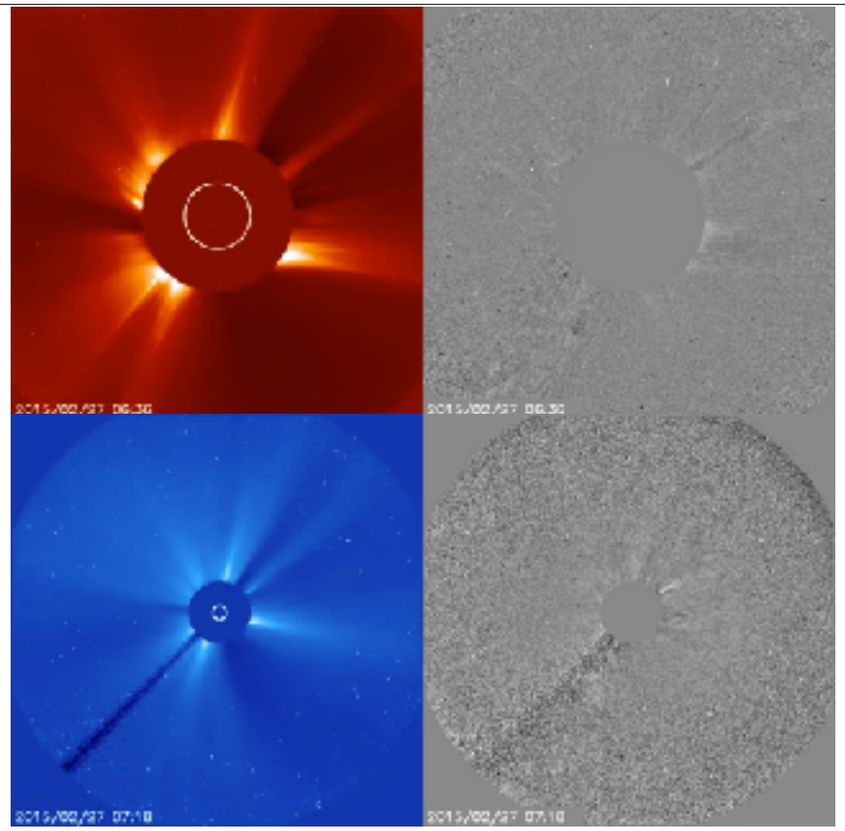
# Coronagraphs



SOHO / LASCO c2&c3 running difference



weerkaatst licht

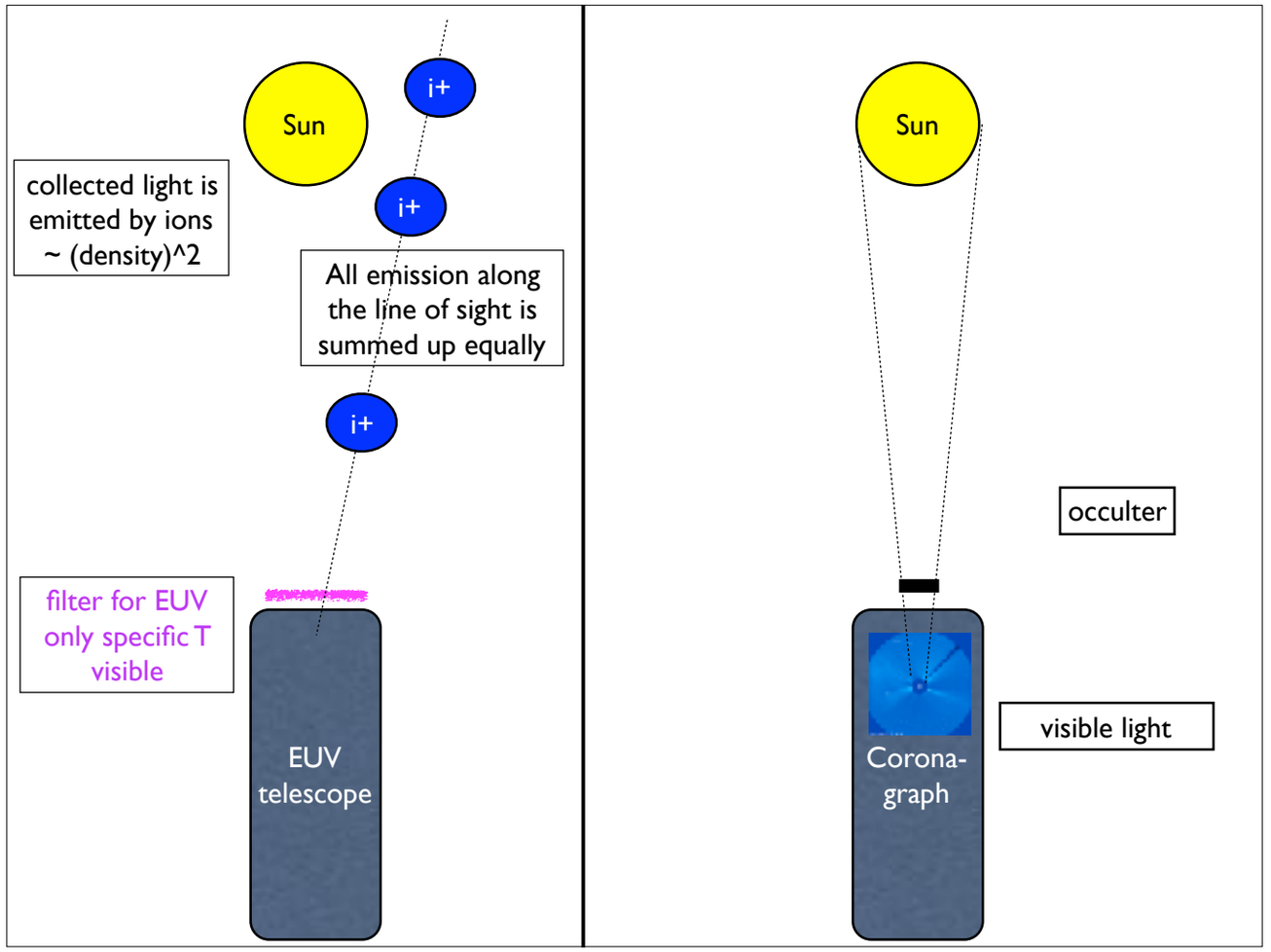
The total solar eclipse August 21, 2017
What happens:
-visible light from the disc bounces off from  plasma in the corona in our direction (Thompson scattering)
-the solar disc is a million times brighter than the corona, the light we see during eclipse is always there but swamped in the much brighter direct light

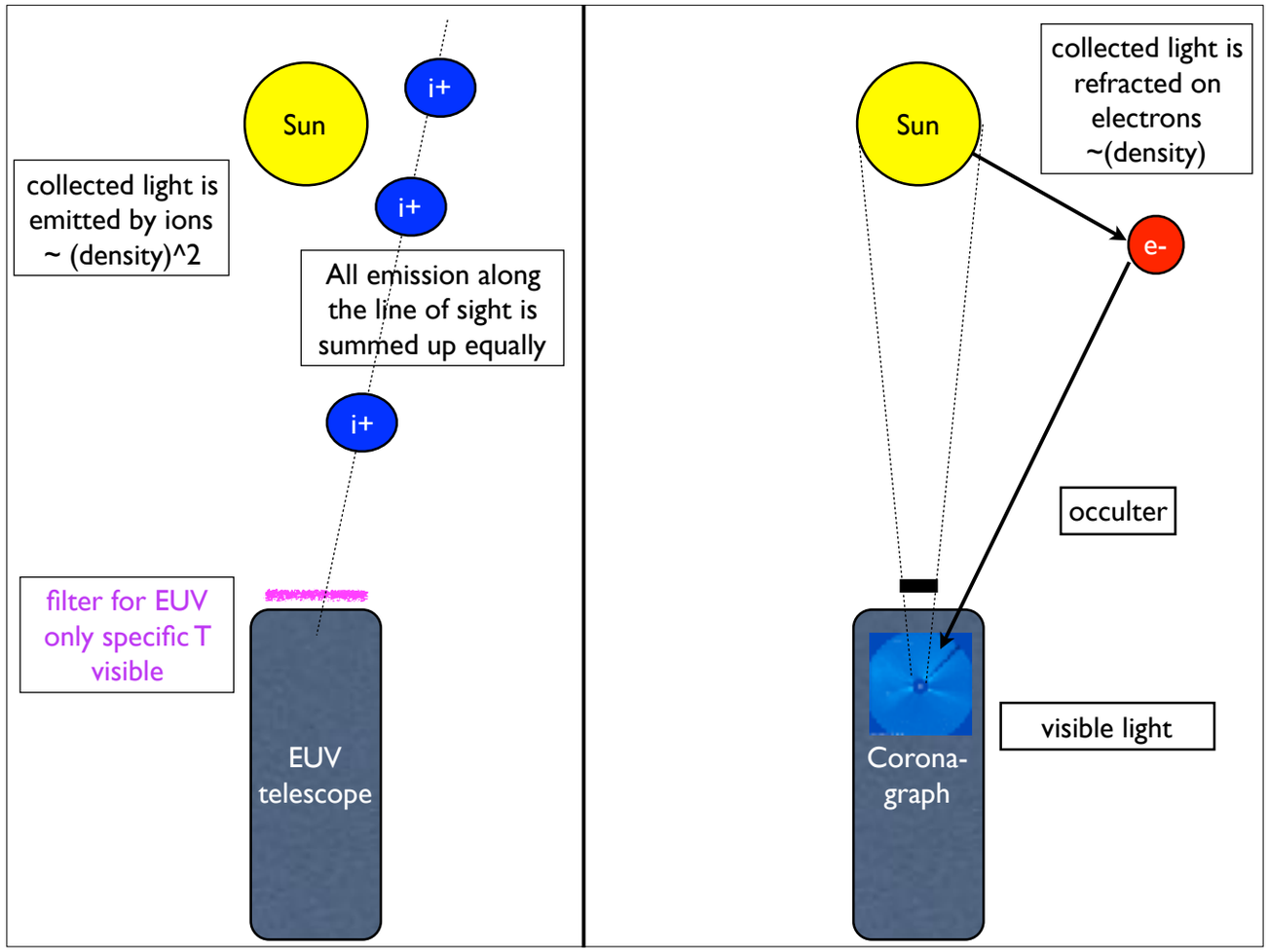
Seeing the corona ‘naturally’ is exceptional on astronomical scales:
- the apparent size of moon and star have to  match the distance planet-star
- the moon should have no atmosphere
- the planets atmosphere should be transparant

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

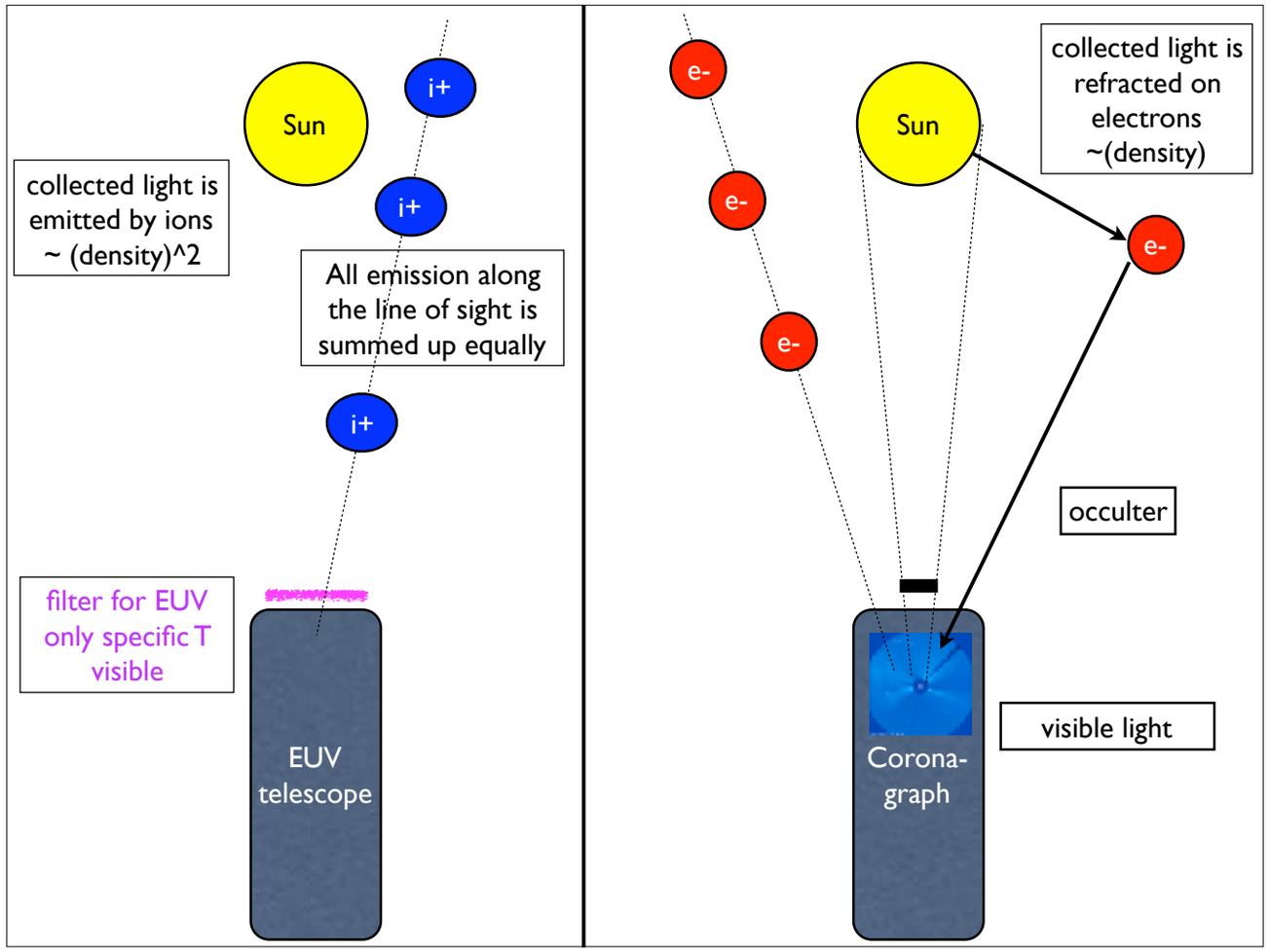
Why is the atmosphere of the Earth, relatively speaking so much smaller?

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


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
Sun
occulter
Corona-graph
visible light




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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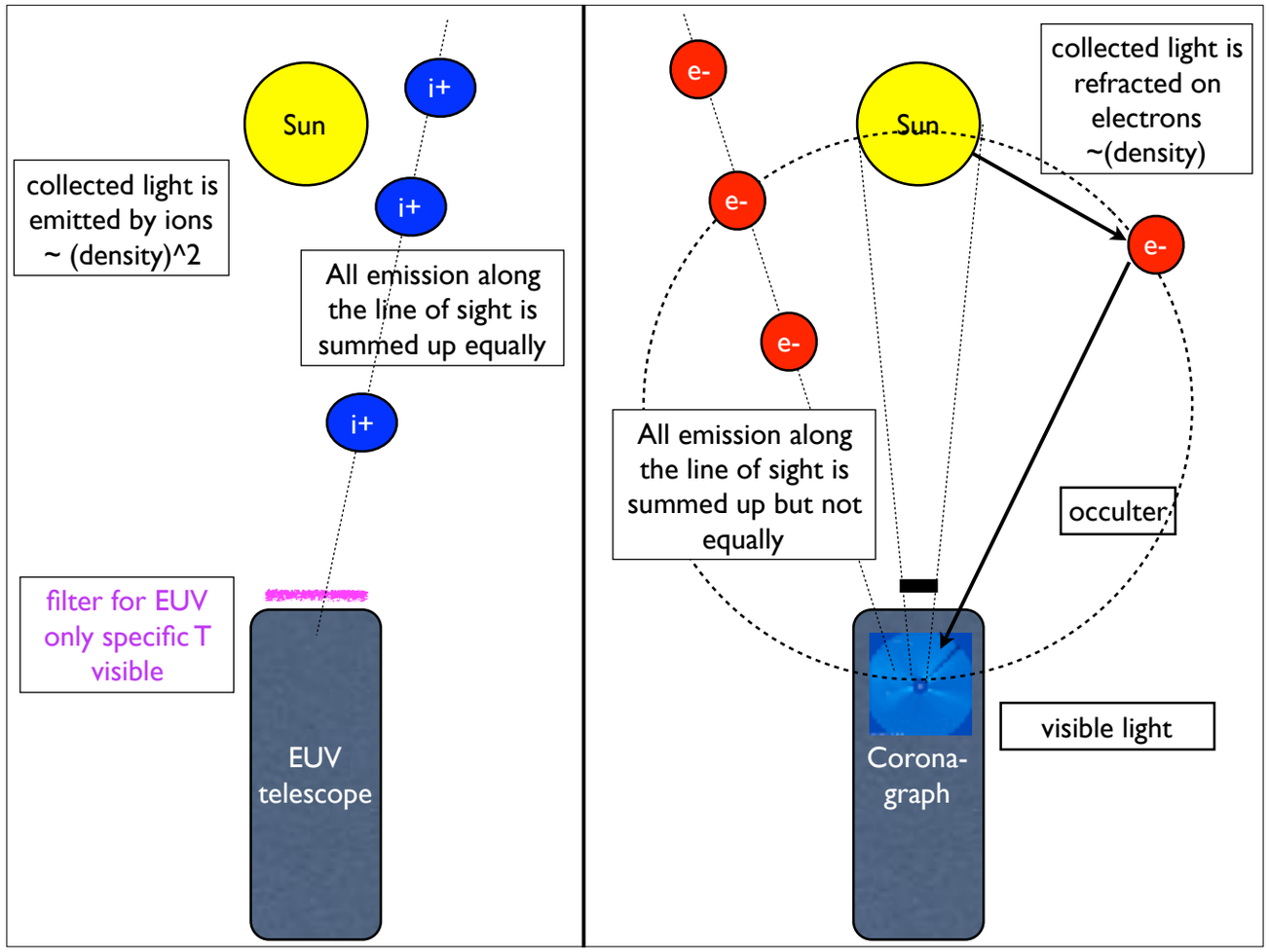
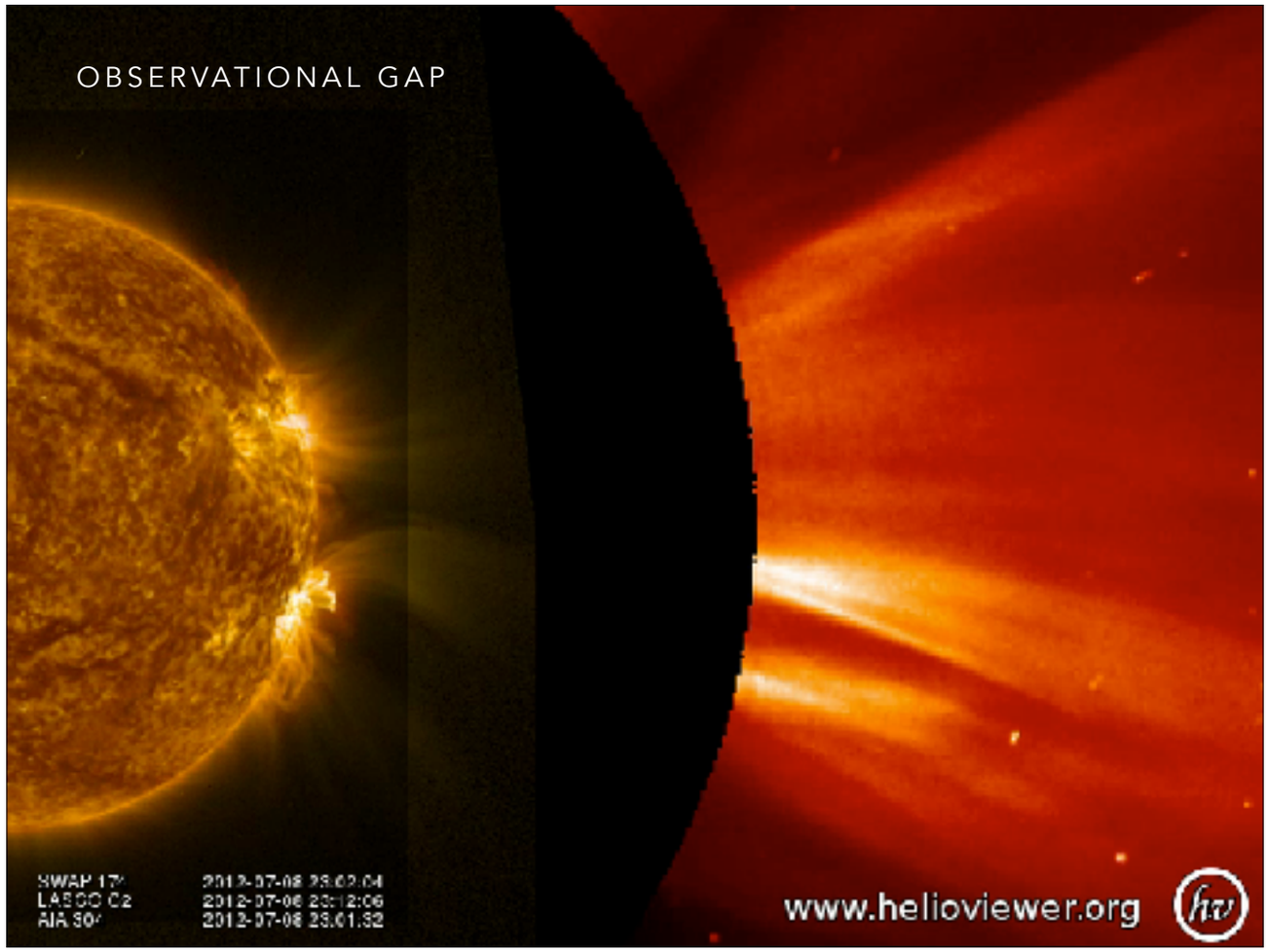



de coronagrafisch beelden tonen dus niet de hele corona maar slechts het plasma dat zich op een bol bevindt met de afstand telescoop-zon als diameter.

Daarom ook dat je een halo ziet als de wolk naar ons toekomt.



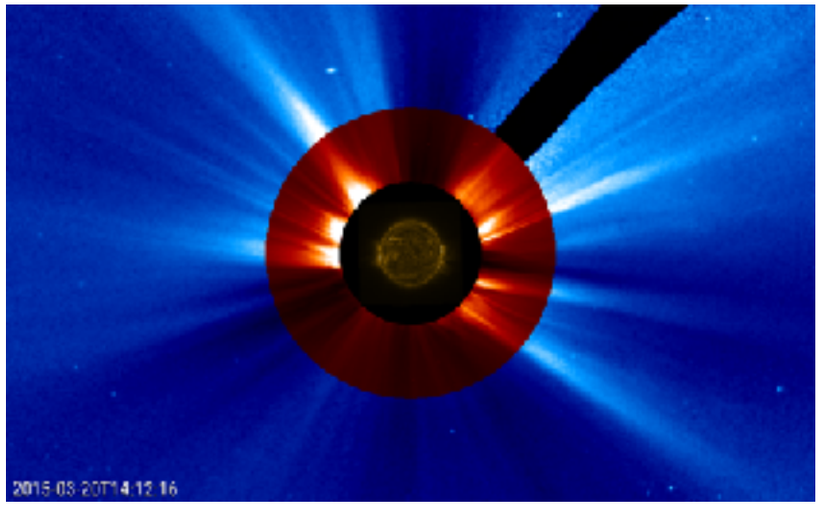

Net daar waar het leuk begint te worden:

- Ground-based radio observations of type II bursts show that shocks often form in the inner corona, namelijk in het gat!
- Waar versnelt de zonnewind: in het gat !
- CME initiatie mechanisme is nog steeds niet goed begrepen. Verschillende mechanismen werden voorgesteld, maar om te zien wie het bij het rechte eind heeft moeten we het gat kunnen waarnemen.

Hoe gaan we dit gat dichten?

OBSERVATIONAL GAP

We eclipse the bright sun and watch the corona in visible light.




It is impossible with the existing techniques to lower the inner boundary of the red part of the image.

**Technische beperkingen bij bestaande coronagrafen** –
**op aarde** last van verstrooid licht,
**in de ruimte bij een externally occulted coronagraaf** heb je geen last van verstrooid licht, maar heb je weer last van diffractie en technisch is het niet mogelijk om het plaatje ver weg te houden.
**In de ruimte bij een internally occulted coronagraaf** moet je al het licht in de telescoop binnen laten en kan het daar dan weer gaan botsen: je hebt last van intern verstrooid licht.

Je kan zeggen, maak dat plaatje dan toch kleiner. Maar je moet de hele satelliet zeer goed richten om de zon achter het plaatje te houden.

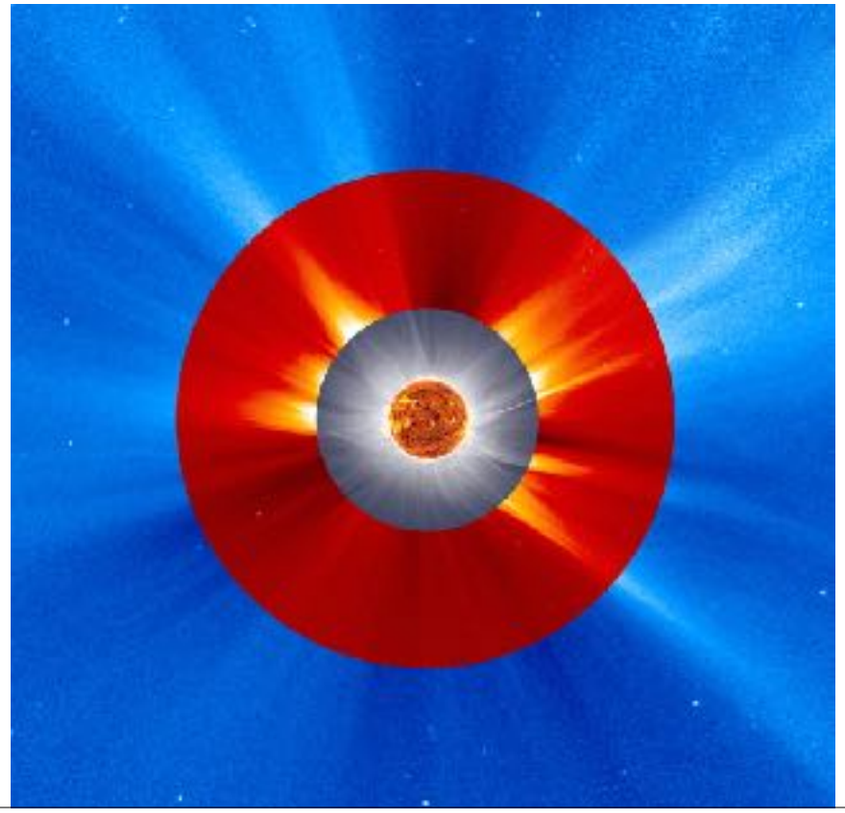
OBSERVATIONAL GAP

# We watch natural solar eclipses.



OBSERVATIONAL GAP

# We bring together both observations and close the gap.



Een zonneeclips past mooi in het gat

OBSERVATIONAL GAP

## Very nice but …



Maar telkens wachten op een totale eclipse, naar daar reizen en dan nog geluk hebben met het weer, is ook niet echt een optie

OBSERVATIONAL GAP




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.

Coronagraph spacecraft 340 kg; Occulter spacecraft 200 kg

CSC: 1.1 by 1.8 by 1.7 metres (3.6 ft × 5.9 ft × 5.6 ft)
OSC: 0.9 by 1.4 metres (3.0 ft × 4.6 ft)

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

External coronagraph

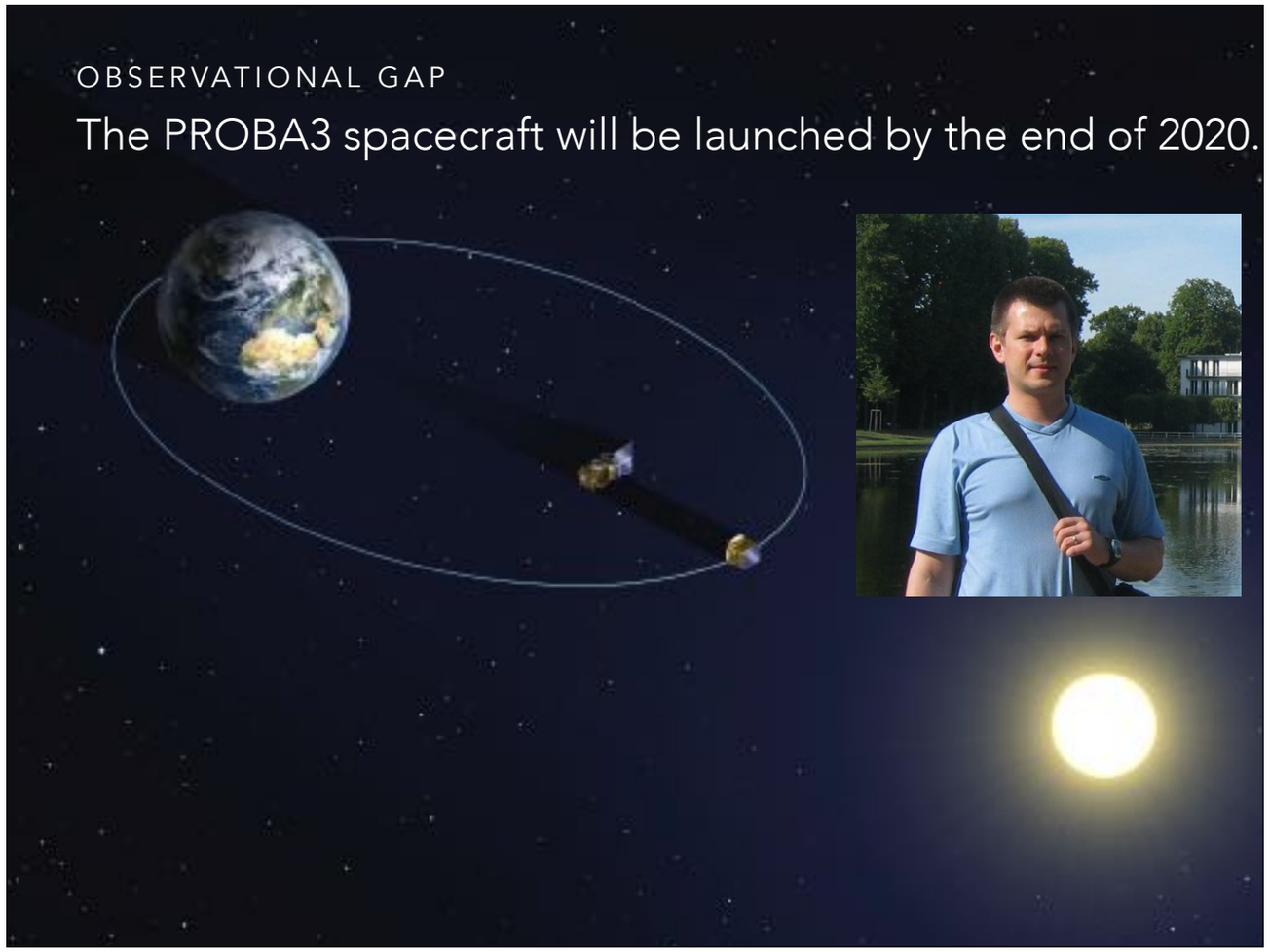
Proba-3 is ESA’s – and the world’s – first precision formation flying mission. A pair of satellites will fly together maintaining a fixed configuration as a ‘large rigid structure’ in space to prove formation flying technologies.
The mission will demonstrate formation flying in the context of a large-scale 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.

tandem
vliegen tot op de mm samen, arc second precision
De twee vormen samen een virtuele gigantisch grote satelliet - samenvliegen gebeurt autonoom, zonder interventie door mensen op aarde.

collision avoidance manoeuvre: mogen niet tegen elkaar vliegen of van elkaar wegvliegen.
normal operations: formatie-vliegen en coronagrafische waarnemingen

Accuracy of 1 mm
The sun is a million times brighter than the corona. So to study the corona you have to eclipse it.

https://www.youtube.com/watch?v=zWRIkek4q3o




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.

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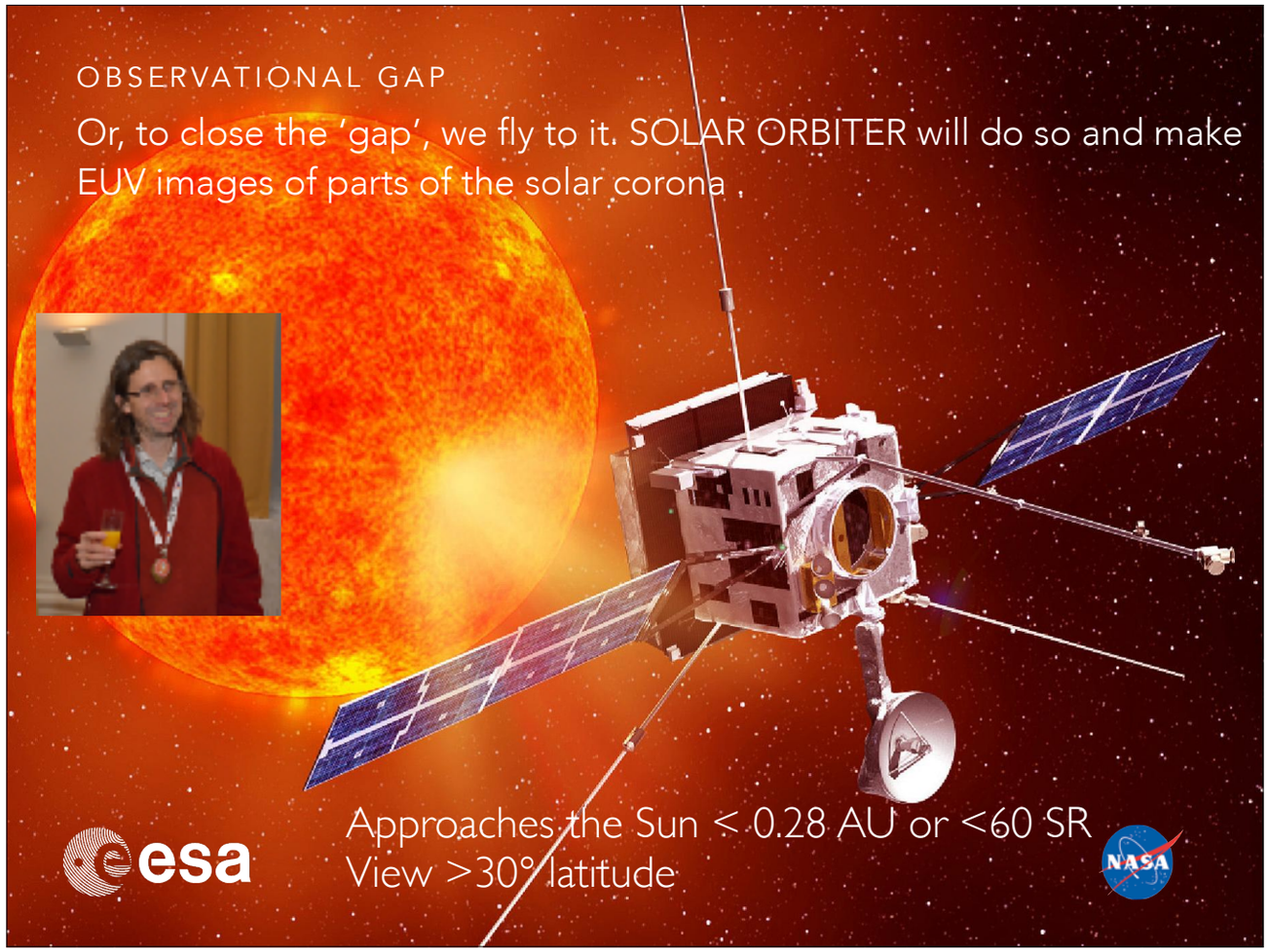



Post-launch PI, detector characterisation and calibration, on-board data processing algorithms, operations

We bestuderen het gat van dichtbij.

0.28 AU: dit is binnen de baan van Mercurius, planeet dichtst bij de zon
Sun-stationary satellite - blijft boven 1 gebied hangen in het perihelium.

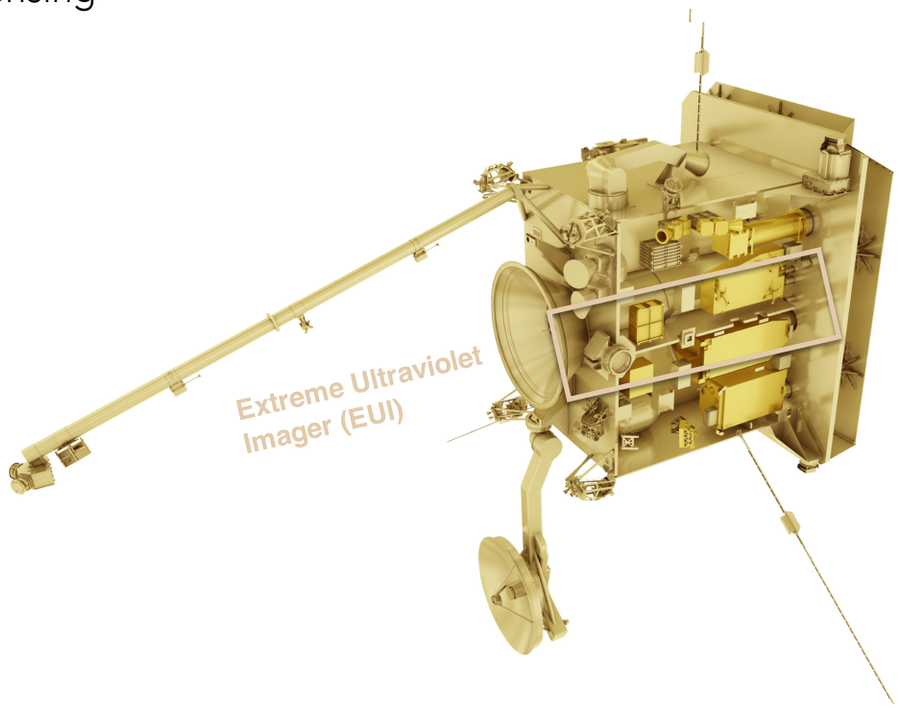
Following launch, Feb 2019, Solar Orbiter will begin its journey to the Sun. This will require a **cruise phase lasting approximately 3 years**. During this time, the instruments will be commissioned, and some in-situ data will be acquired. During the cruise, Solar Orbiter will use gravity assists from Venus and the Earth. These swing-bys will put Solar Orbiter into a **168-day-long orbit** around the Sun from which the spacecraft will begin its scientific mission.

During the course of the mission, additional Venus gravity assist manoeuvres will be used to increase the **inclination** of Solar Orbiter’s orbit, helping the instruments **see the polar regions** of the Sun clearly, for the first time. Solar Orbiter will eventually view the poles from an angle higher than 30 degrees, compared to 7 degrees at best from Earth.

The spacecraft will make a close approach to the Sun every five months. **Around closest approach Solar Orbiter will be positioned for several days over roughly the same region of the solar atmosphere** like geostationary satellites are stationed over particular spots on the Earth's surface, so the spacecraft will seem to 'hover' for a while over the Sun. Solar Orbiter will therefore be able to watch magnetic activity building up in the atmosphere that can lead to powerful solar flare or eruptions.

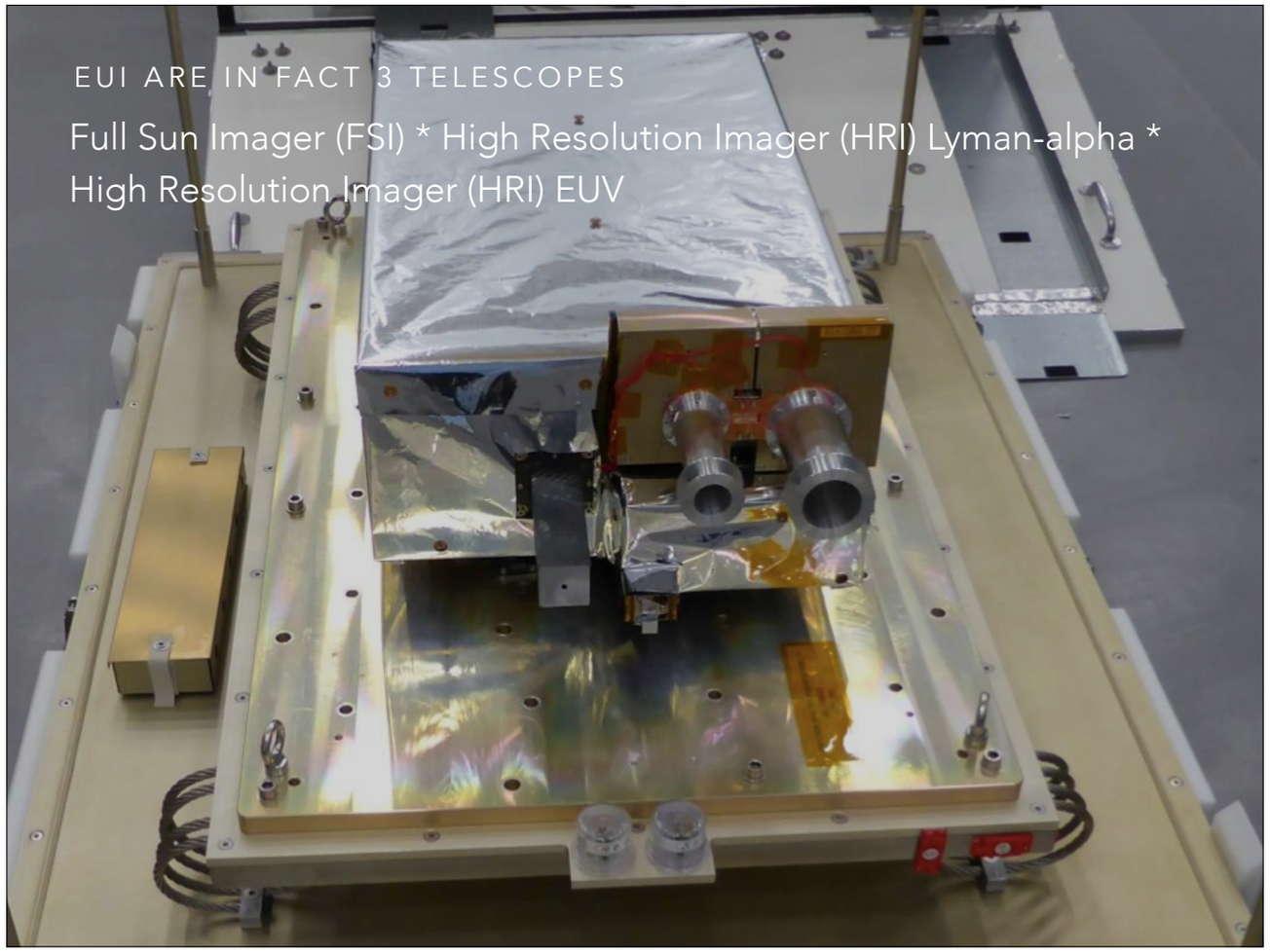


Launch Feb 2019 ; Mission 2019-2028 ; 10 instruments ; in-situ & remote sensing




Three-axis stabilised, Sun pointing
Heat-shield at front - de gaatjes om door te kijken zijn heel klein. Elke foton telt.

Mass: 1750kg
Power: 1100W




Persconferentie op 6 juni 2017 op CSL

Le CSL livrera le modèle de vol de l'instrument EUI dans les prochains jours, en vue de son installation sur le satellite au début de l'été 2017. Le lancement de Solar Orbiter depuis le Cap Canaveral en Floride est prévu en Février 2019, à bord d'une fusée ATLAS.

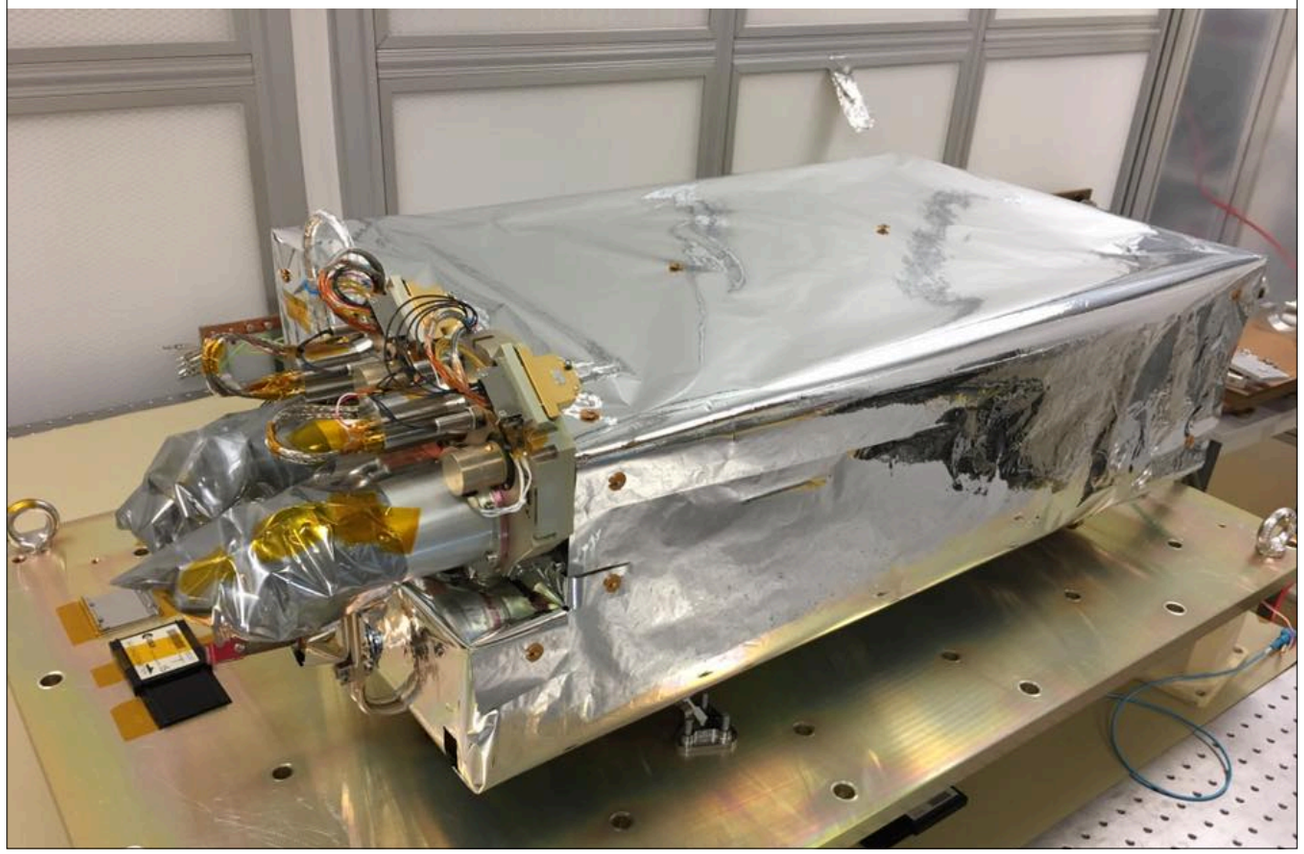
Fine structure of the corona?
Can small scale heating events explain the heating of the corona
Dynamics of Small-scale coronal brightening
Which oscillations will we see if we increase temporal resolution

The EUI instrument suite is composed of two high resolution imagers (HRI), one at Lyman-α and one dual-band in the extreme UV, alternatively at 174 and 335 Å, respectively named "HRILy-α" and "HRIEUV", and one dual-band full-sun imager (FSI) working alternatively at the 174 and 304 Å EUV passbands, named "FSI174/304".

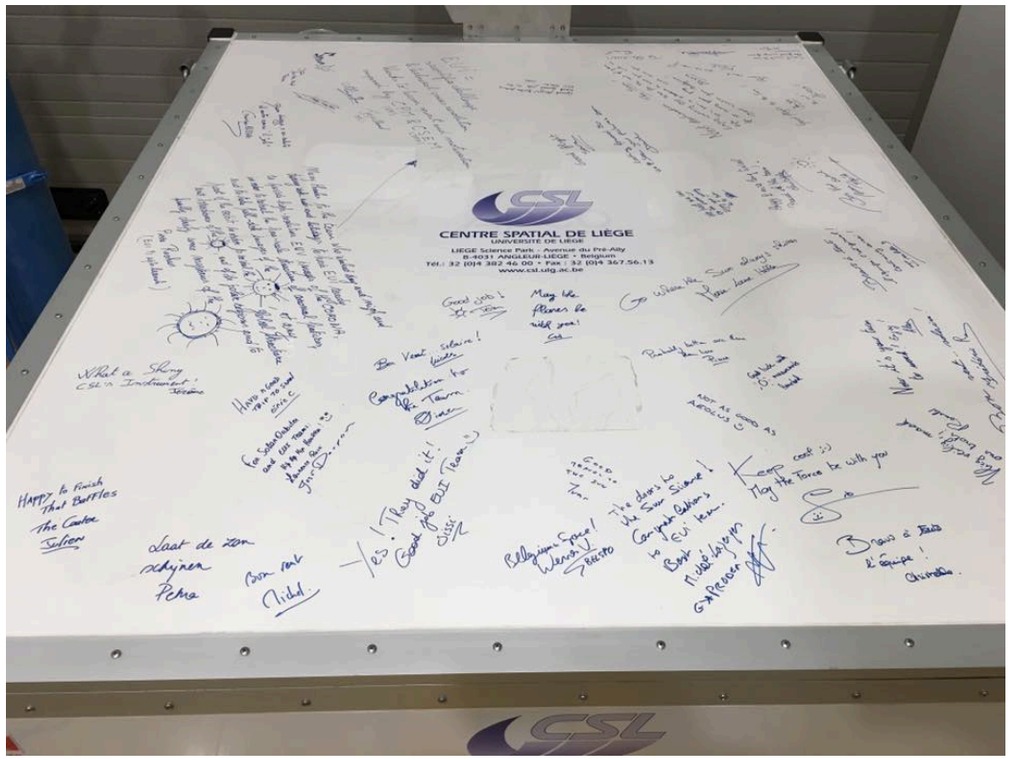
FSI174/304 —- dual band in het (E)UV
HRILy-α —- in het UV
HRIEUV —-  dual band 174 and 335 Å

H Lyman Alpha - 121.6 nm - instrument HRI - dit is het UV
He II - 30.4 nm - transition region
Fe overgang  EUV  - 17 nm - low corona - in het EUV
Fe overgang

Inpakken …

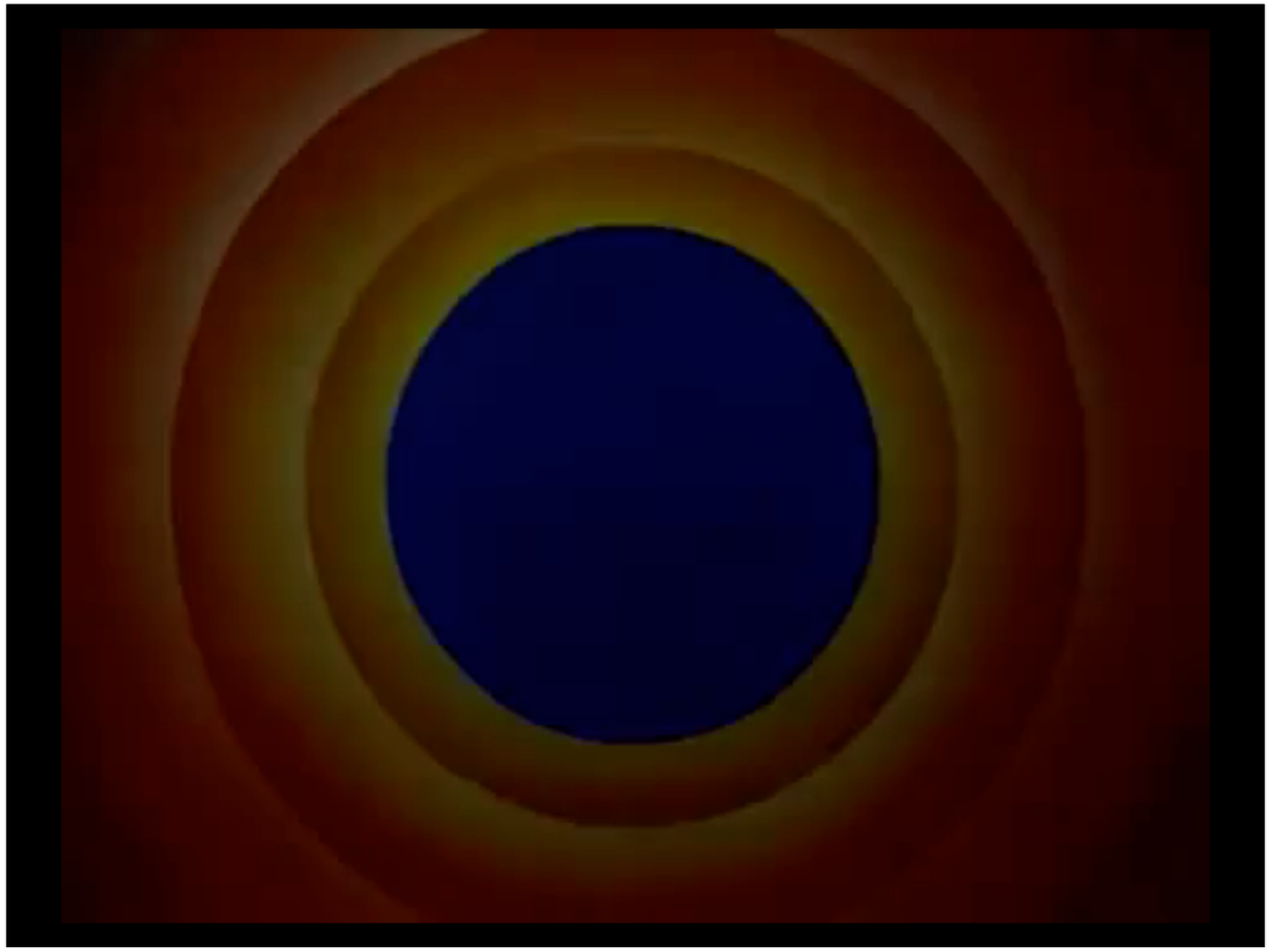


# In een doos steken …



# En een feestje geven!

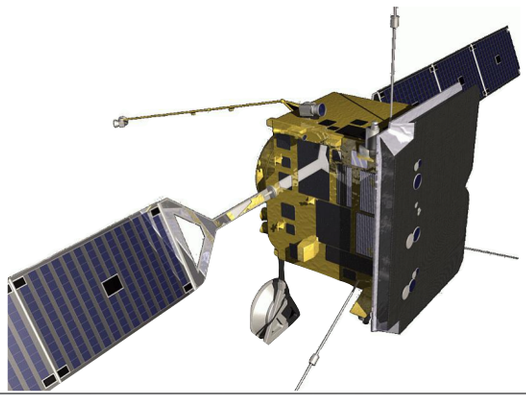




## Solar Orbiter

- ESA project
- some instruments and launch contributed by NASA

- launch Feb 2019
- perihelion 60 solar radii
- in-situ measurements and solar and heliospheric images



## Parker Solar Probe

- NASA project
- European participation in some instruments

- launch July 31 2018
- perihelion 9 solar radii
- in-situ measurements and heliospheric images

