The Sun

- and the Sun-Earth Connection

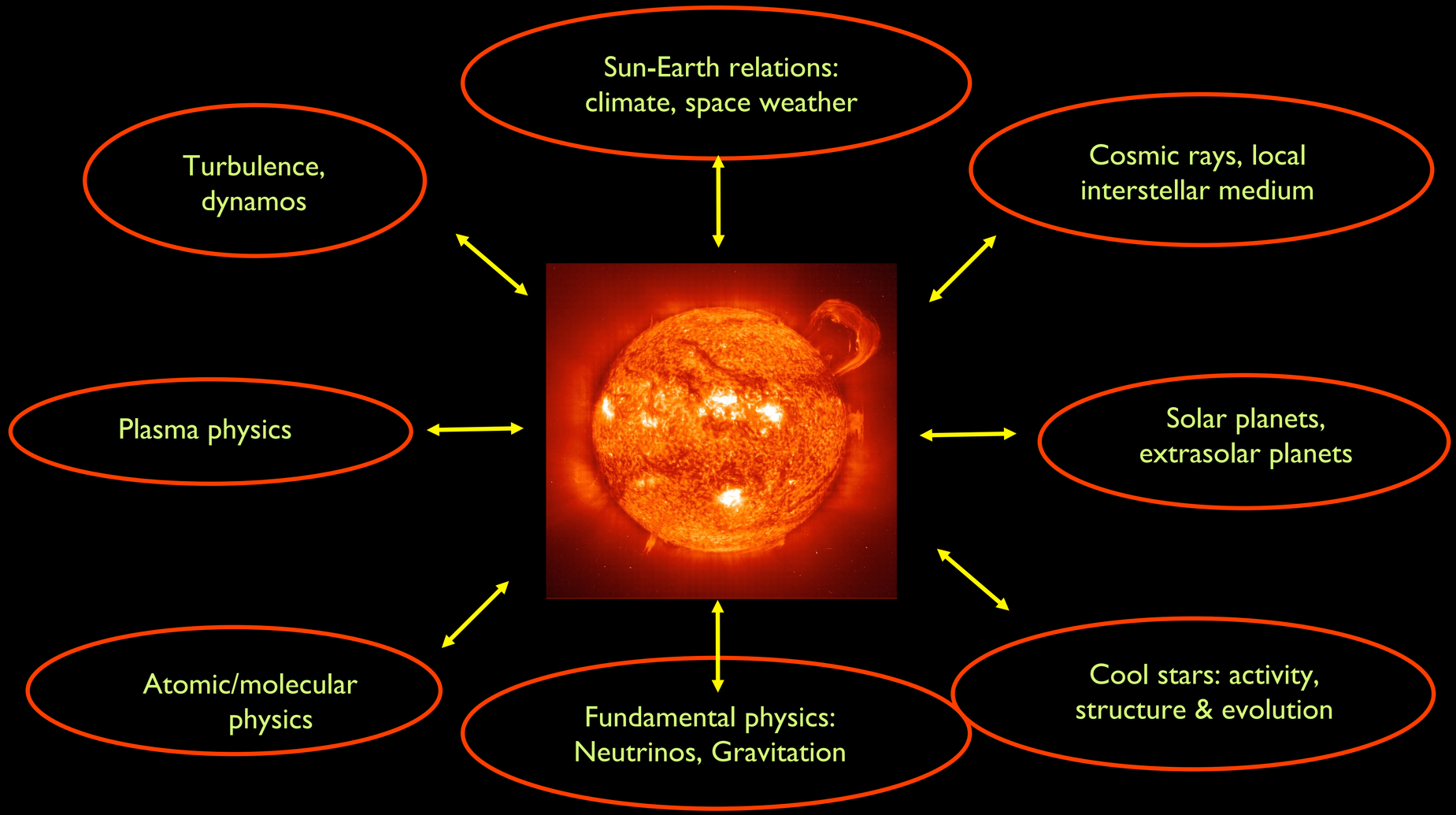
PÅL BREKKE

Norwegian Space Centre

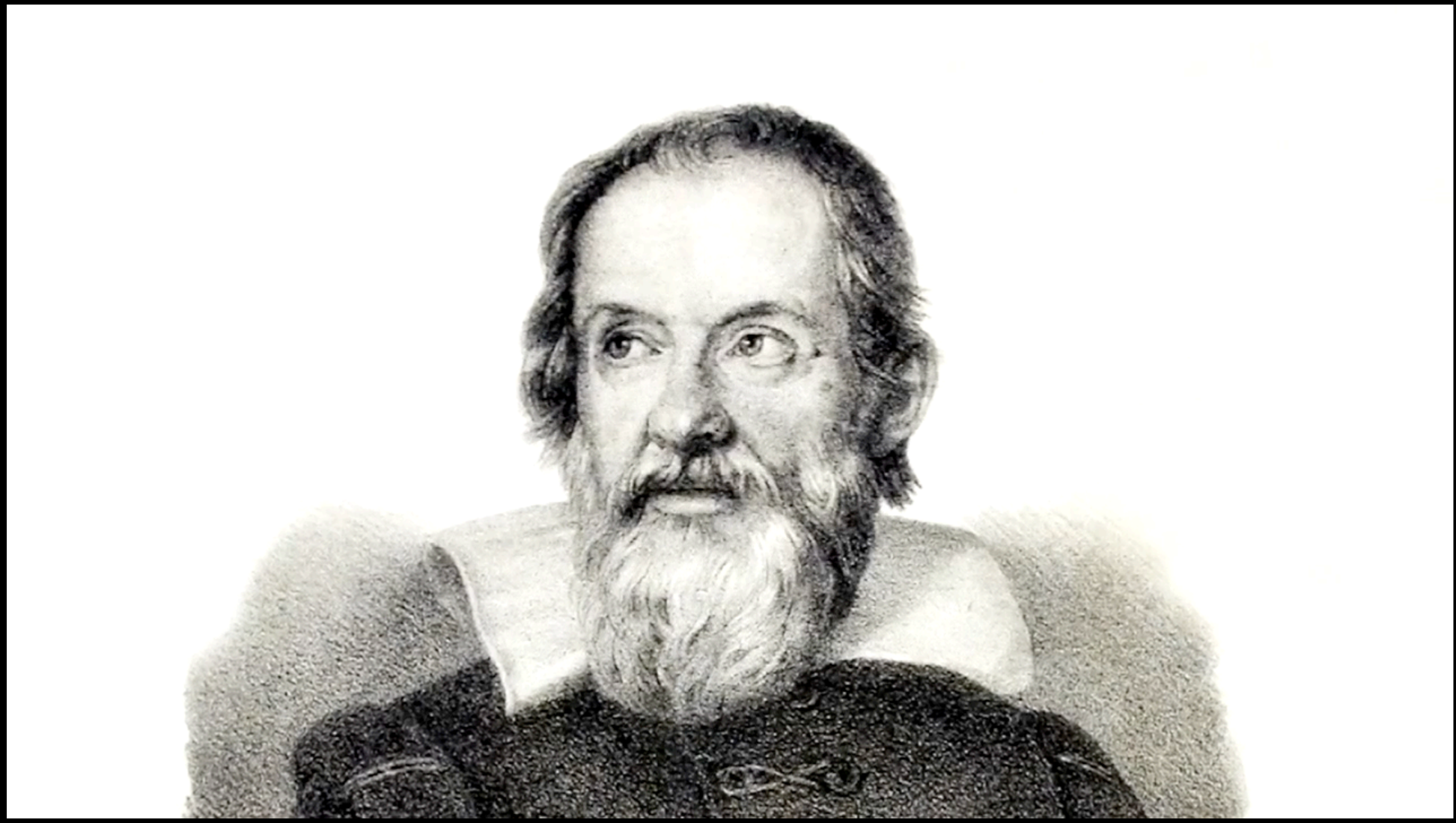
The Sun

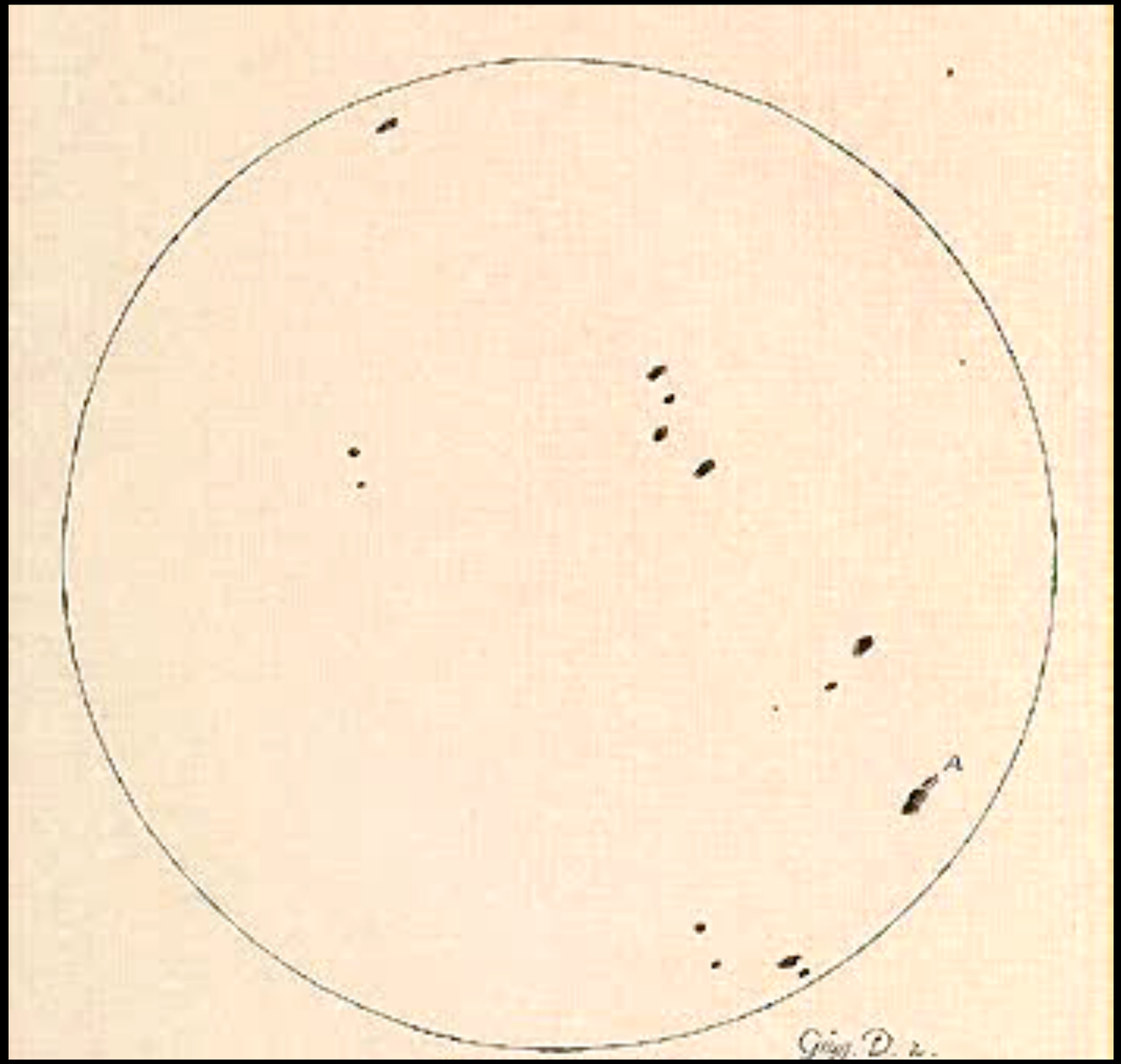
- The Sun is a normal star: middle aged (4.5 Gyr) main sequence star of spectral type G2
- The Sun is a special star: it is the only star on which we can resolve the spatial scales on which fundamental processes take place.
- The Sun is a special star: it provides almost all the energy to the Earth
- The Sun is a special star: it provides us with a unique laboratory in which to learn about various branches of physics.

Solar Physics in Relation to Other Fields



Galileo Galilei (1564-1642)



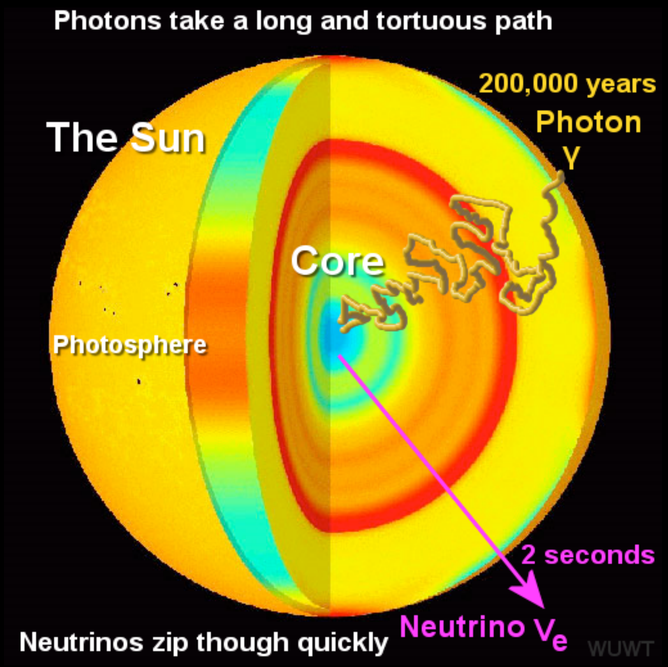


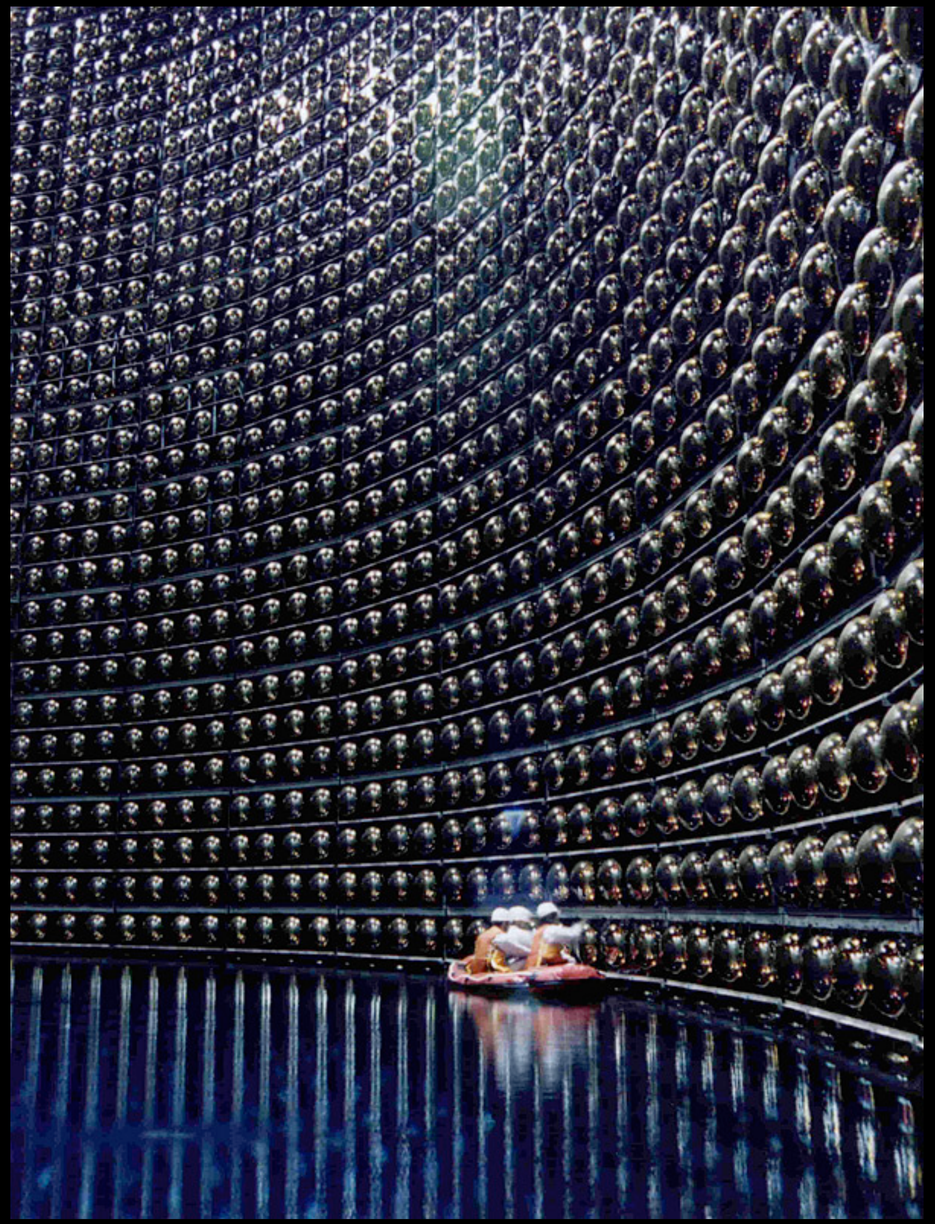
The Sun

The Sun - 150 million km away

Solar Neutrinos

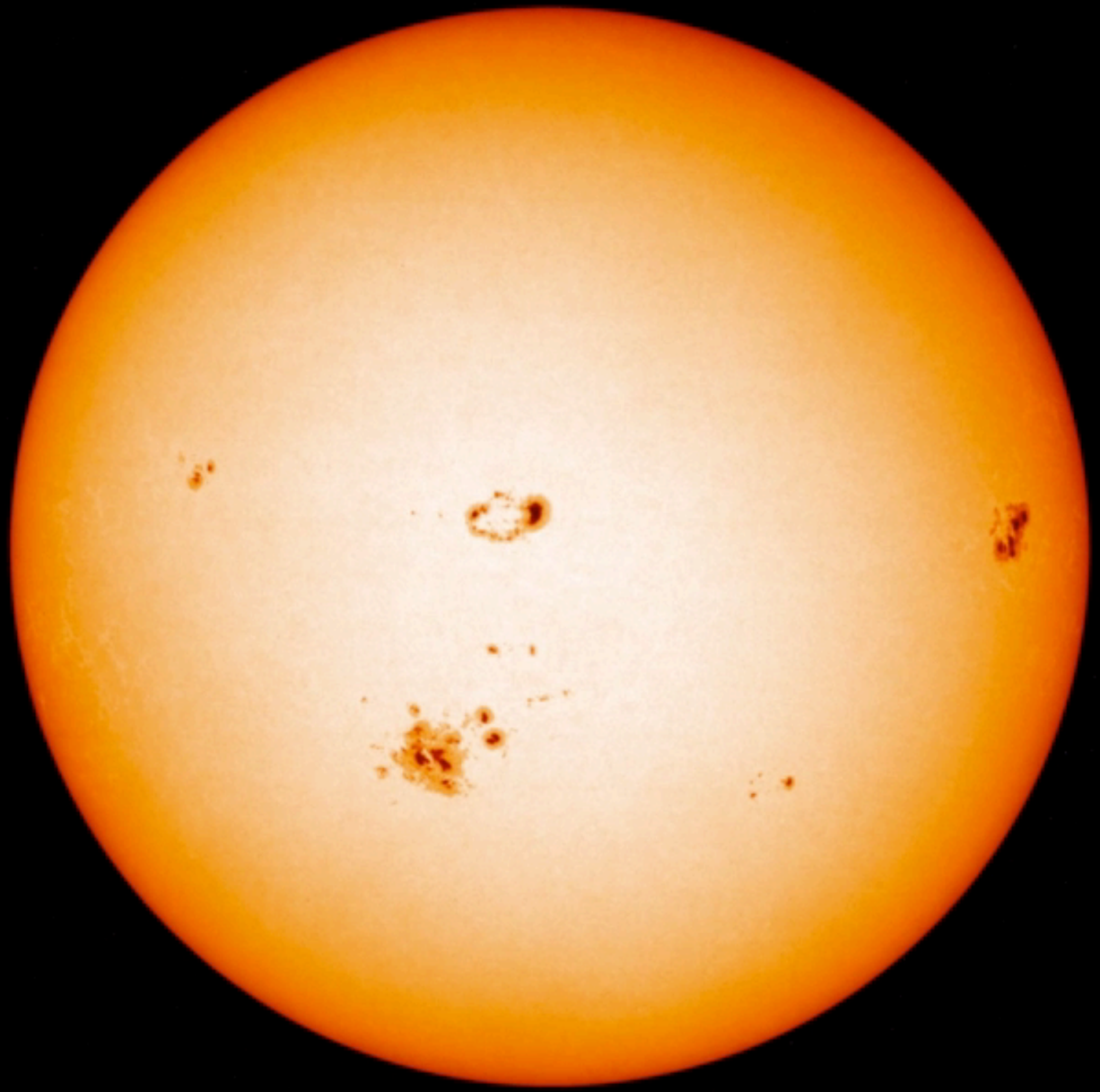
- 30 billion neutrinons passes your fingernail each second
- Neutrino-detectors has measured about 1/3 of the expected number derived from solar models.
- This has been called the «Solar Neutrino problem»
- Was the temperature in the solar core much lover than 15 million C?
- Or does some of the neutrinos change identity?



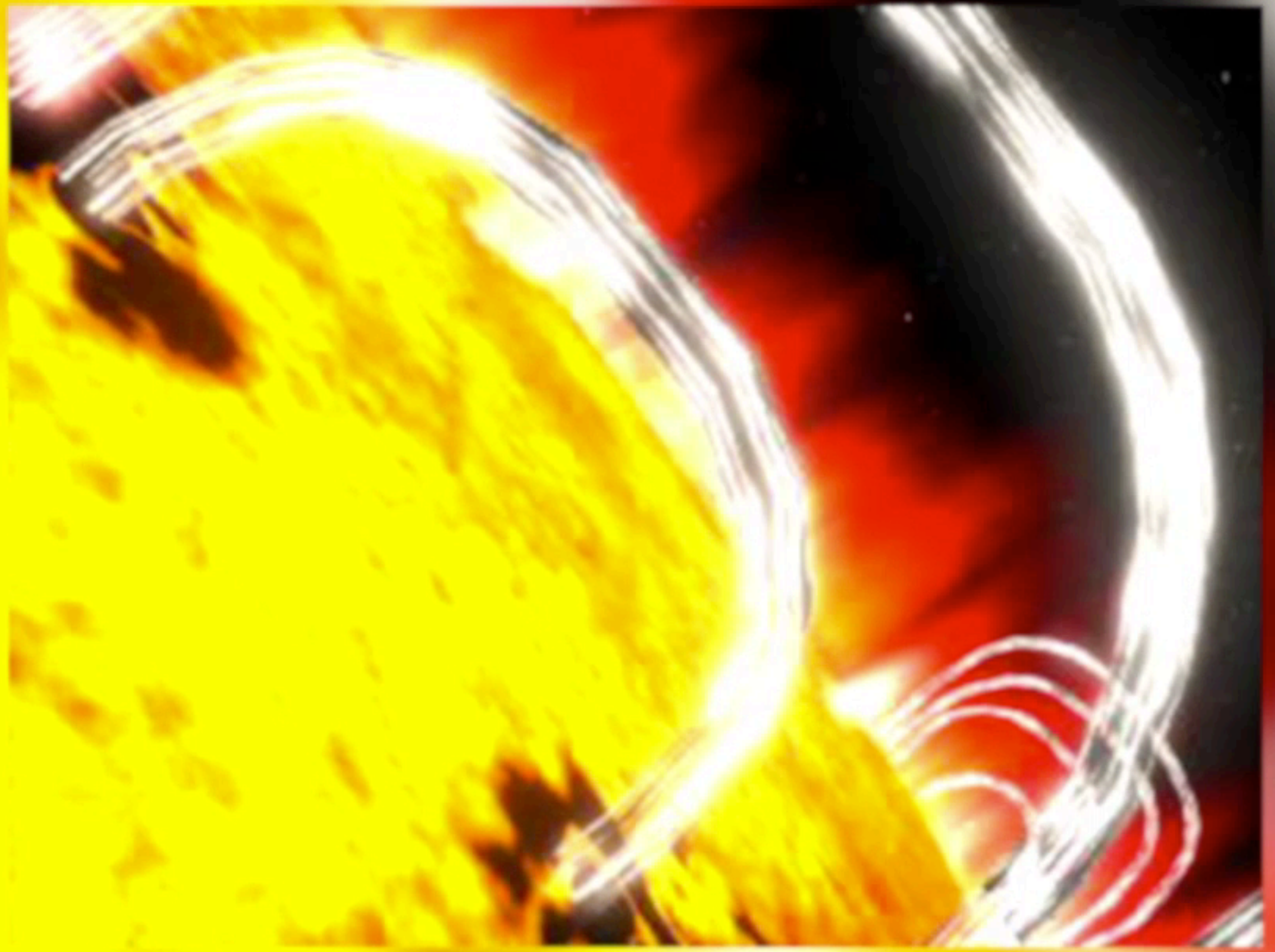


Super- Kamiokande Neutrino Detector in Japan

SUNSPOTS

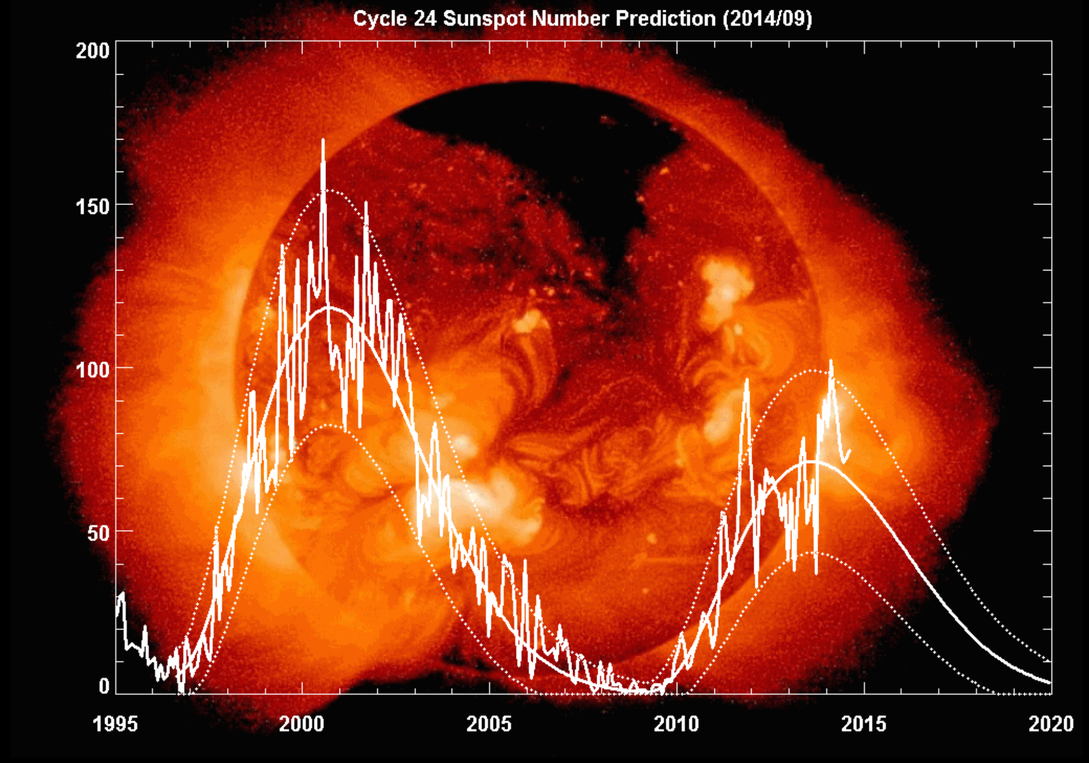


SUNSPOTS

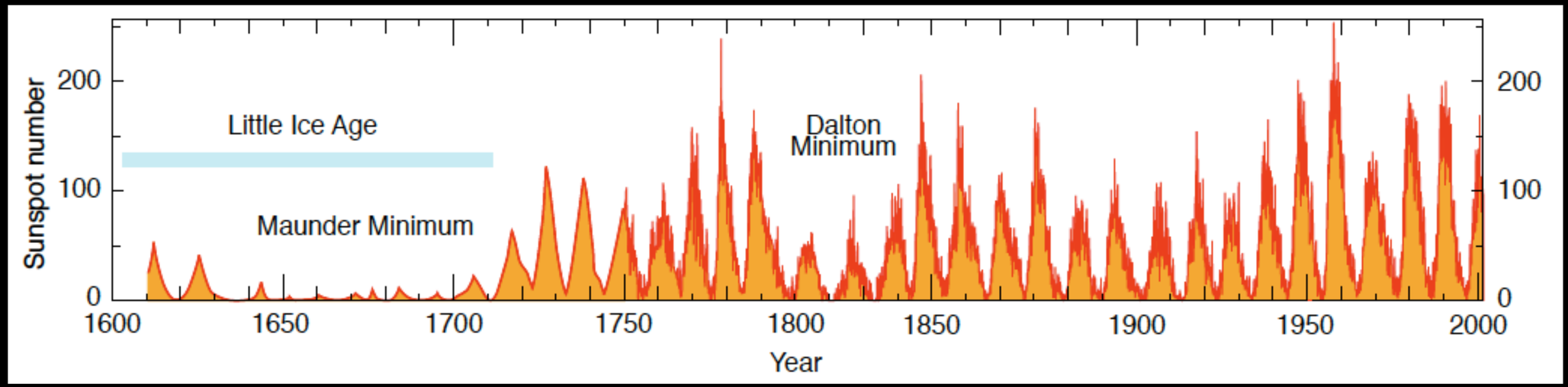


Sunspot and Sunspot Cycles

Historical Sunspot Records

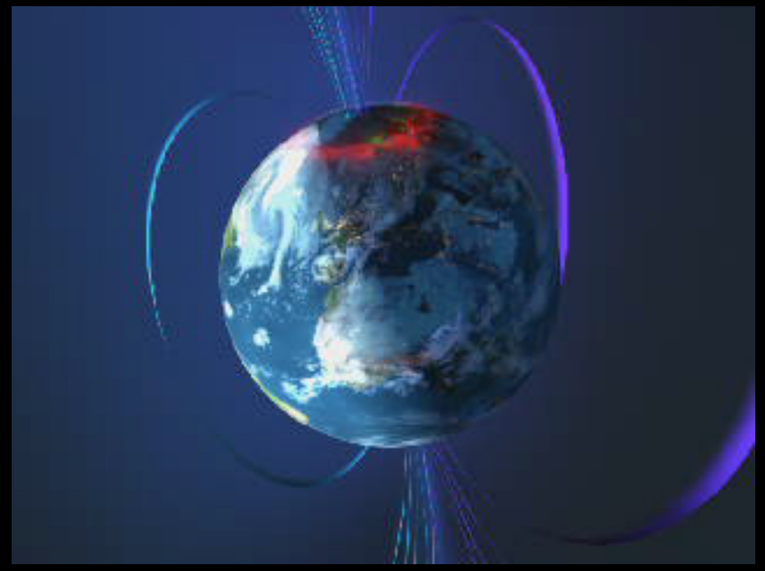


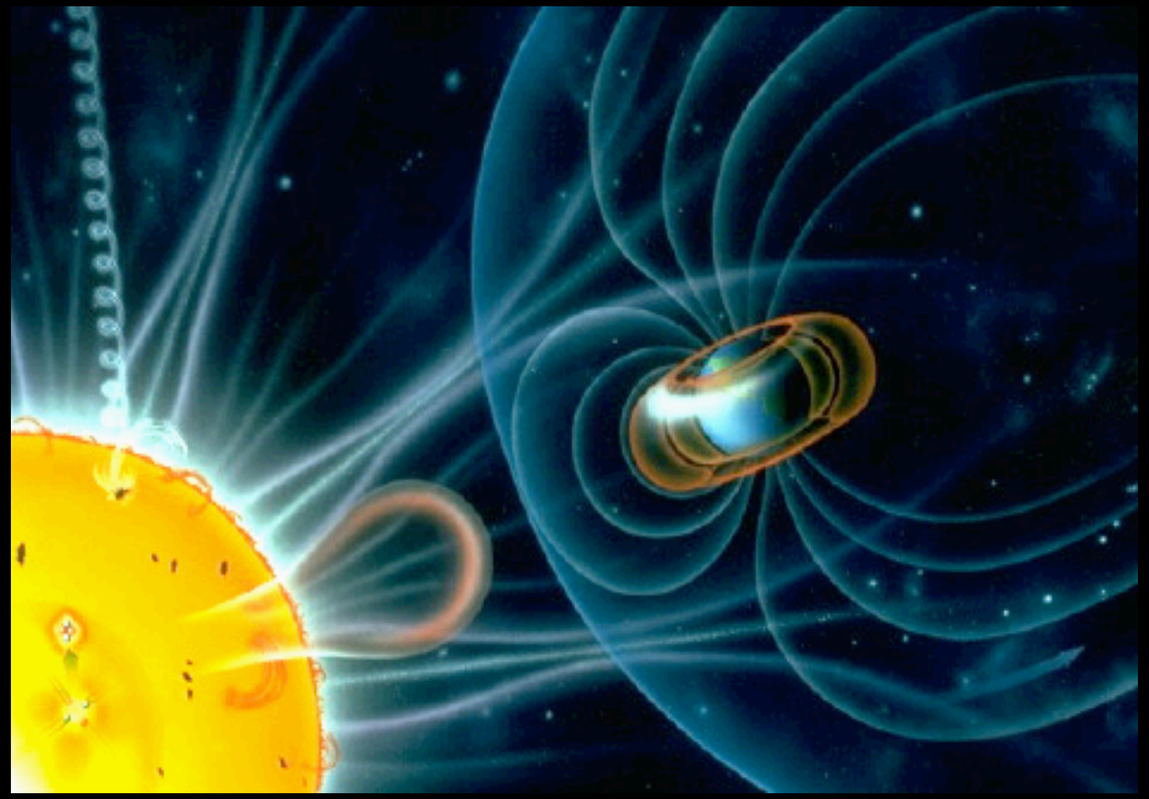
Hathaway/NASA/ARC



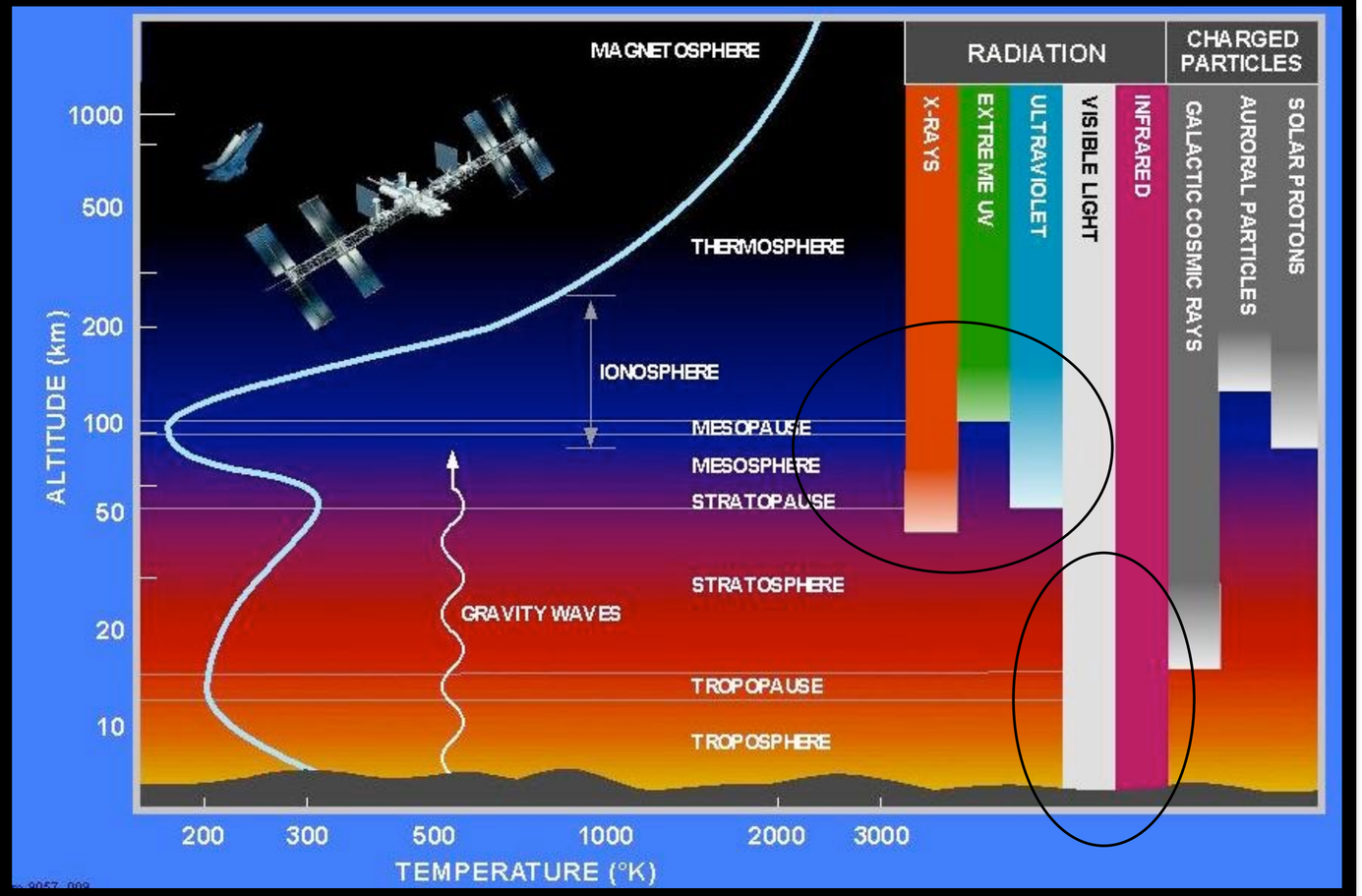
The Solar Wind

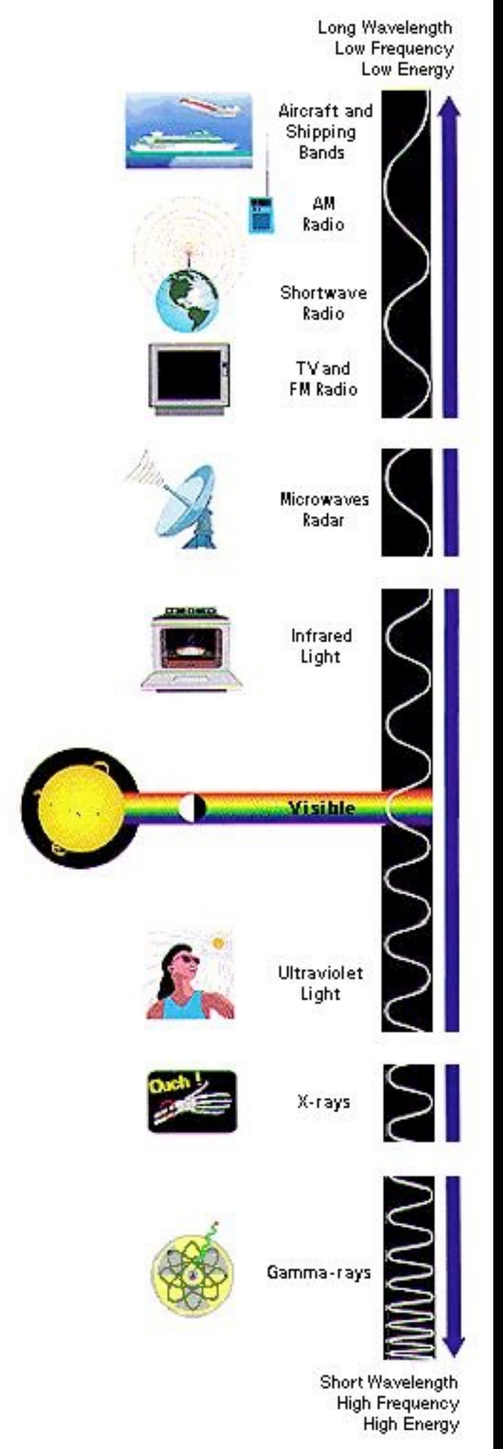
- A constant stream of particles flows from the Sun's corona, with a temperature of about a million degrees and with a velocity of about 1.5 million km/h.
- Gusts in the solar wind will buffet our magnetosphere and lead to a geomagnetic storm.





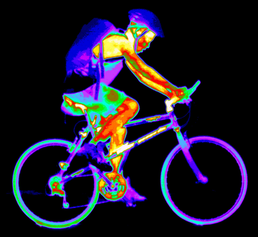
The Electromagnetic Spectrum





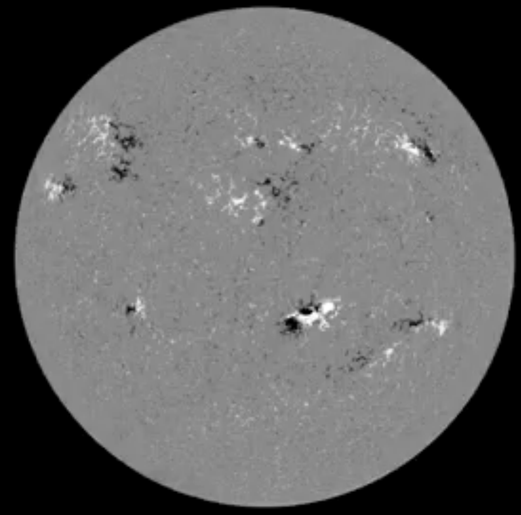
The Sun from Space

Spactral Imaging



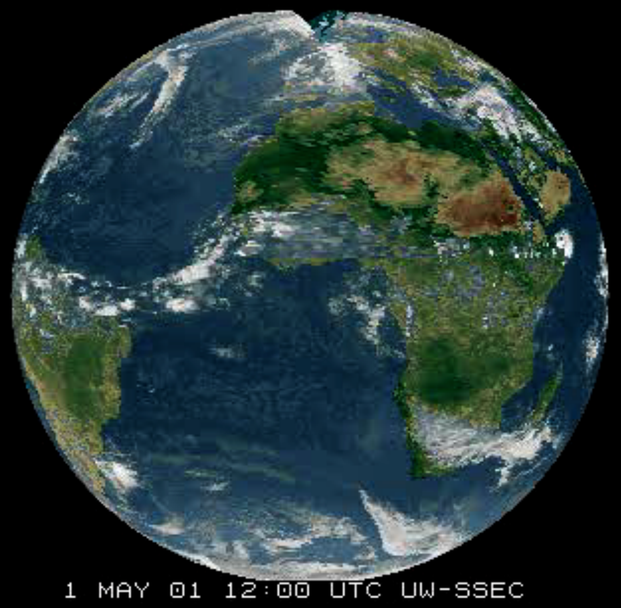
🡸 Different spectral images of a biker

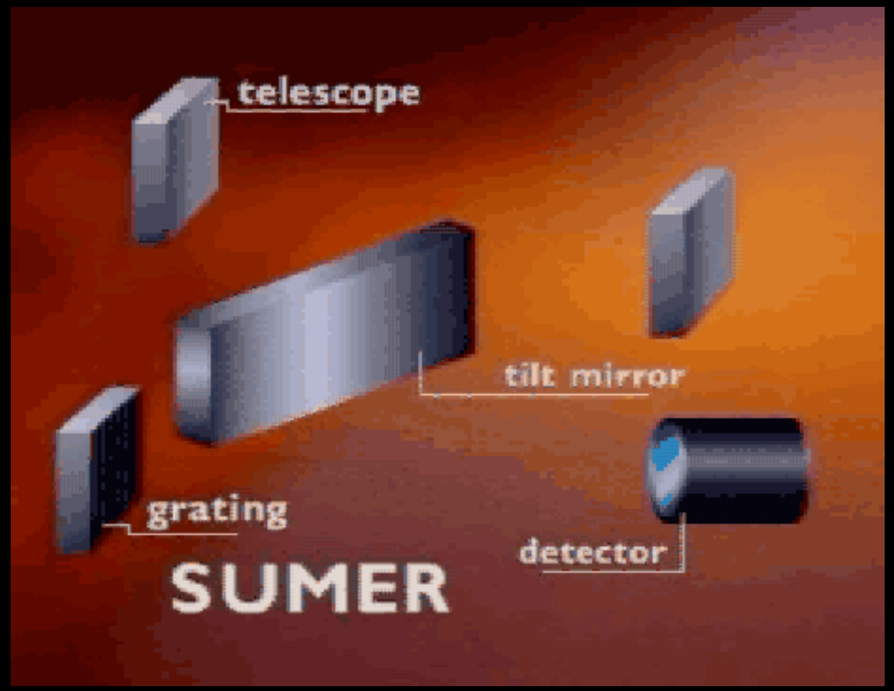
Different spectral images of the Sun

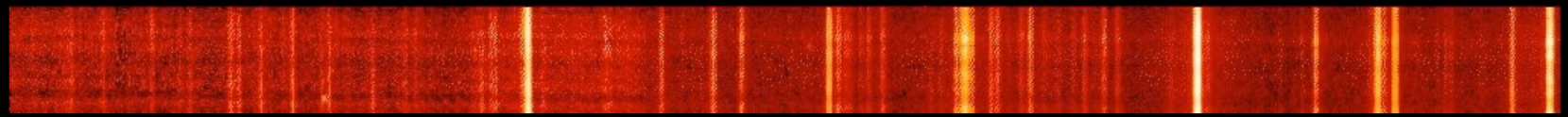


Why Spectroscopy?

- From studying the position, shape and intensity of spectral lines we can derive physical properties of the emitting gas like:
  - Temperature
  - Density
  - Flow velocities



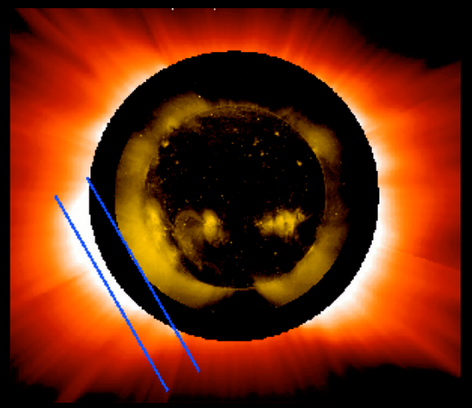




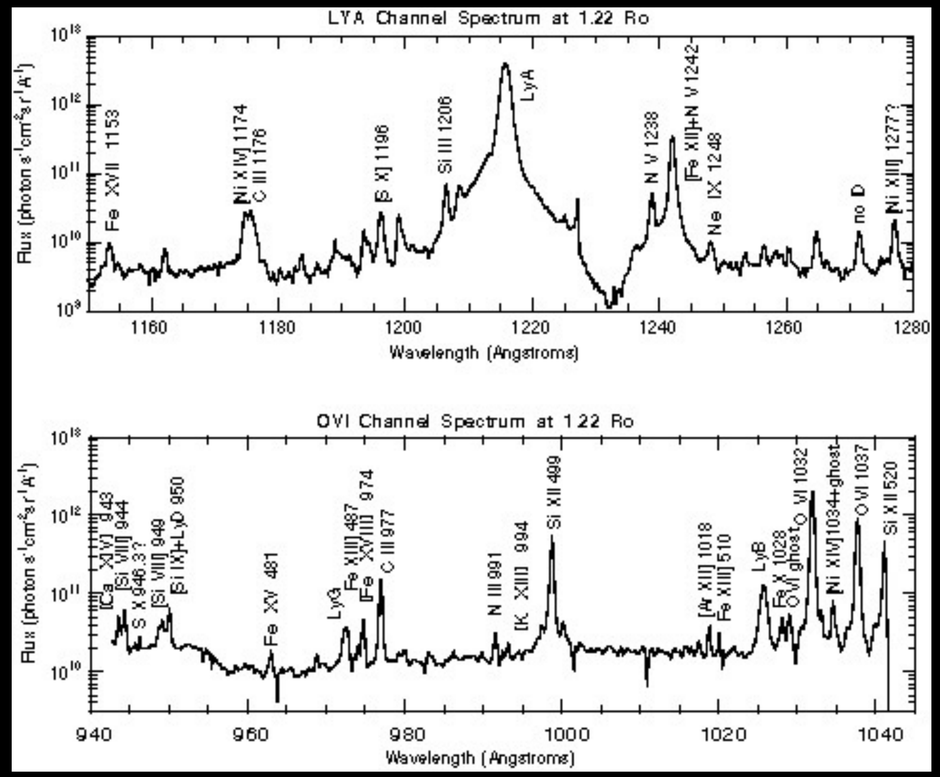
Spectrum is like fingerprints of a star

Spectrum is like fingerprints of a star.

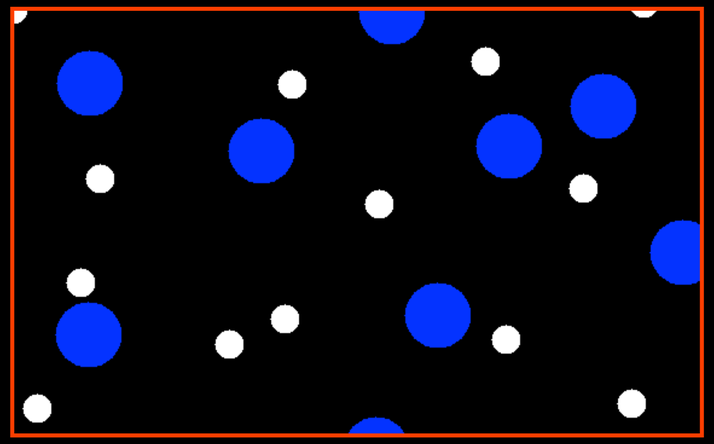
- It provides information about the physical properties of the star:
  - composition, abundance, temperature, density and
  - line-of-sight motions, etc.
- Once we have these information, we can develop models and
- theories to understand how a star works.

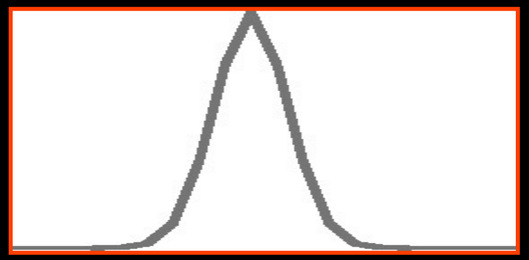


SOHO/UVCS Observations of the corona above an active region

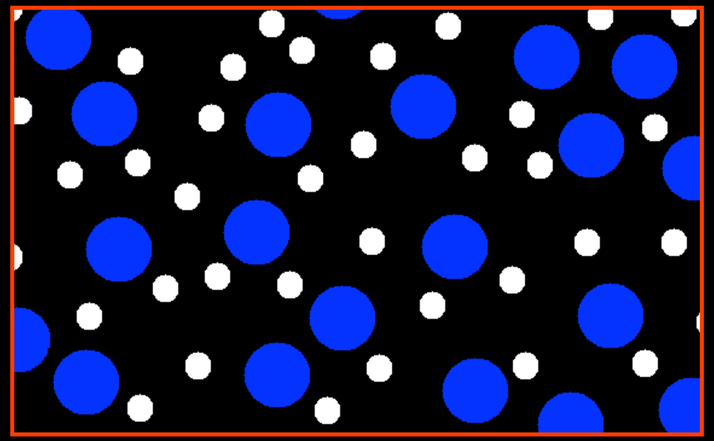


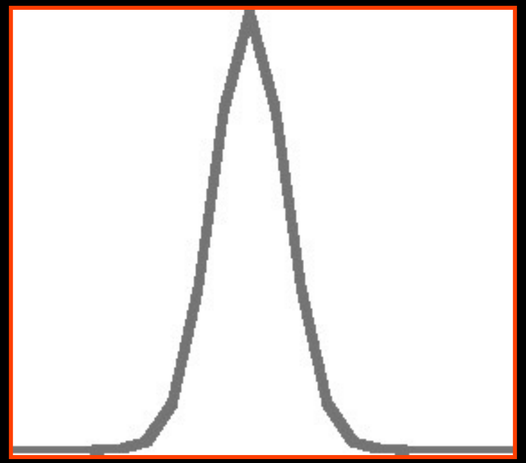
What can we learn from a spectrum
#1: Line Intensity





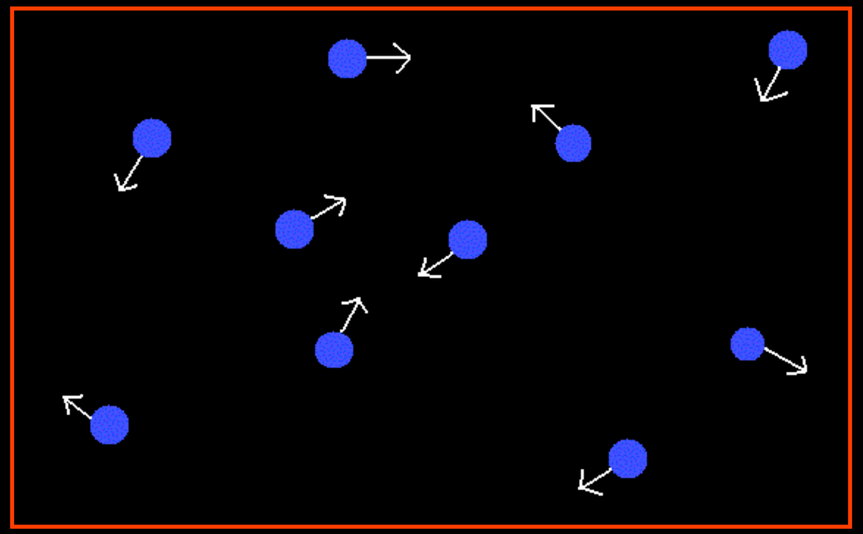
Less particles
→lower intensity
(fainter line)

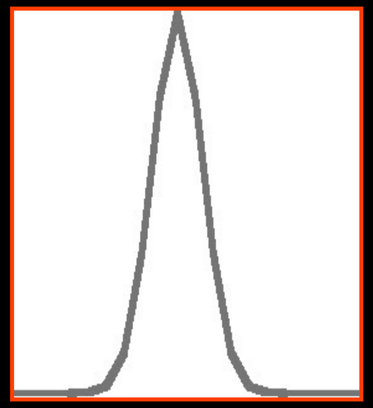




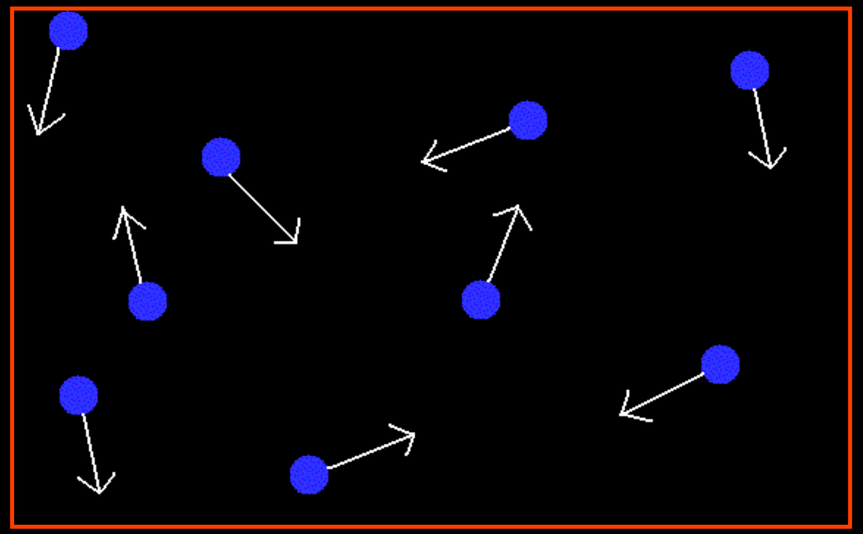
More particles
→higher intensity
(brighter line)

What can we learn from a spectrum
#2: Line Profile

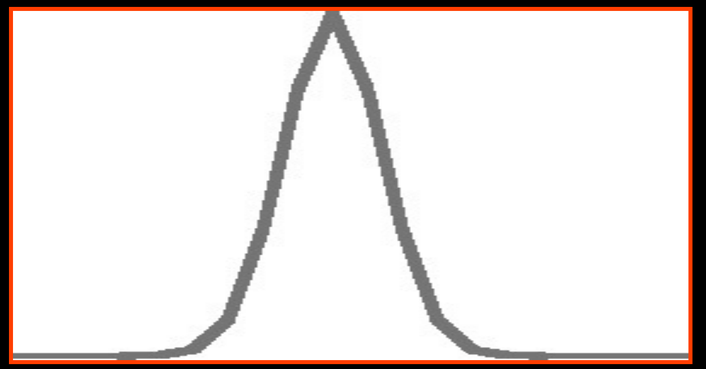




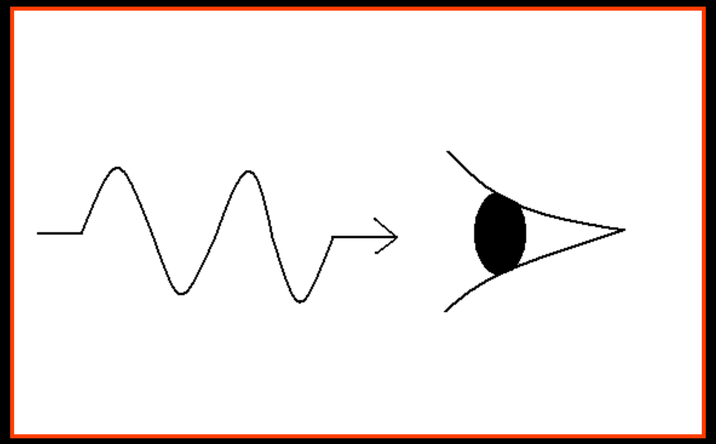
Slower random motion
→ narrower width

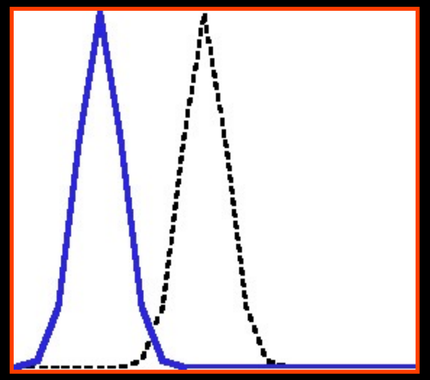


Faster random motion - higher temp.
→ wider width

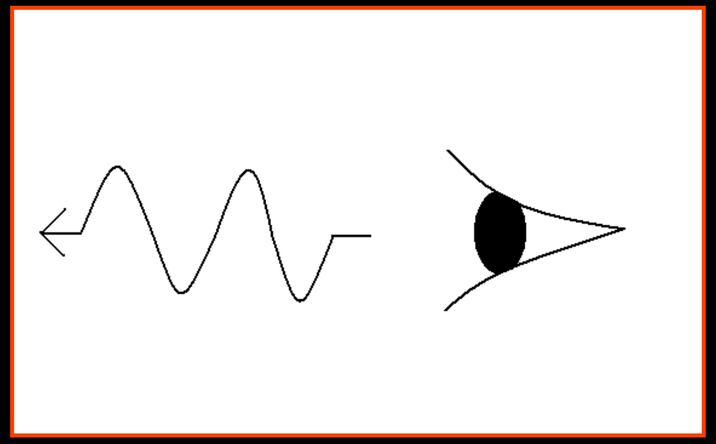


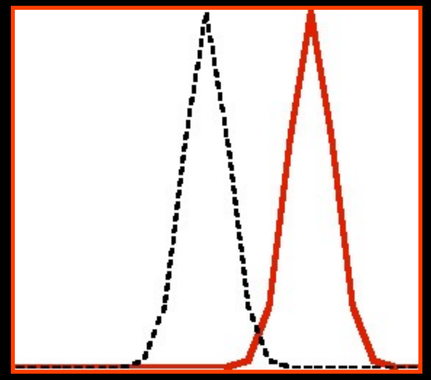
What can we learn from a spectrum
#3: Line Shift





Source moving toward us
→ blue shift (shorter wavelength)

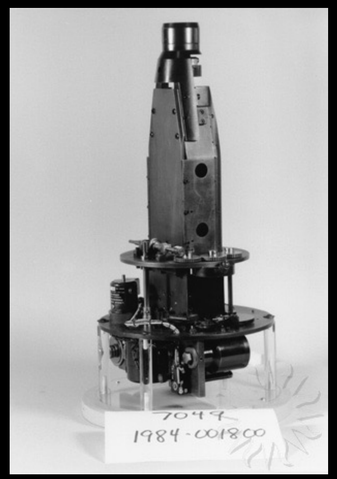




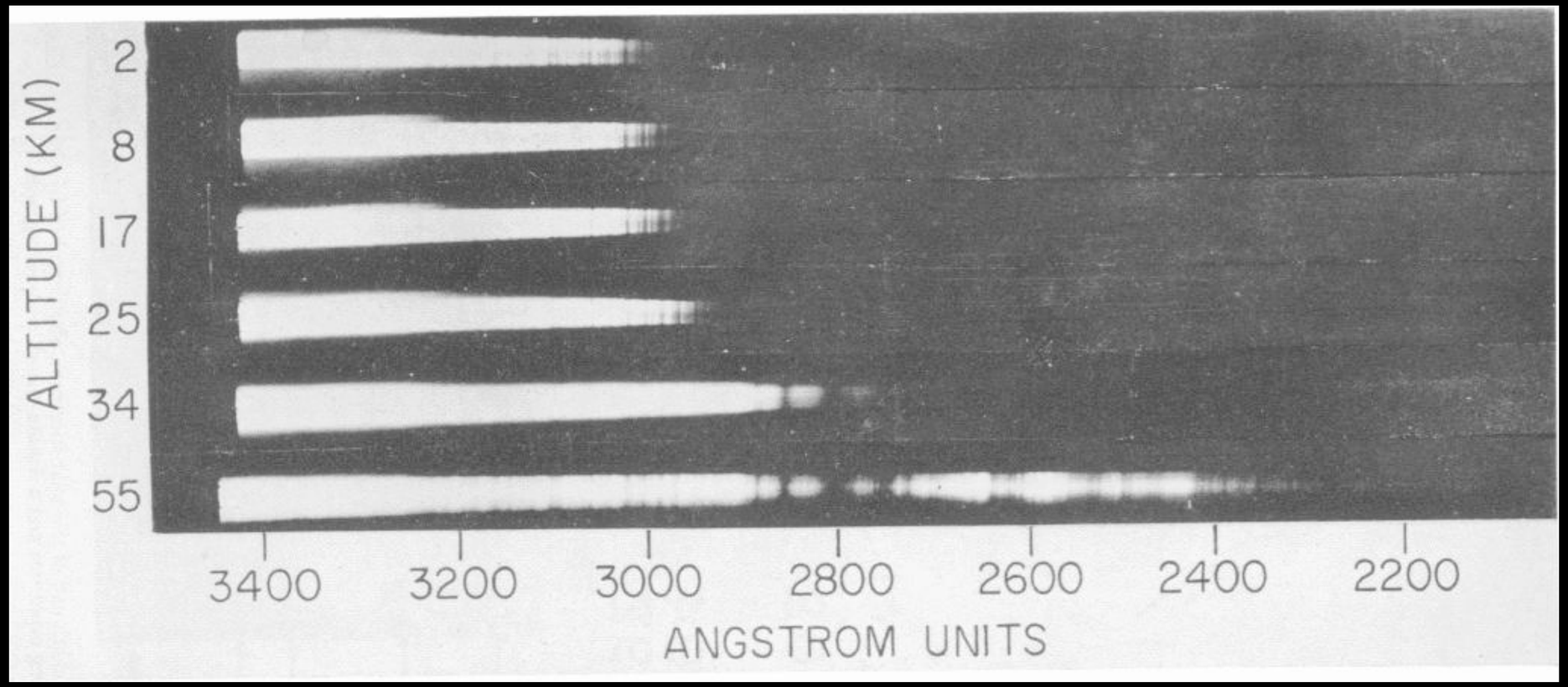
Source moving away from us
→ red shift (longer wavelength)

First Glimpse of the Sun from Space

- After World War II, captured V2 rockets provided a means for sending scientific instruments above the bulk of the earth's atmosphere, which absorbed ultraviolet (UV) radiation.
- To study the nature of that absorption, and to examine the ultraviolet portion of the solar spectrum, a group at the Naval Research Laboratory (NRL) in Washington D.C. led by physicist Richard Tousey designed a rugged solar spectrograph to fly in the V2 warhead. 12 spectrometers were built
- The first spectrograph was placed in the warhead of the missile for a flight in June 1946 and confirmed that recovery was going to be a major problem.
- The spectrographs were then placed in the tail fins, and explosive bolts were added break the vehicle into two pieces on descent, destroying is aerodynamic form.
- The first successful flight of the NRL UV spectrograph was on October 10, 1946. The missile reached an altitude of 173 km and the series of spectra obtained during ascent showed the decrease in UV absorption with altitude and helped set the upper limit to the Earth's ozone layer.

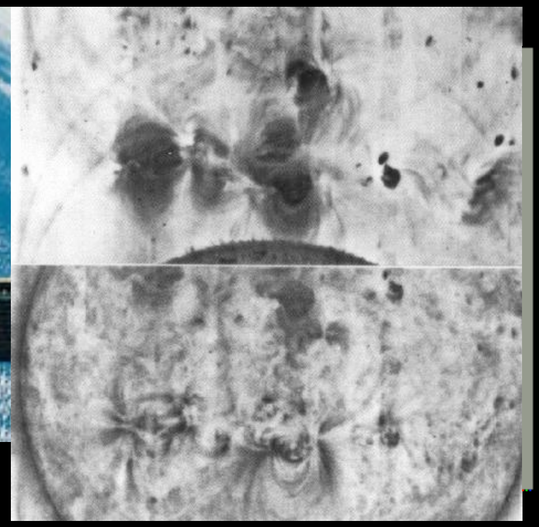


First UV spectrum of the Sun

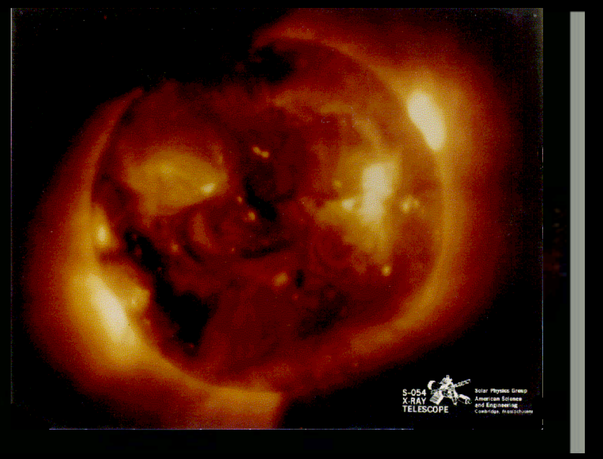


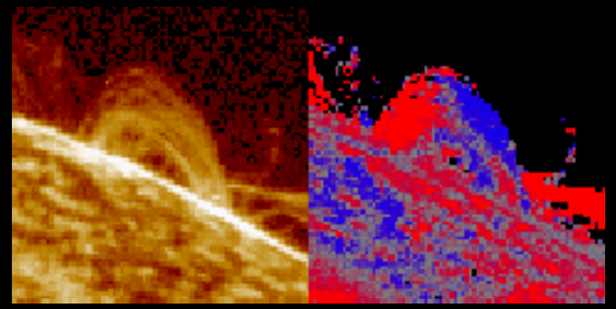
Previous Solar Space Missions

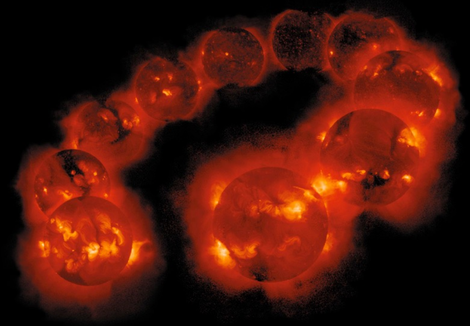
- OSO 1-8 (1962 - 1978)
- Skylab ATM (1973-1977)
  - Coronal holes
  - Coronal loops
  - Spectral atlas
  - Dynamics of the TR
- Helios 1 & 2 (1974-80)
  - Plasma & particles down to 0.3 AU
- SMM (1980 - 1989)
  - Solar irradiance (ACRIM)
  - Flares (Hard and Soft X-ray)
  - CME's
  - UV spectral atlas, dynamics
- Hinotori (1981-1991)
- Coronas-I (1994-1995)
- Yohkoh (1991-2002)
  - Ulysses (1990 - 2009)



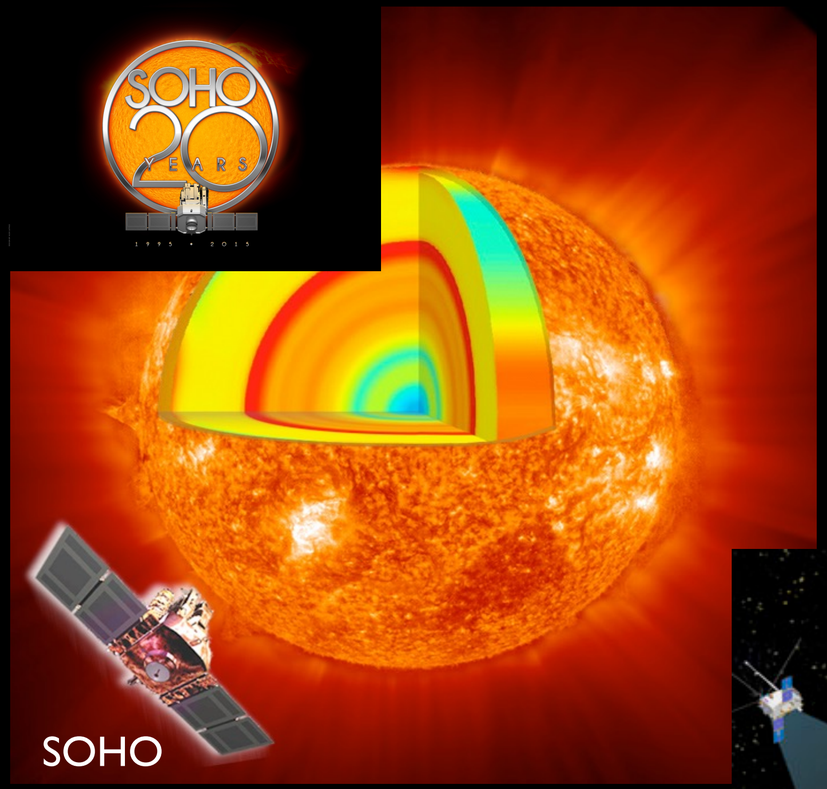
Skylab SO54

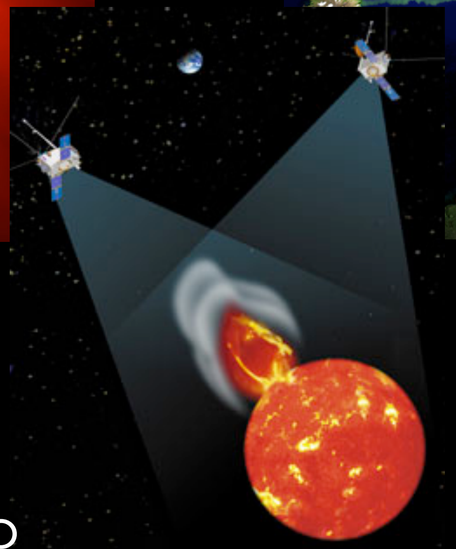




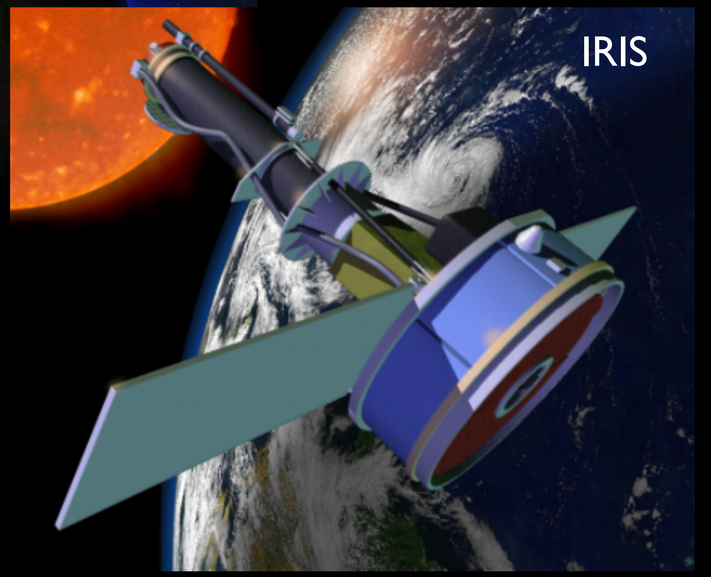


Modern Space Observatories



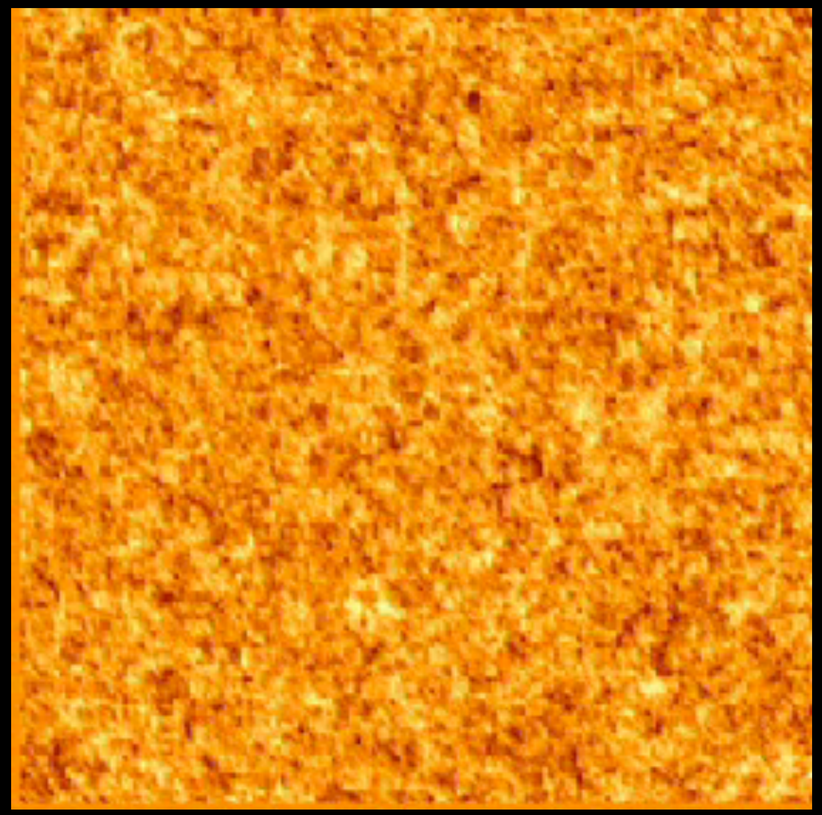


STEREO



Helioseismology

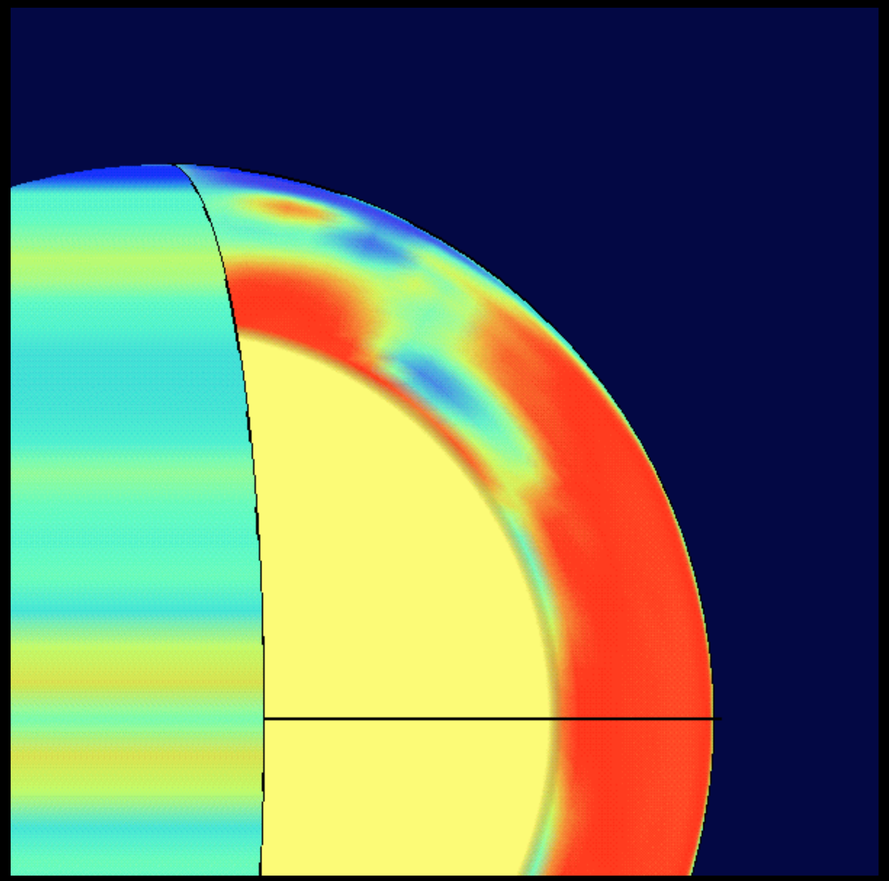
- The entire Sun is vibrating due to sound waves propagating inside.
- The sound waves are refelcted off the surface - casuing the surface to oscillate up and down.
- By observing the escillations, and thus the sound waves we can obtain information about the solar interior (temperature, density and flow velocities).

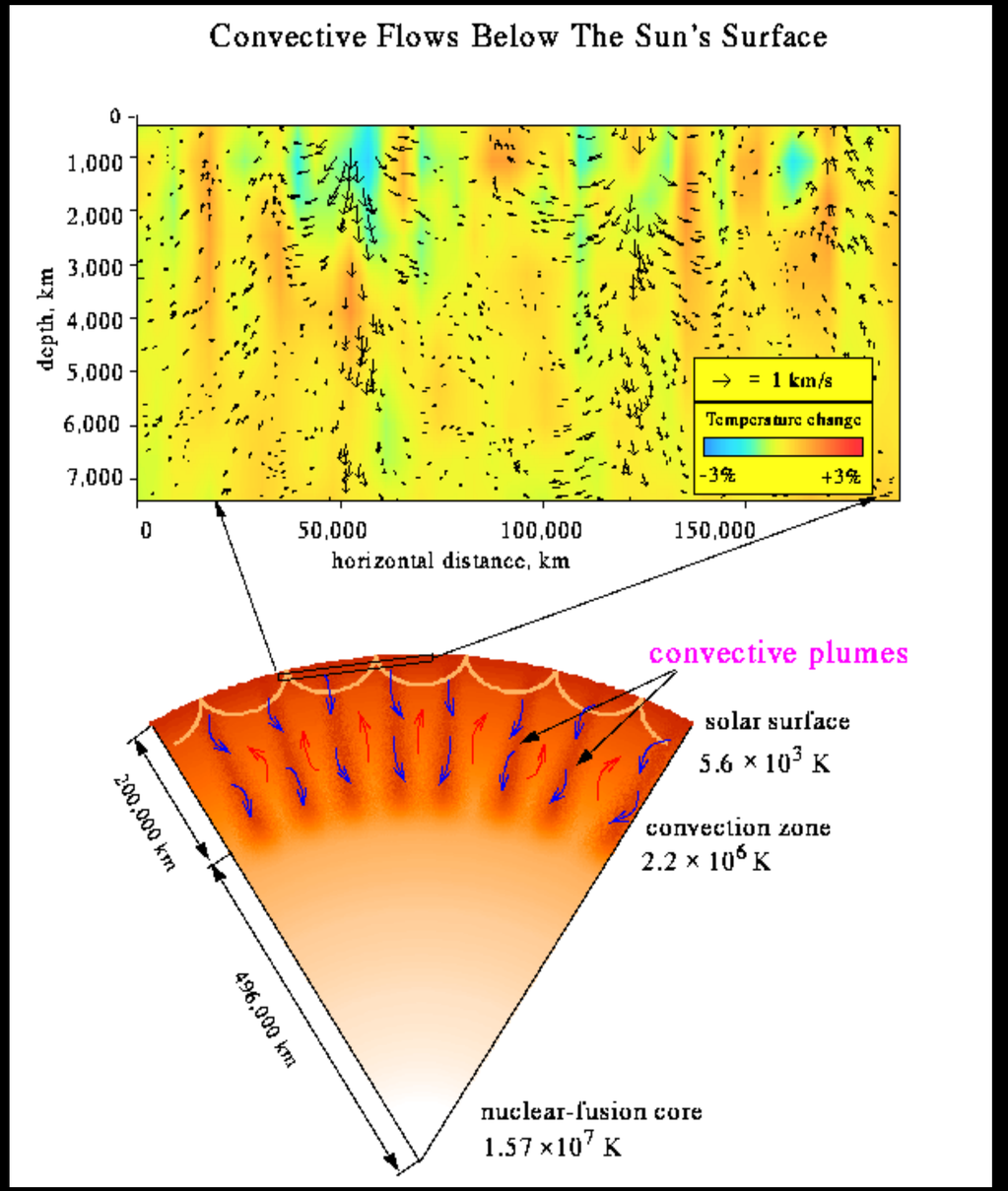


Helioseismology

New technique which is primarily developing with SOHO/MDI data

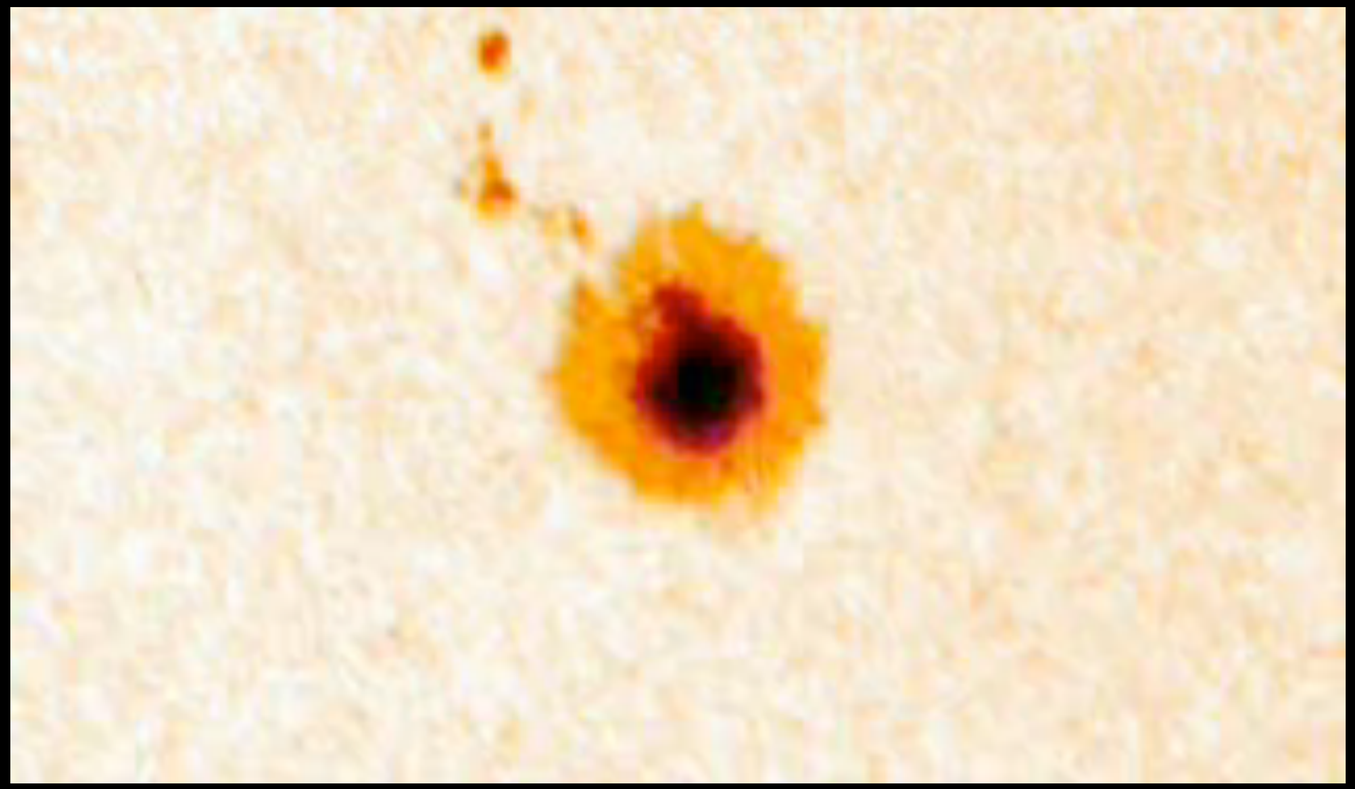
- First ever images of flows in the convection zone of a star
- First images of the subsurface structure of sunspots
- Can give us the first insight into how sunspots are formed

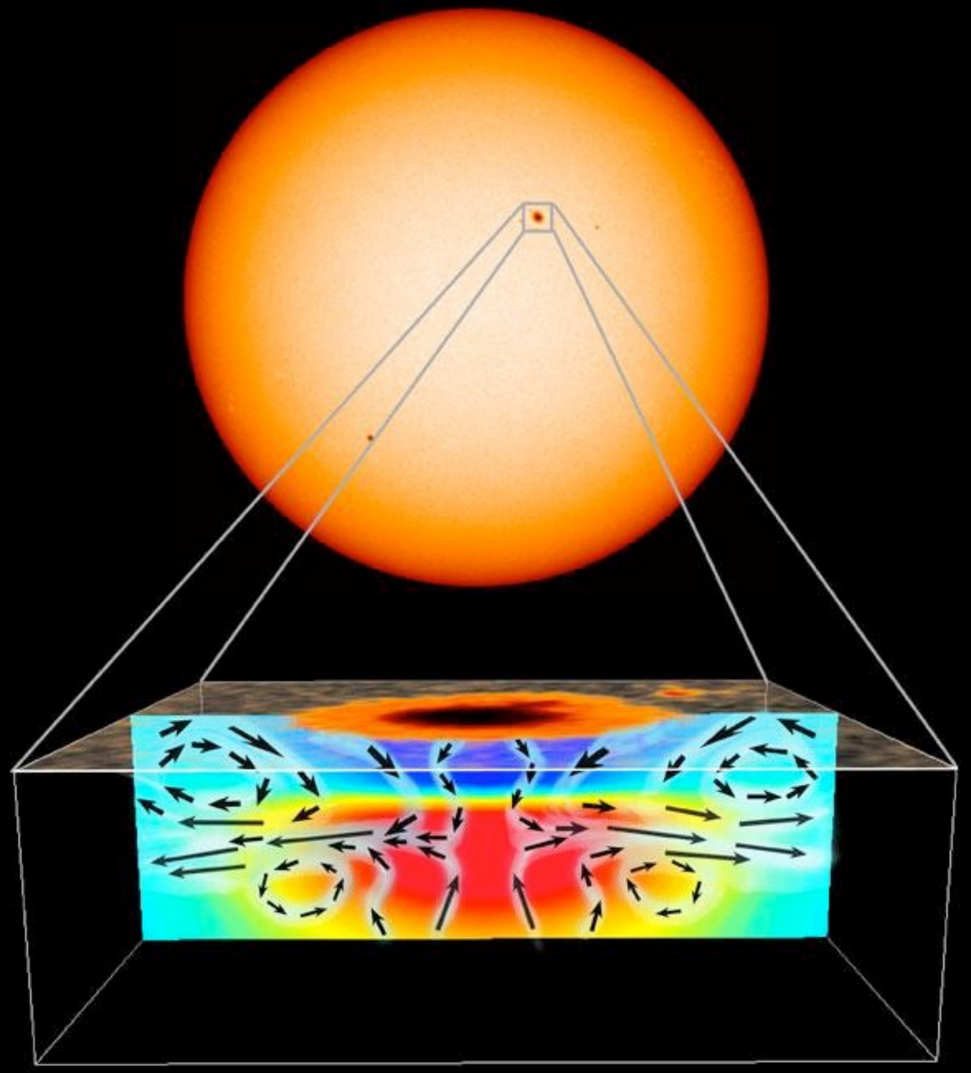




We can «see» below sunspots

- For the first time one could study the layers below sunspots
- How do they form and what sustain them,

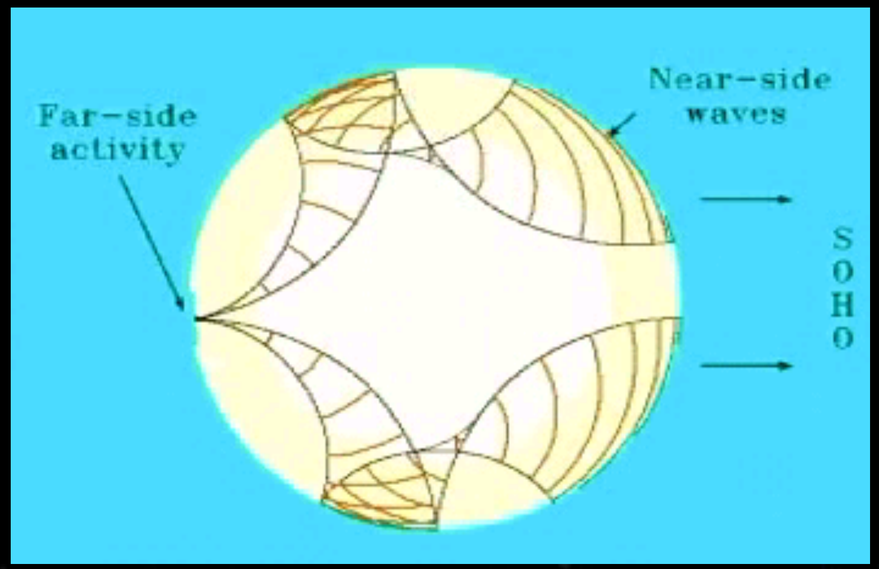




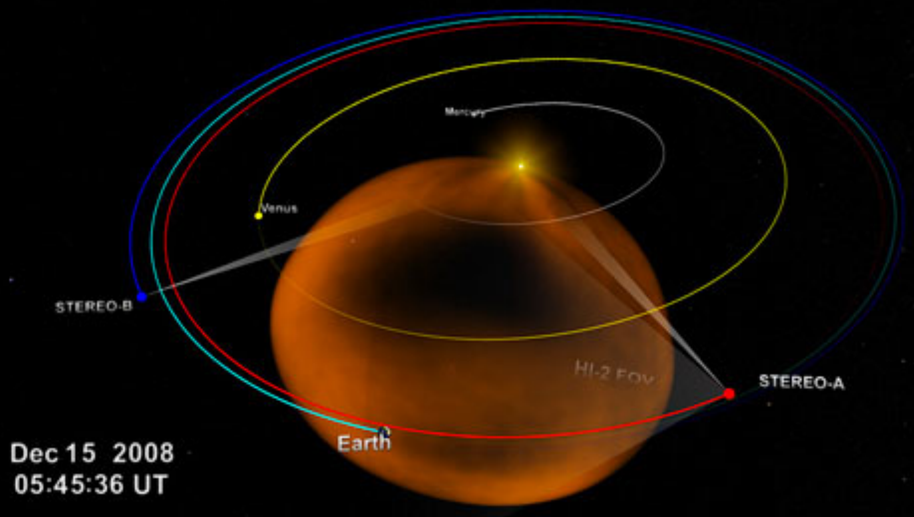
Zhao et al.: 2001, ApJ 557, 384

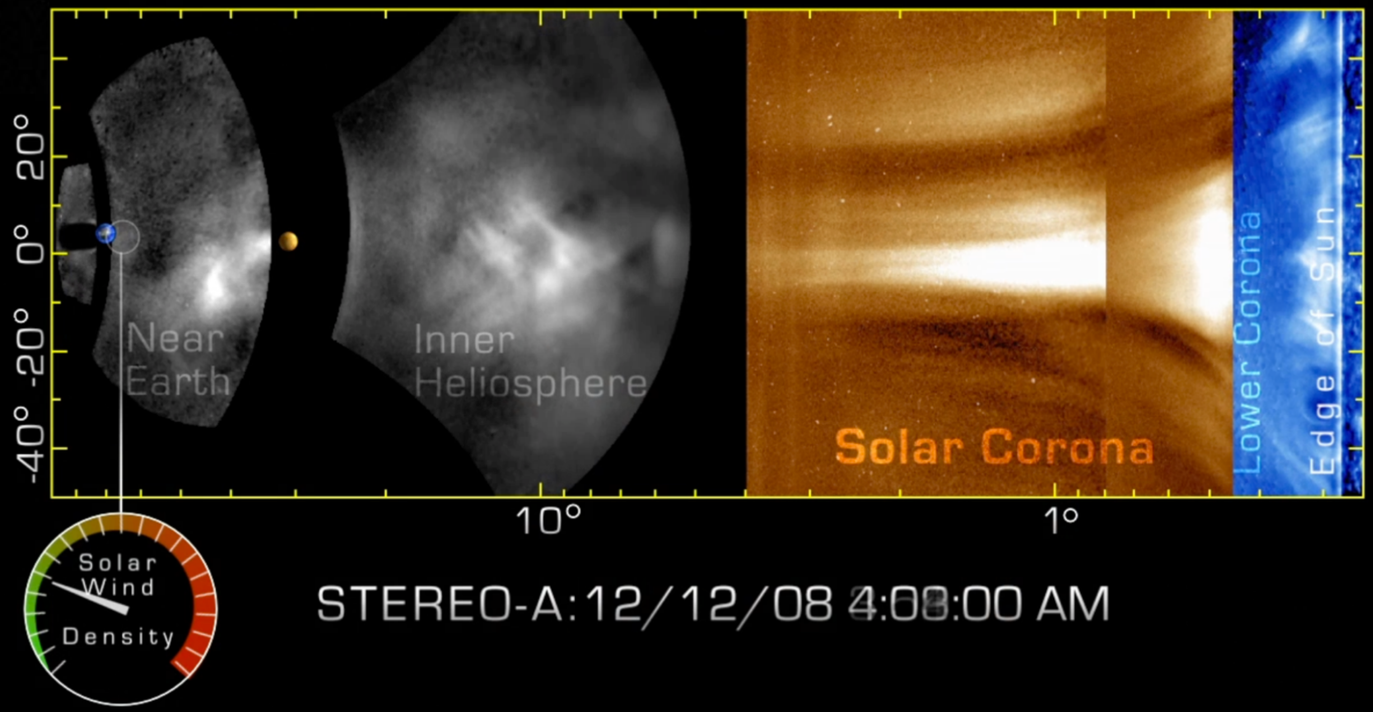
SOHO «see» through the Sun

- Using helioseismology we can even «see» the far side of the Sun.
- Strong magnetic fields cause the sound waves to move slower.

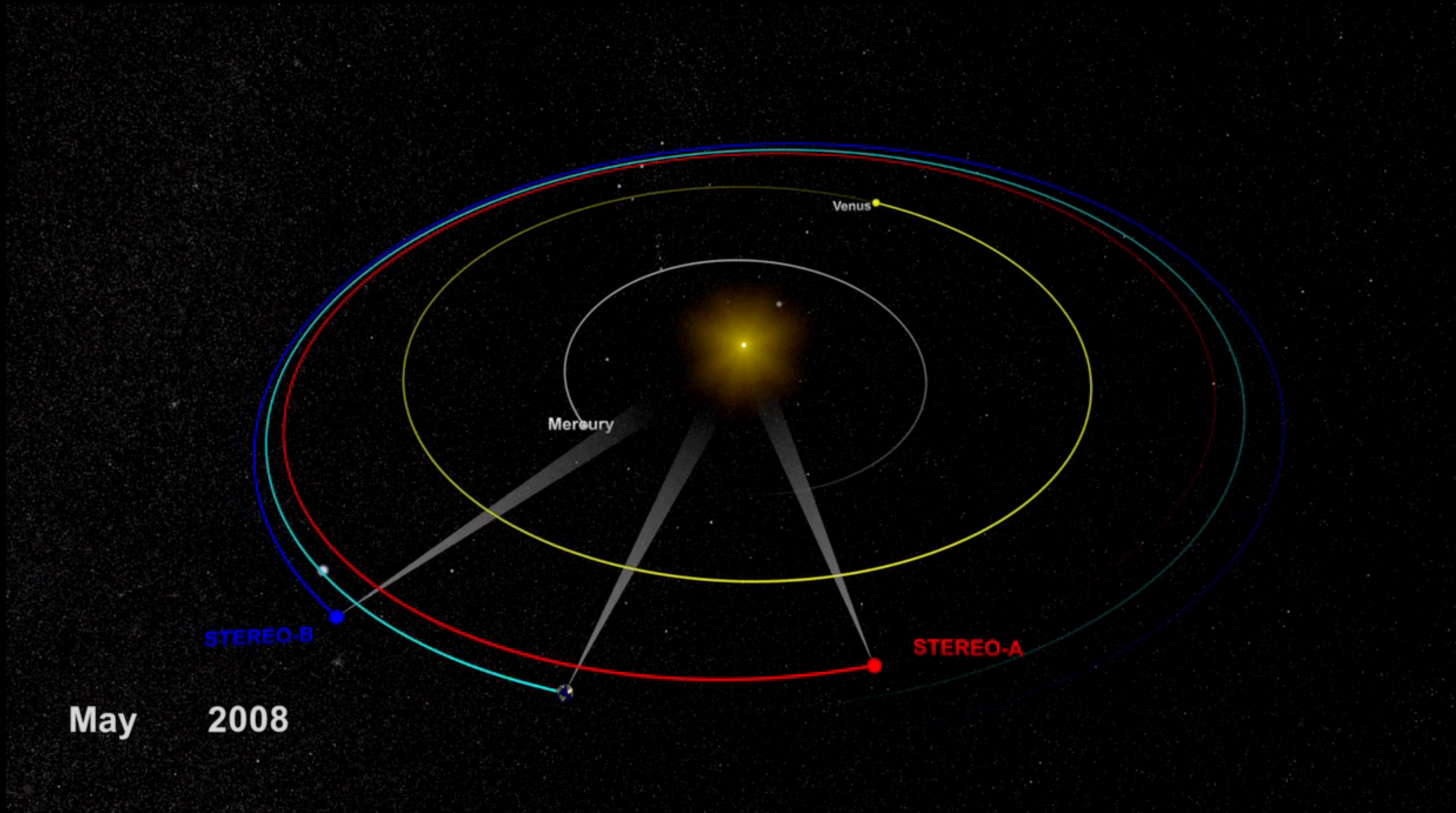


STEREO

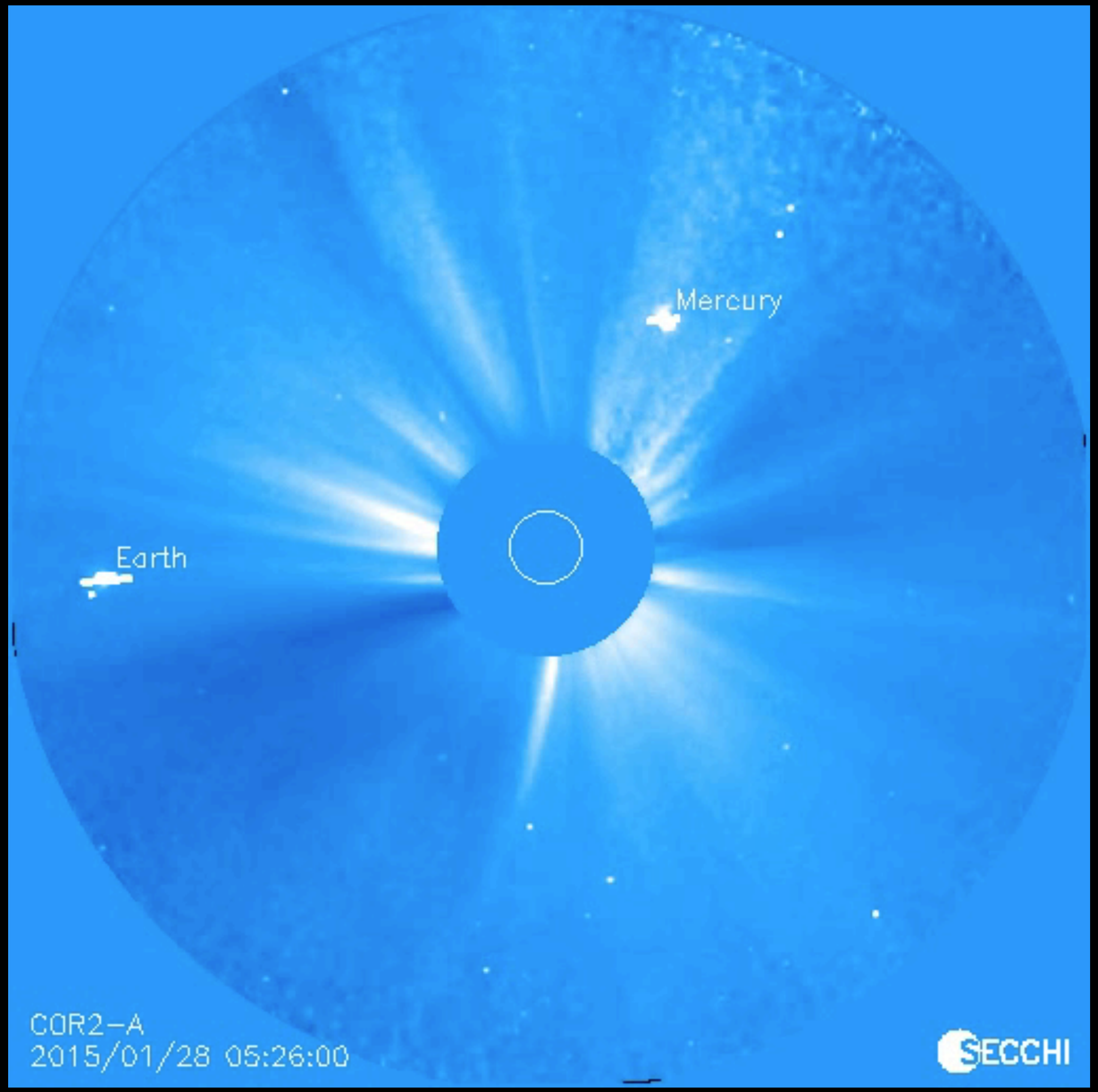

Mercury
Venus
STEREO-B
HI-2 FOV
STEREO-A
Earth
Dec 15 2008
05:45:36 UT


-40° -20° 0° 20°
Near Earth
Inner Heliosphere
Solar Corona
Lower Corona
Edge of Sun
10°
1°
Solar Wind Density
STEREO-A:12/12/08 4:08:00 AM

STEREO



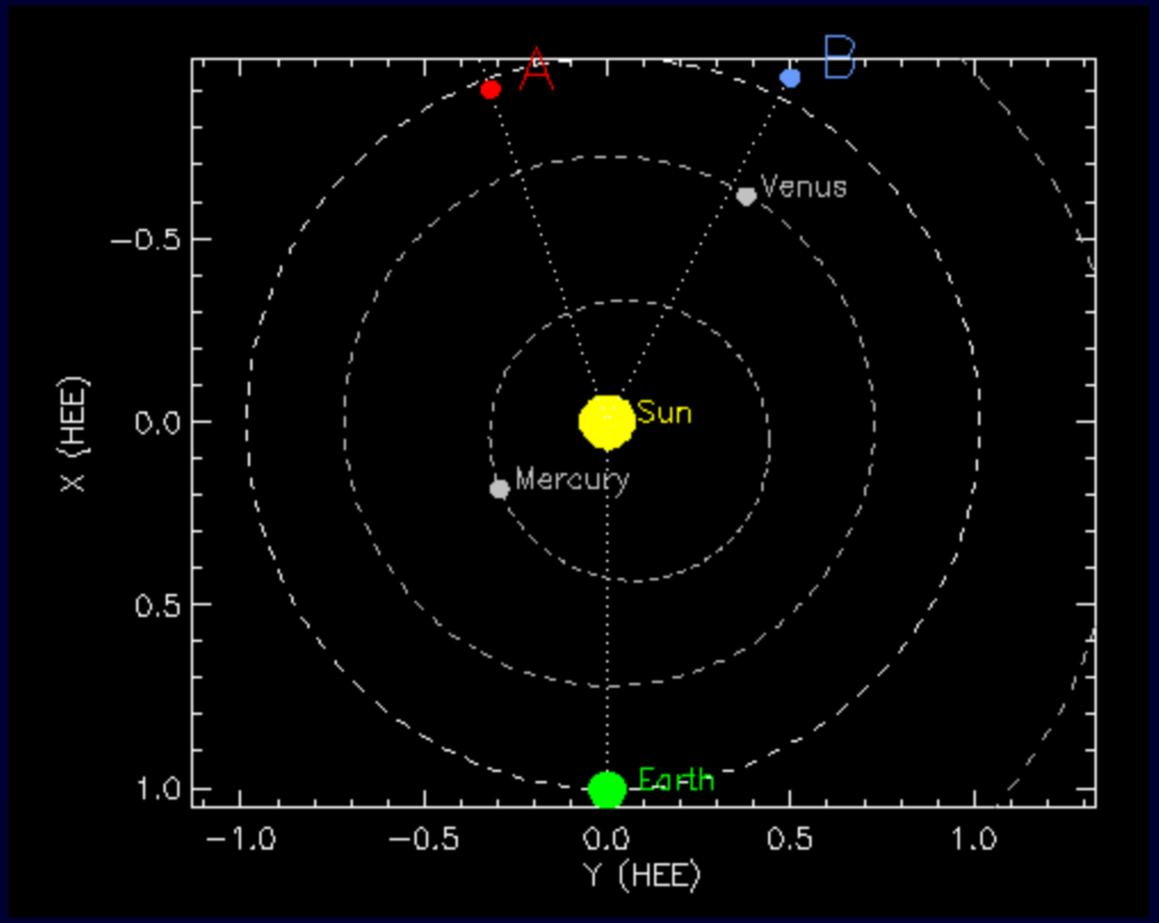
A Selfie from the Other Side of the Sun.



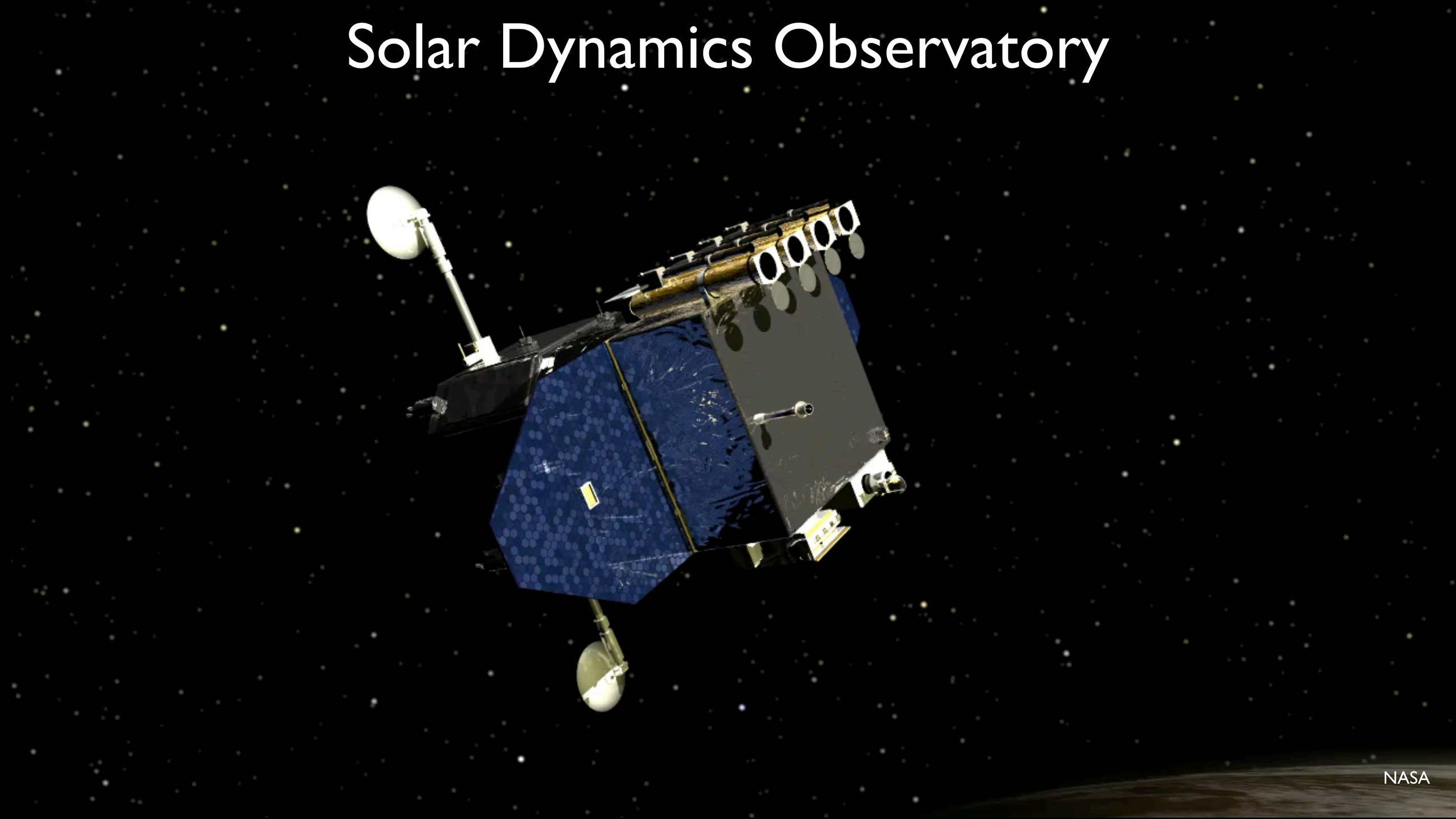
STEREO

Where is STEREO Today?

Positions of STEREO A and B for 18-Apr-2016 05:00 UT

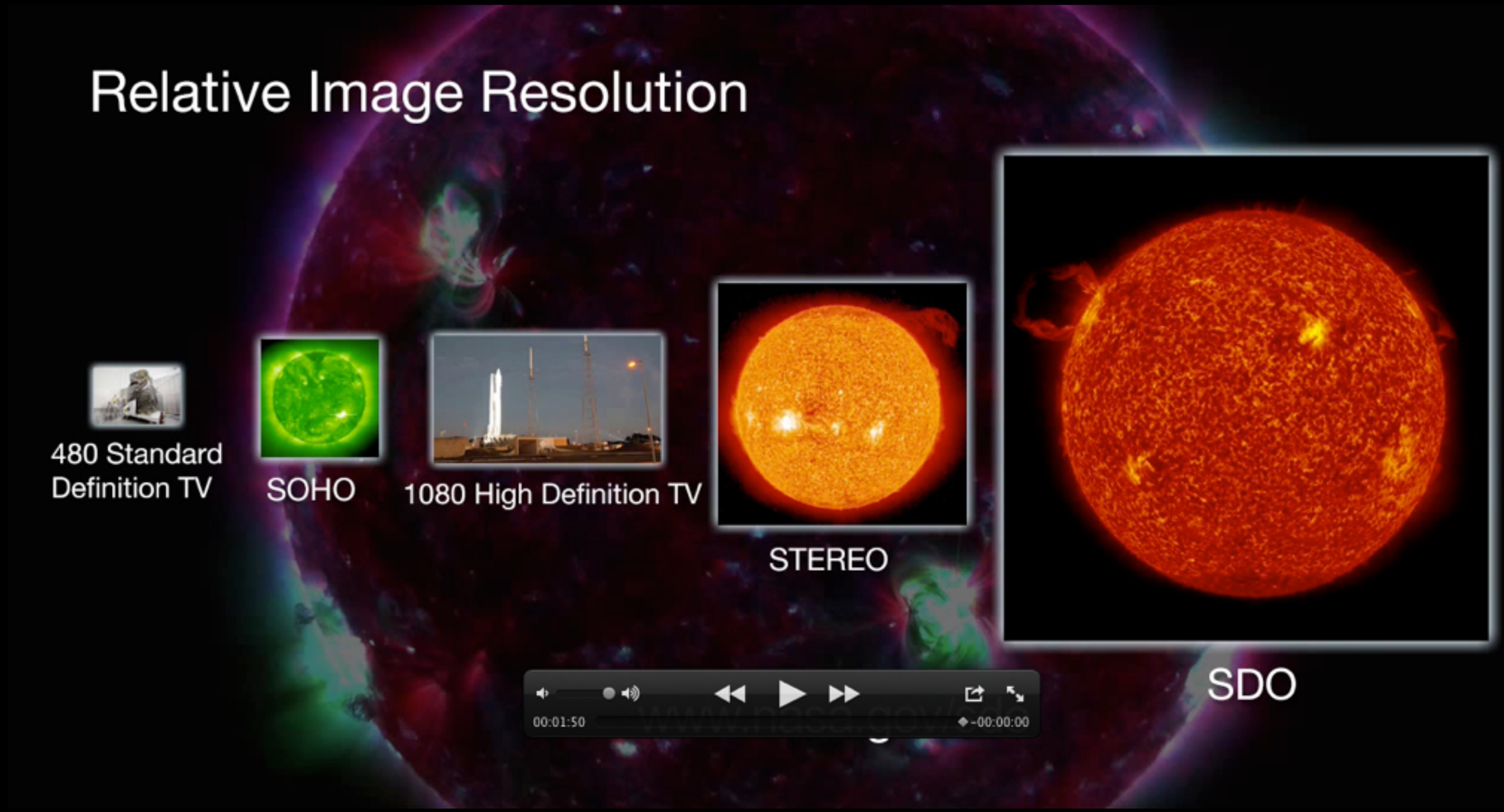


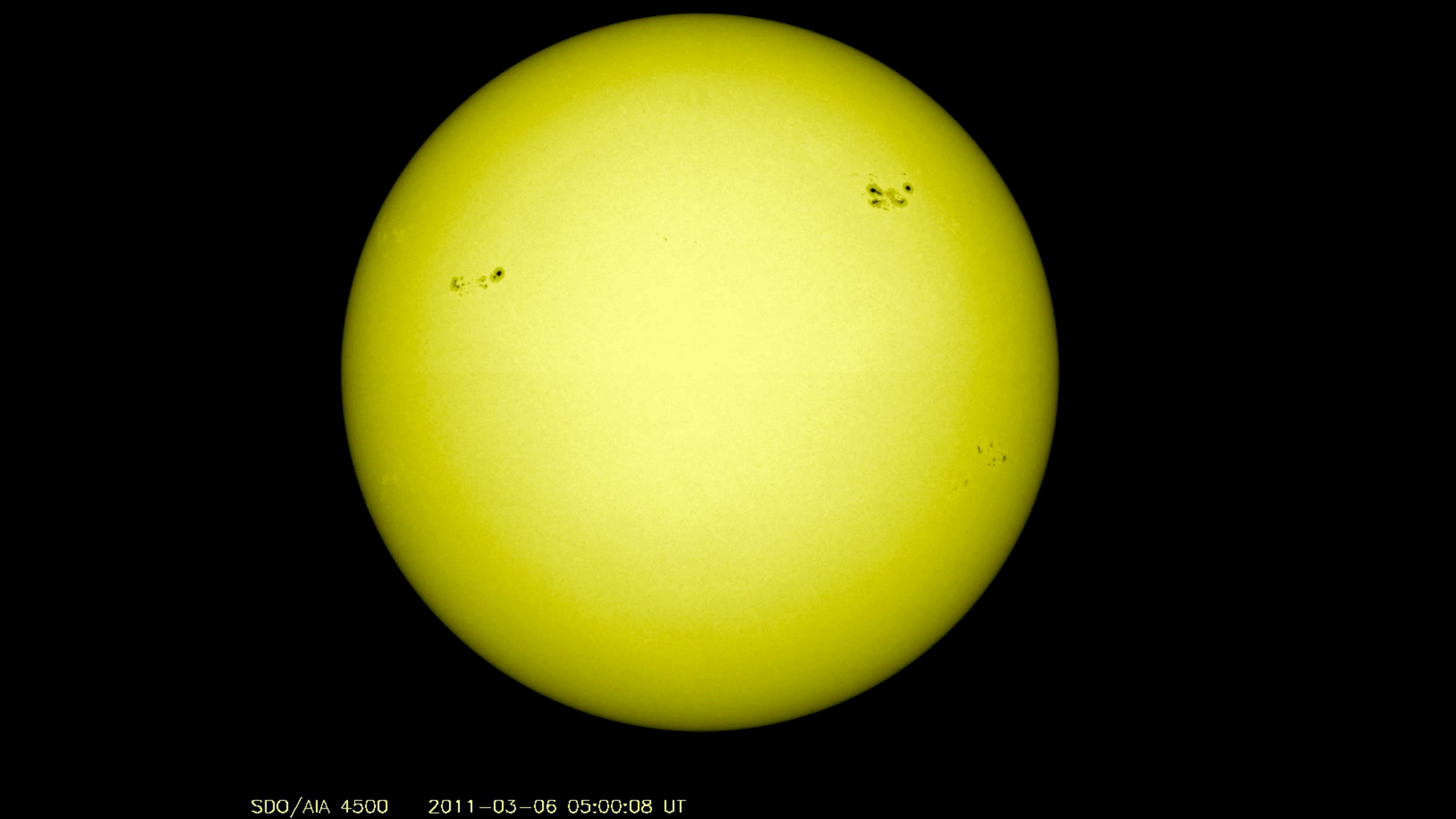
Solar Dynamics Observatory

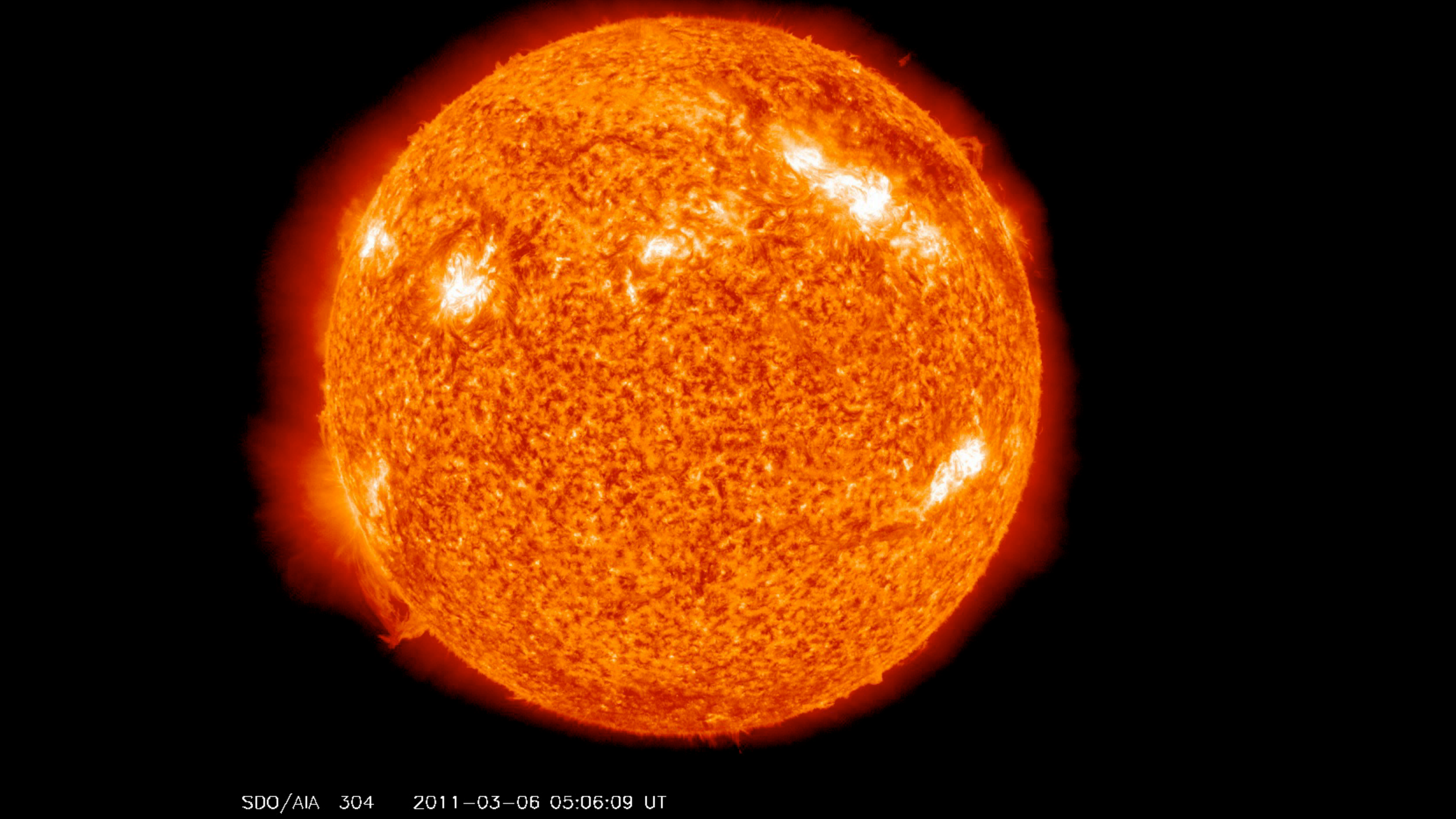


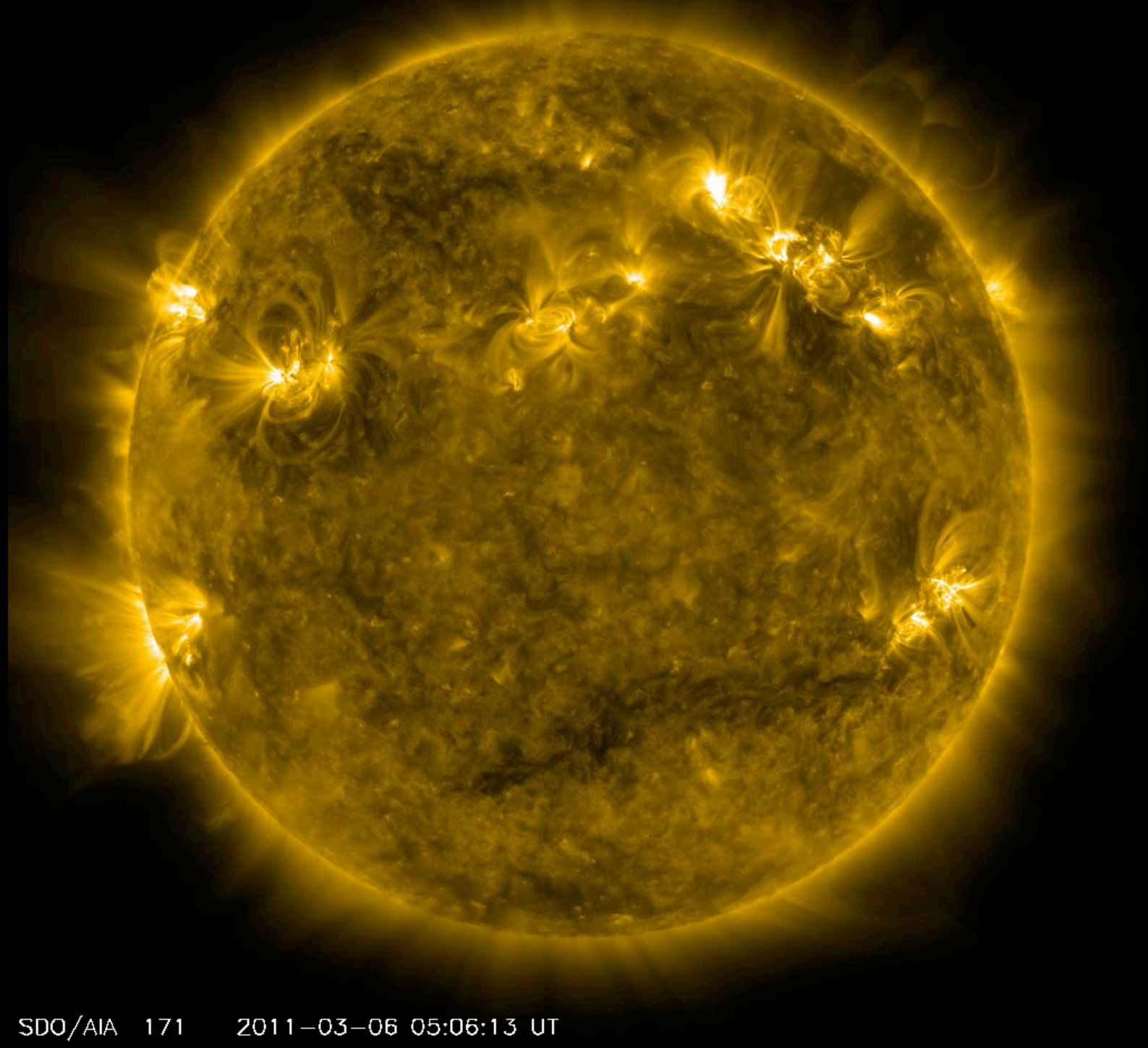
NASA

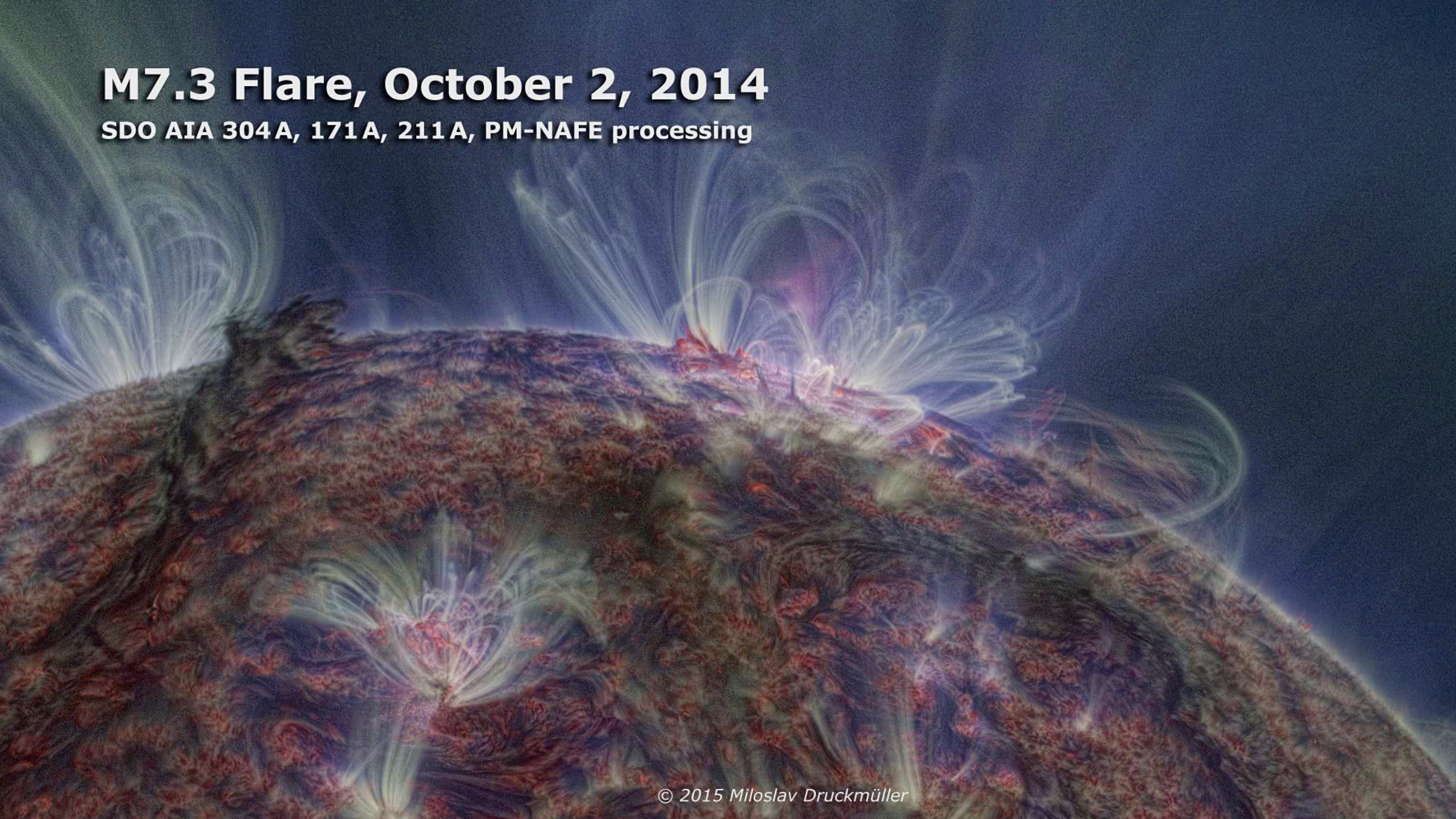
Solar Dynamics Observatory




SDO/AIA 4500 2011-03-06 05:00:08 UT


SDO/AIA 304 2011-03-06 05:06:09 UT

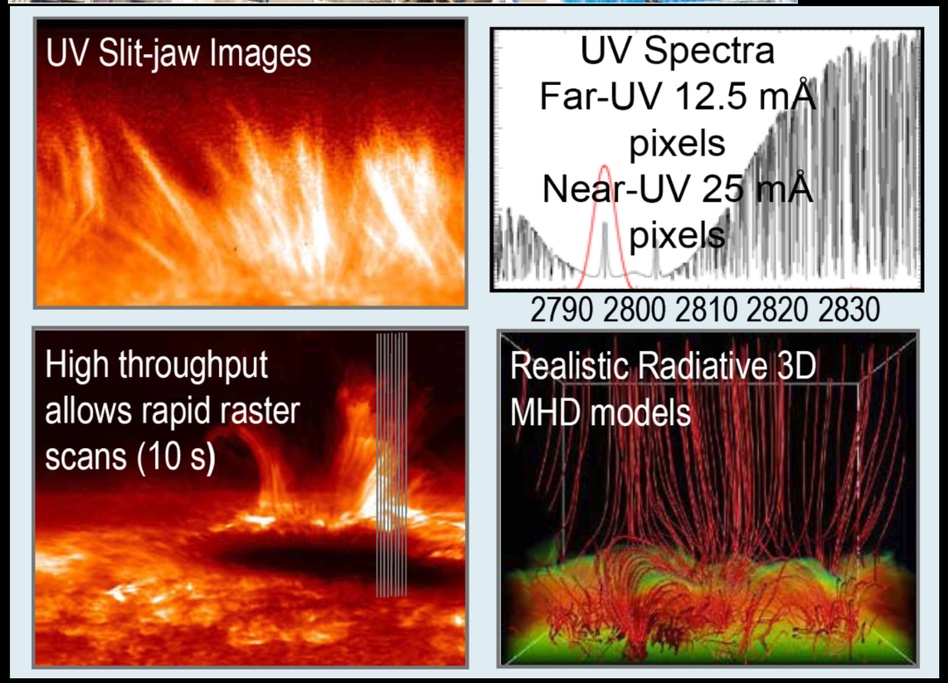

SDO/AIA 171 2011-03-06 05:06:13 UT


M7.3 Flare, October 2, 2014
SDO AIA 304 A, 171 A, 211 A, PM-NAFE processing
© 2015 Miloslav Druckmüller

NASAs IRIS

NASA SMEX solar mission launhed in 2013 - built by Lockheed Palo Alto

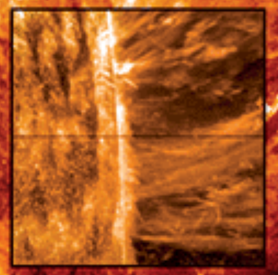
- Super high spatial and temoral resolution
- Norwegian scientists at UiO involved - **in science, data storage, analysis software.**
- Data download at SVALSAT - financed by Norwegian PRODEX (ESA) funding until 2014.



When drug-trial subjects don't take their pills p. 298 | European regulations and consumer genomics p. 299 | An autoimmune target in rheumatoid arthritis p. 300

Science

$10
17 OCTOBER 2014
sciencemag.org
AAAS

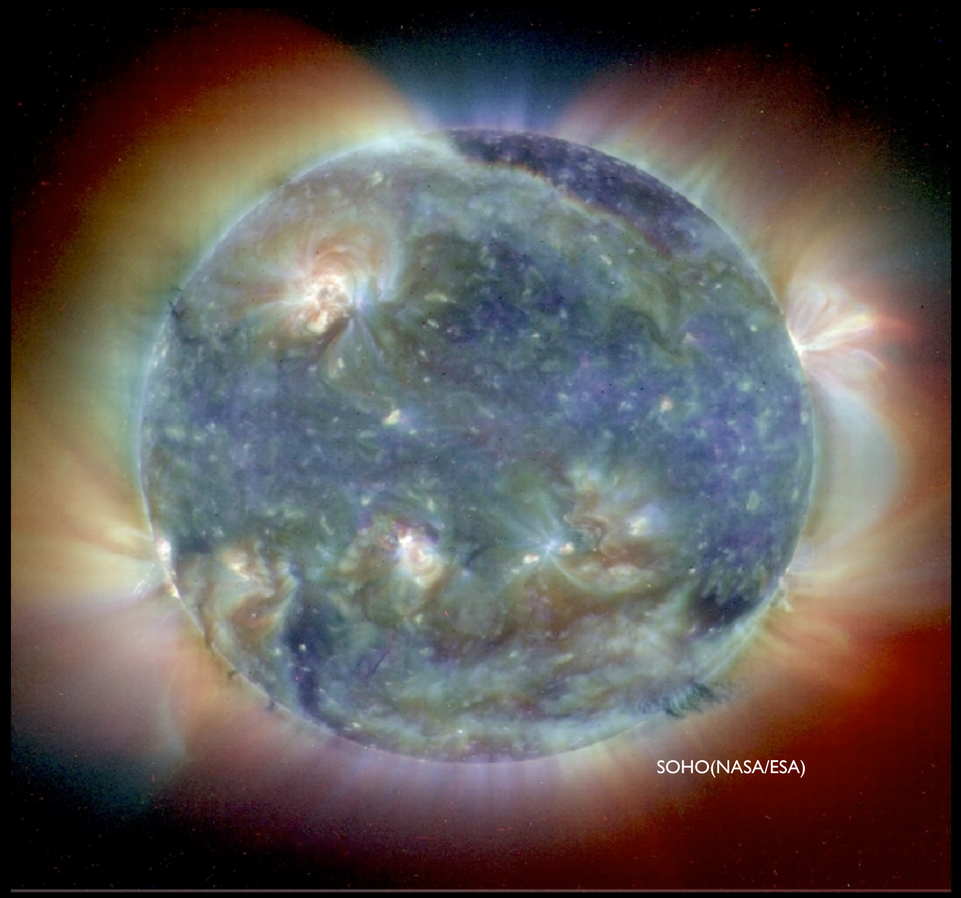


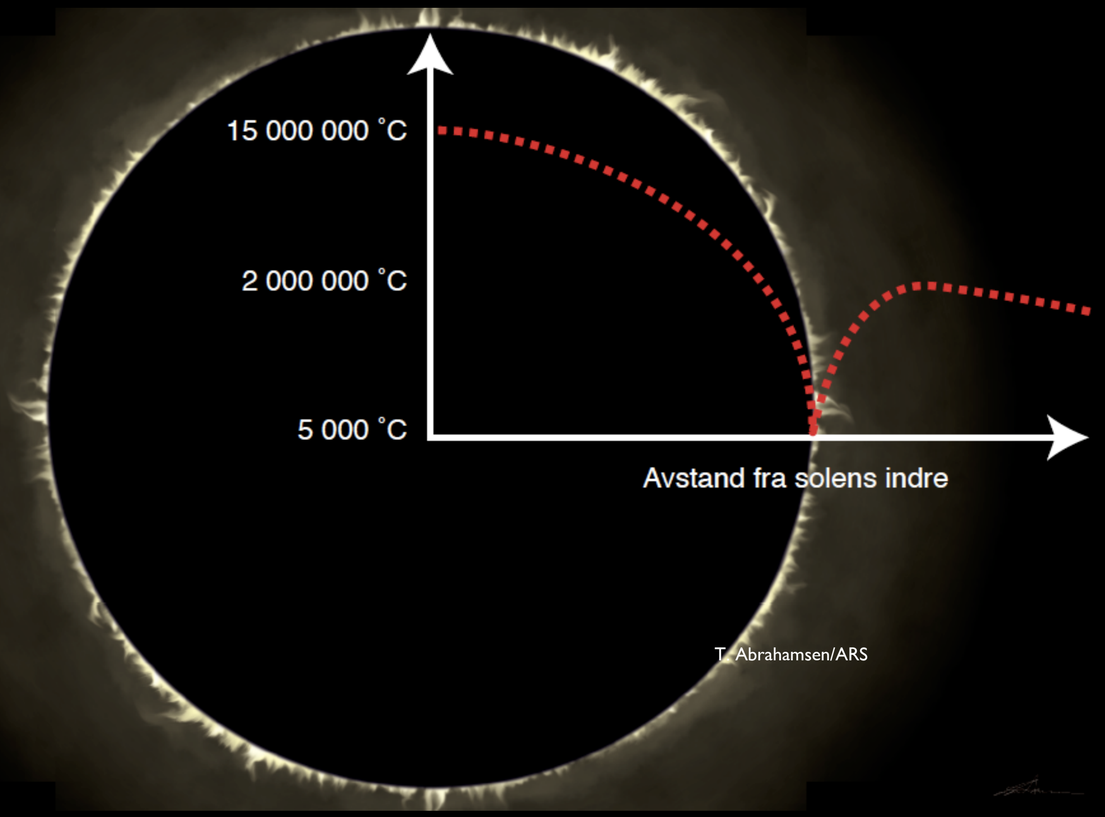
Eyeing the Sun

IRIS takes a close-up look at the solar transition region

pp. 305 & 315

THE OUTER SOLAR ATMOSPHERE – THE CORONA





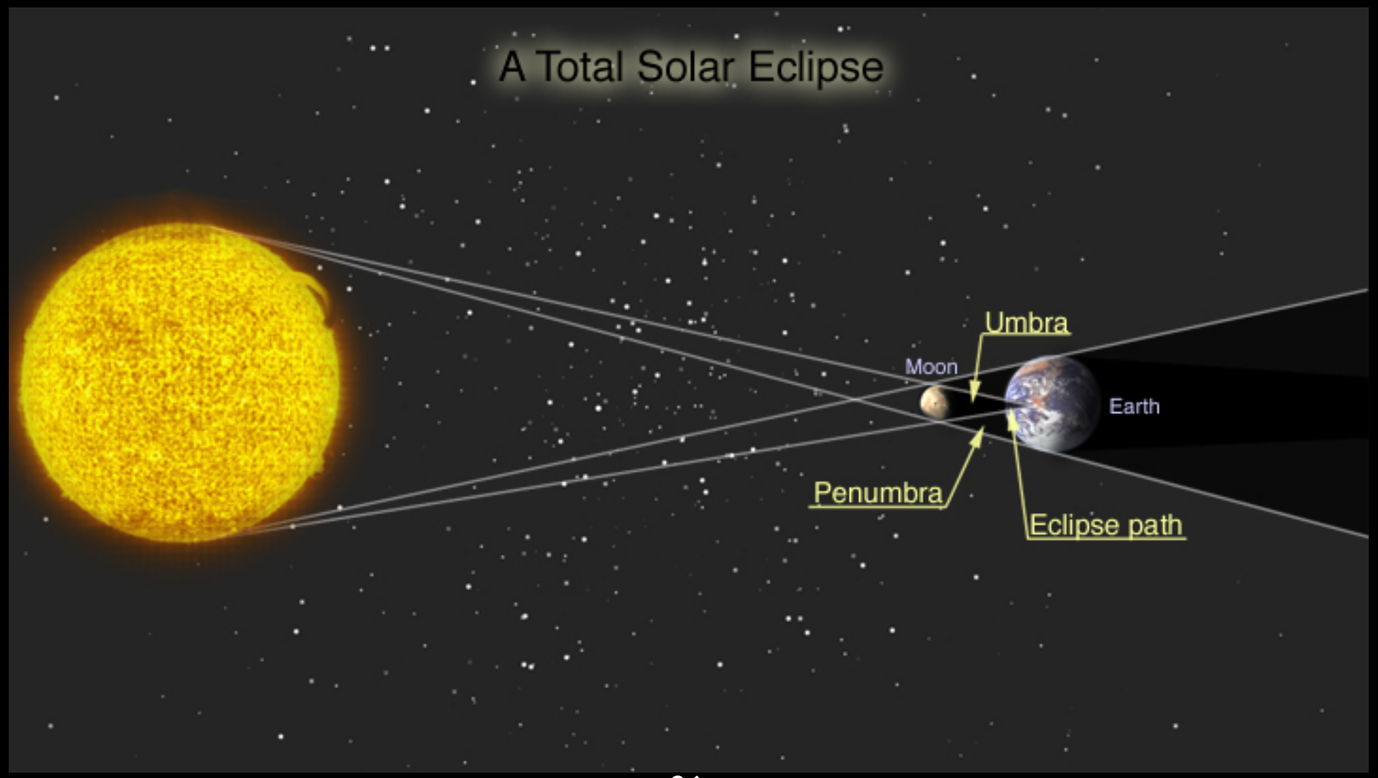
The corona is the outer part of the solar atmosphere and consists mostly of hydrogen gas. The temperature is between 1 and 2 million degrees. The density is very low, less than a millionth of the air density at Earth. The corona emits very little light so it is impossible to see it every day due to the strong light from the photosphere and the scattered light in the Earths atmosphere. Only during a total solar eclipse, when the Moon passes in front of the Sun and blocks the strong light from the photosphere, can we see the spectacular corona with the naked eye. With special telescopes that make artificial eclipses it is possible to study the corona.

SOLAR ECLIPSES

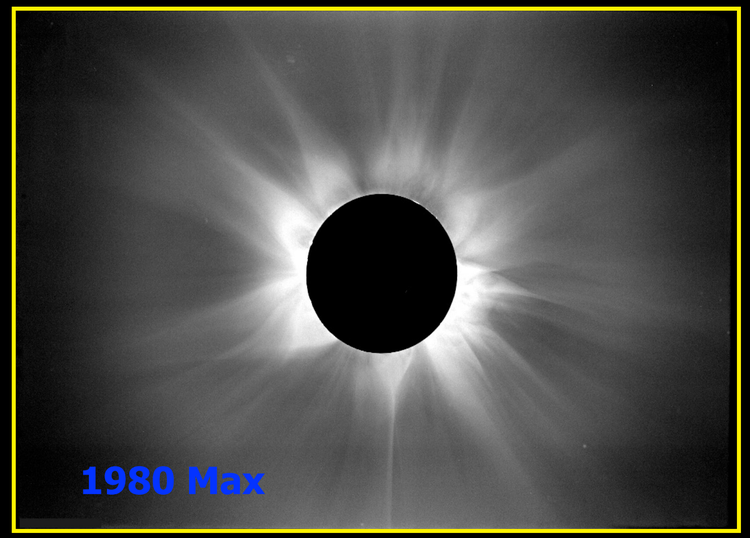
Partial Eclipse

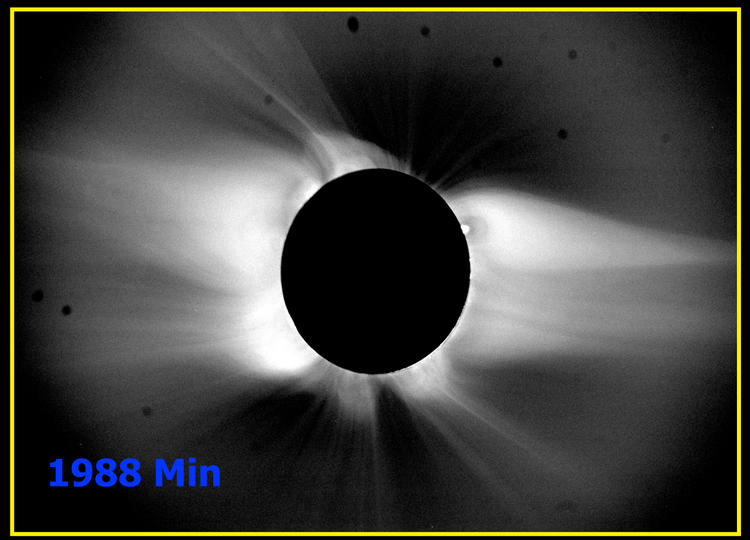
Total Eclipse

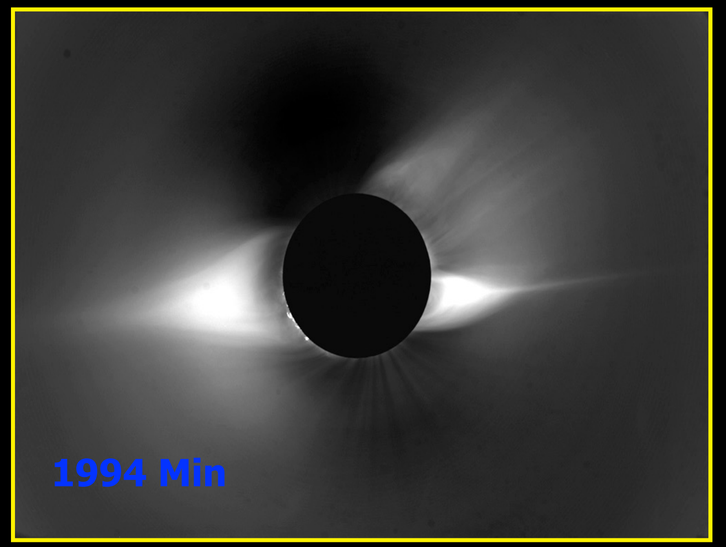
Annular Eclipse



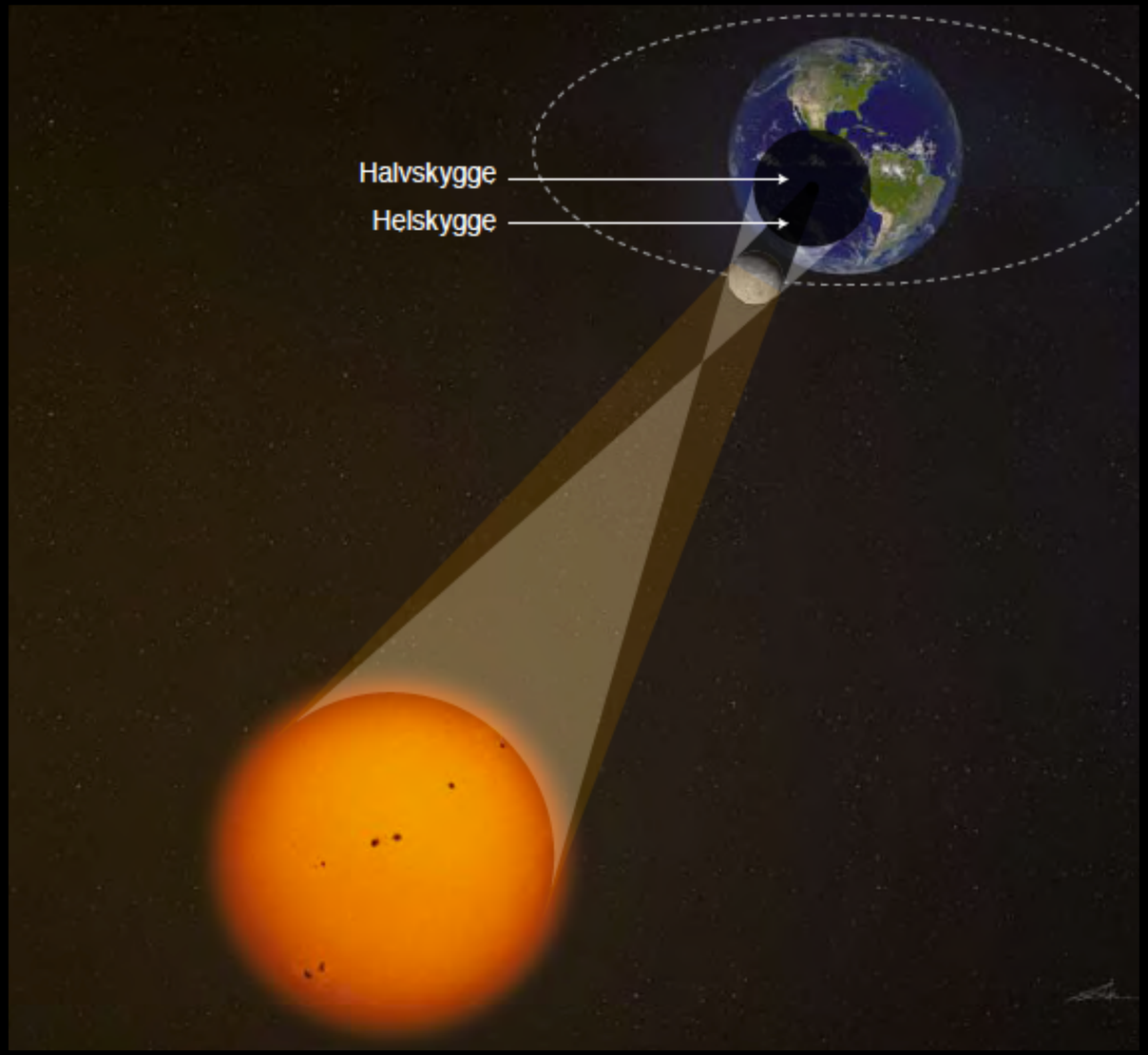
THE CORONA - DURING ECLIPSES

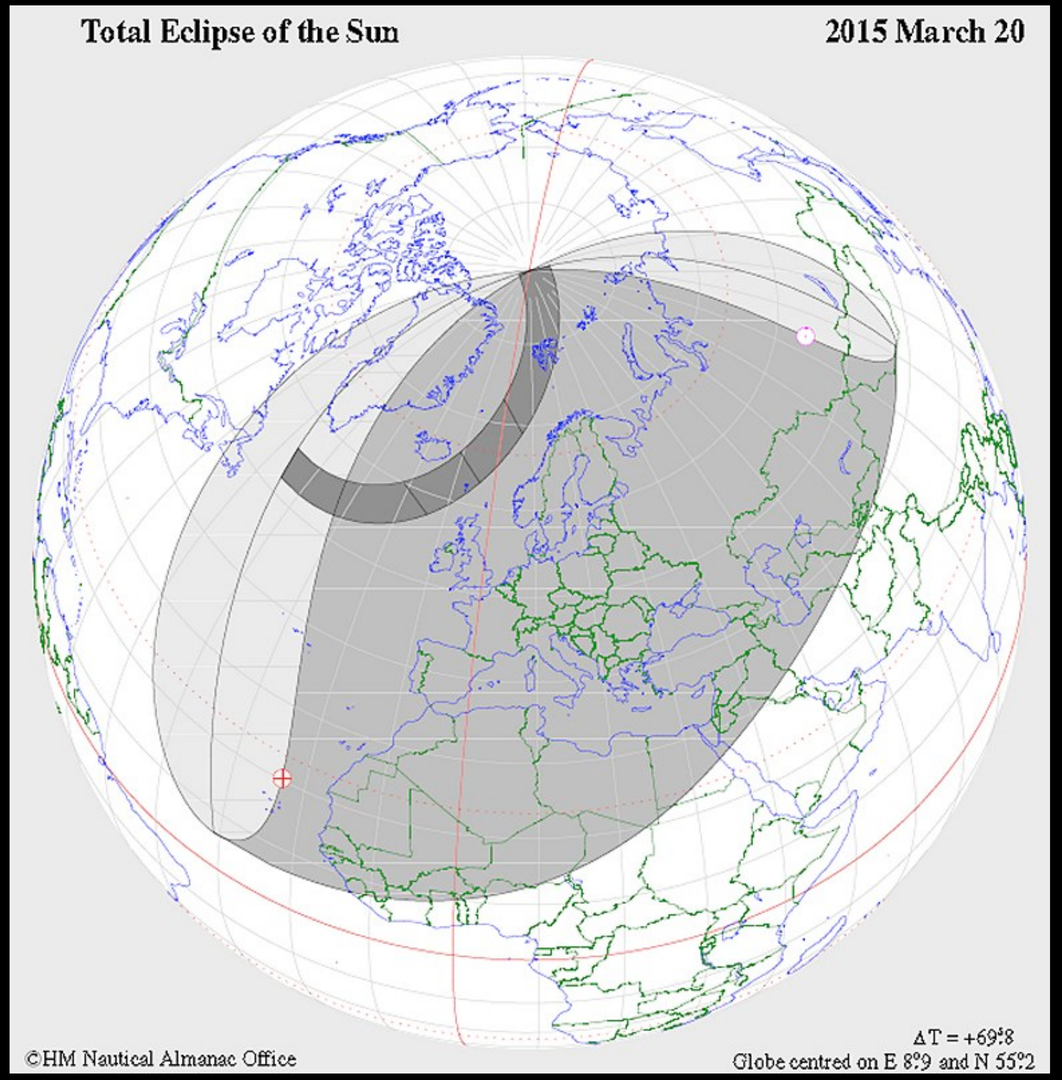






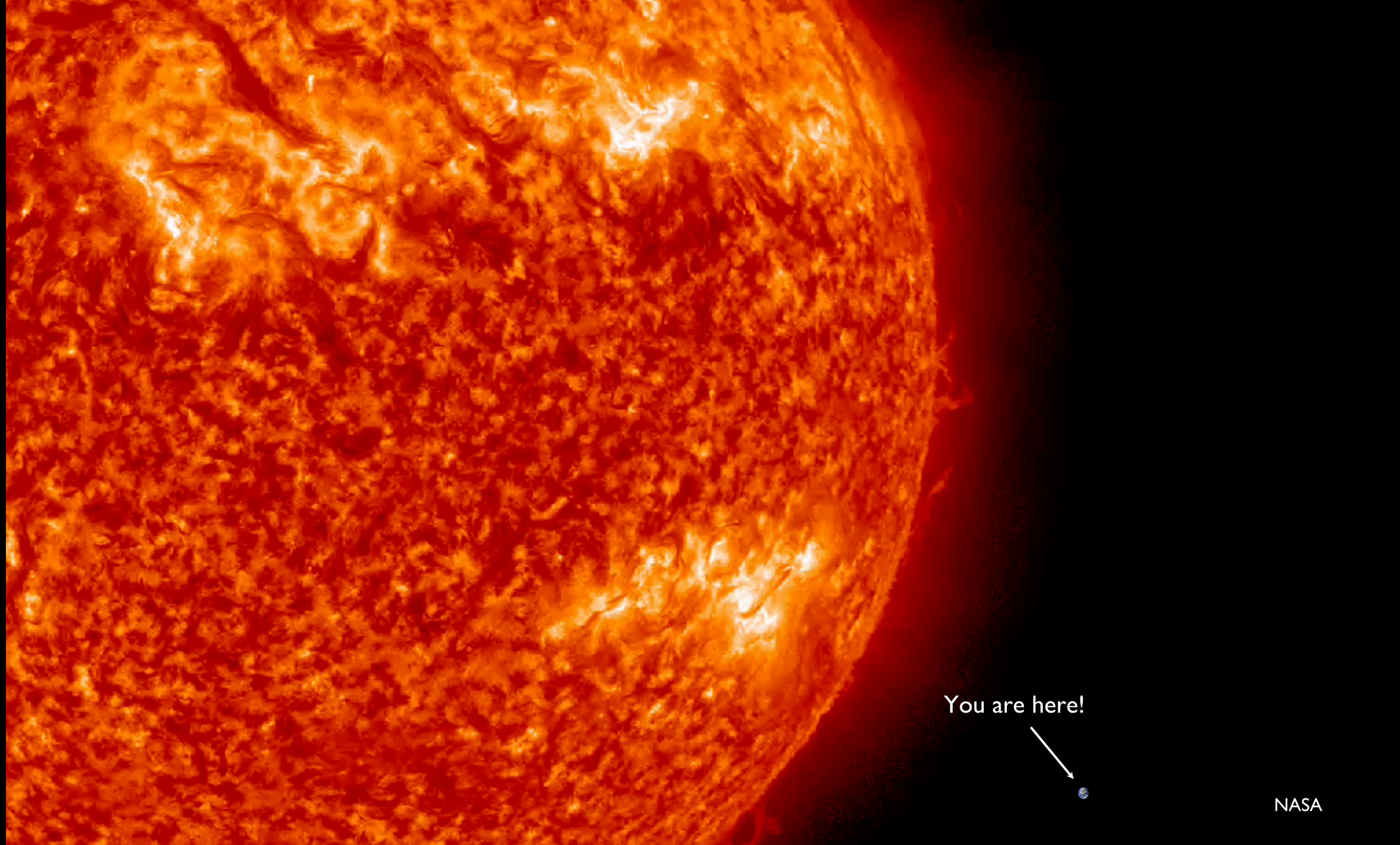
Total eclipse over Svalbard 2015



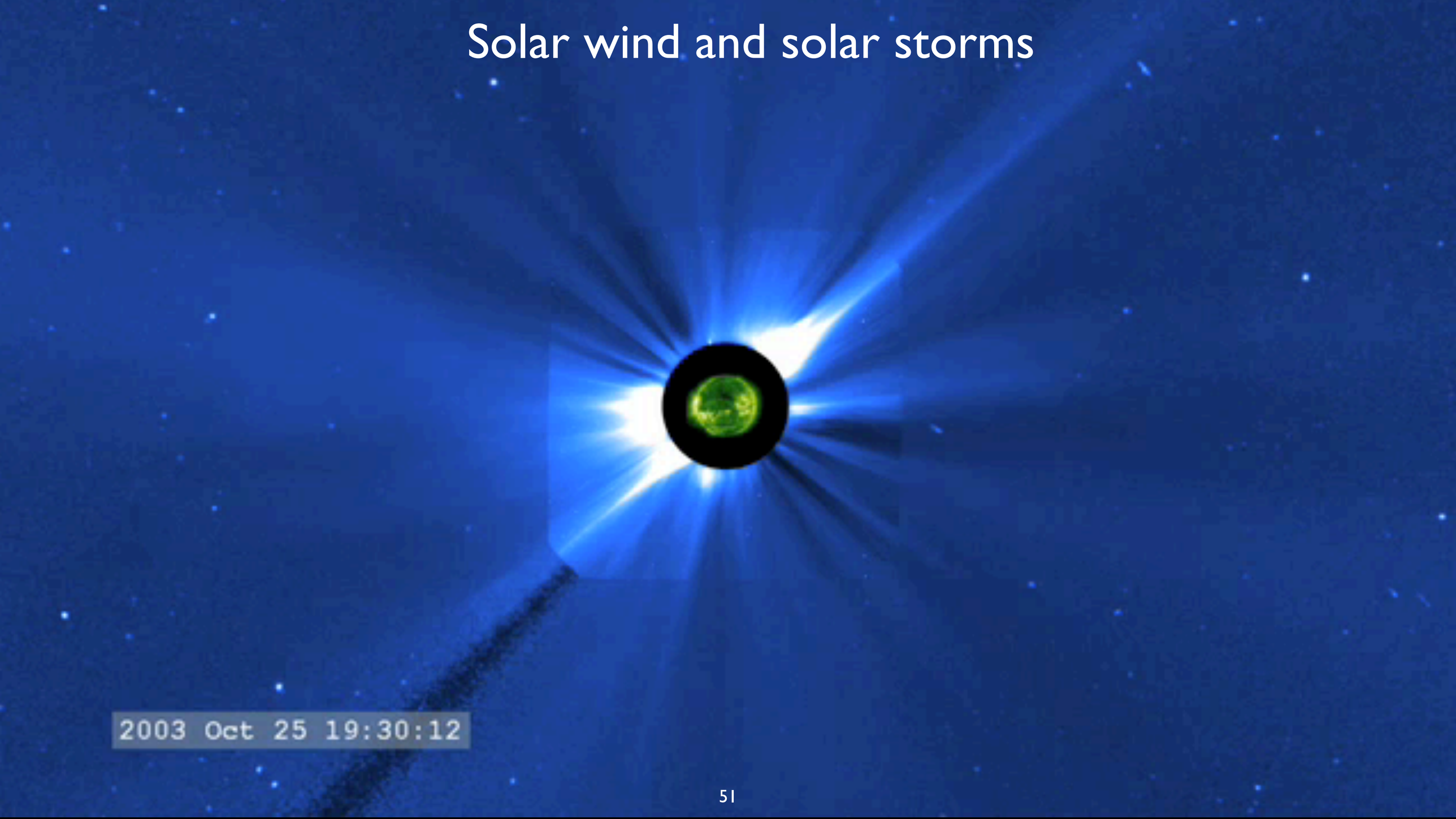


Total Eclipse over Svalbard 20 March

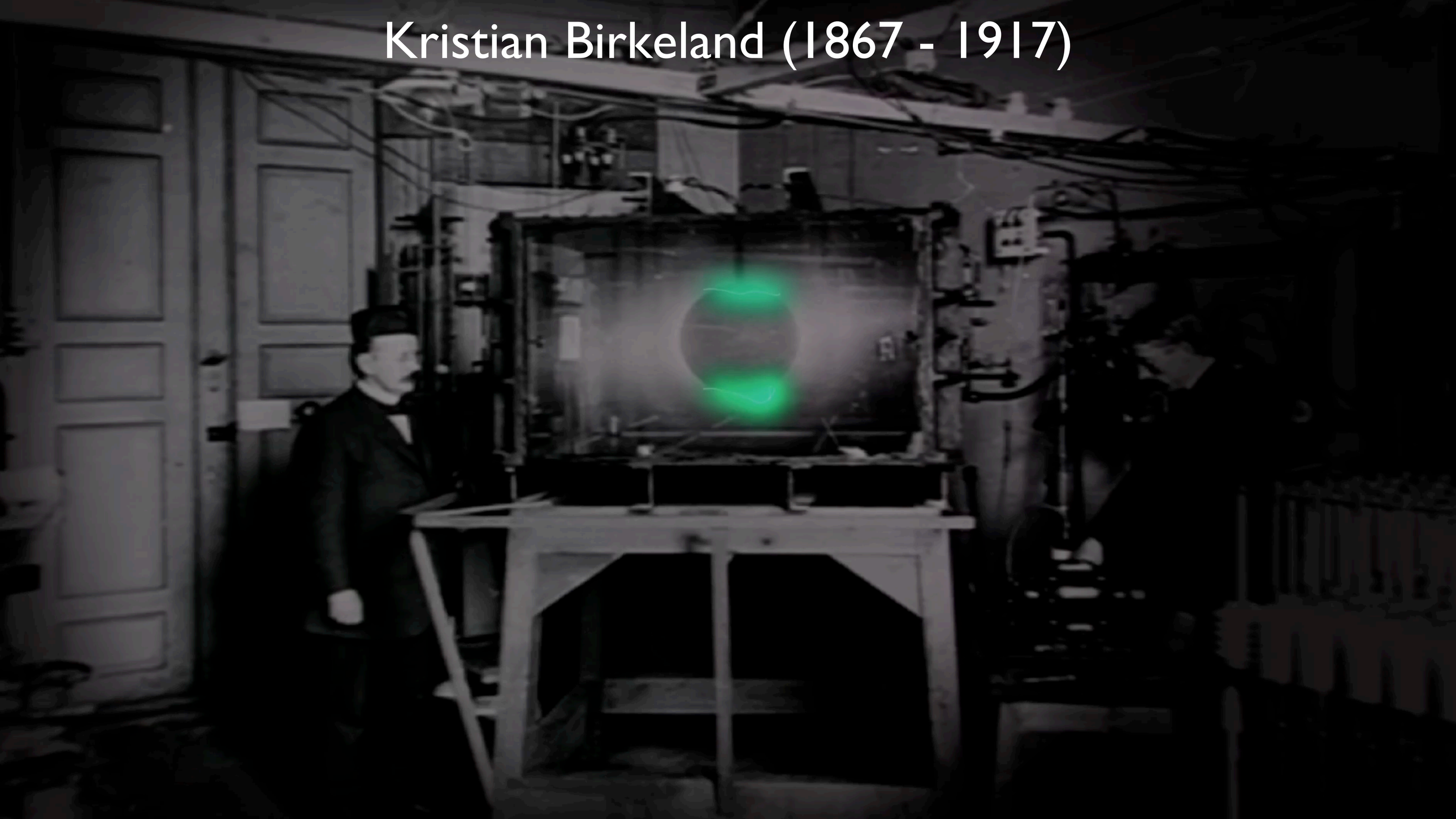
Total Eclise over Svalbard 20 March


You are here!
NASA

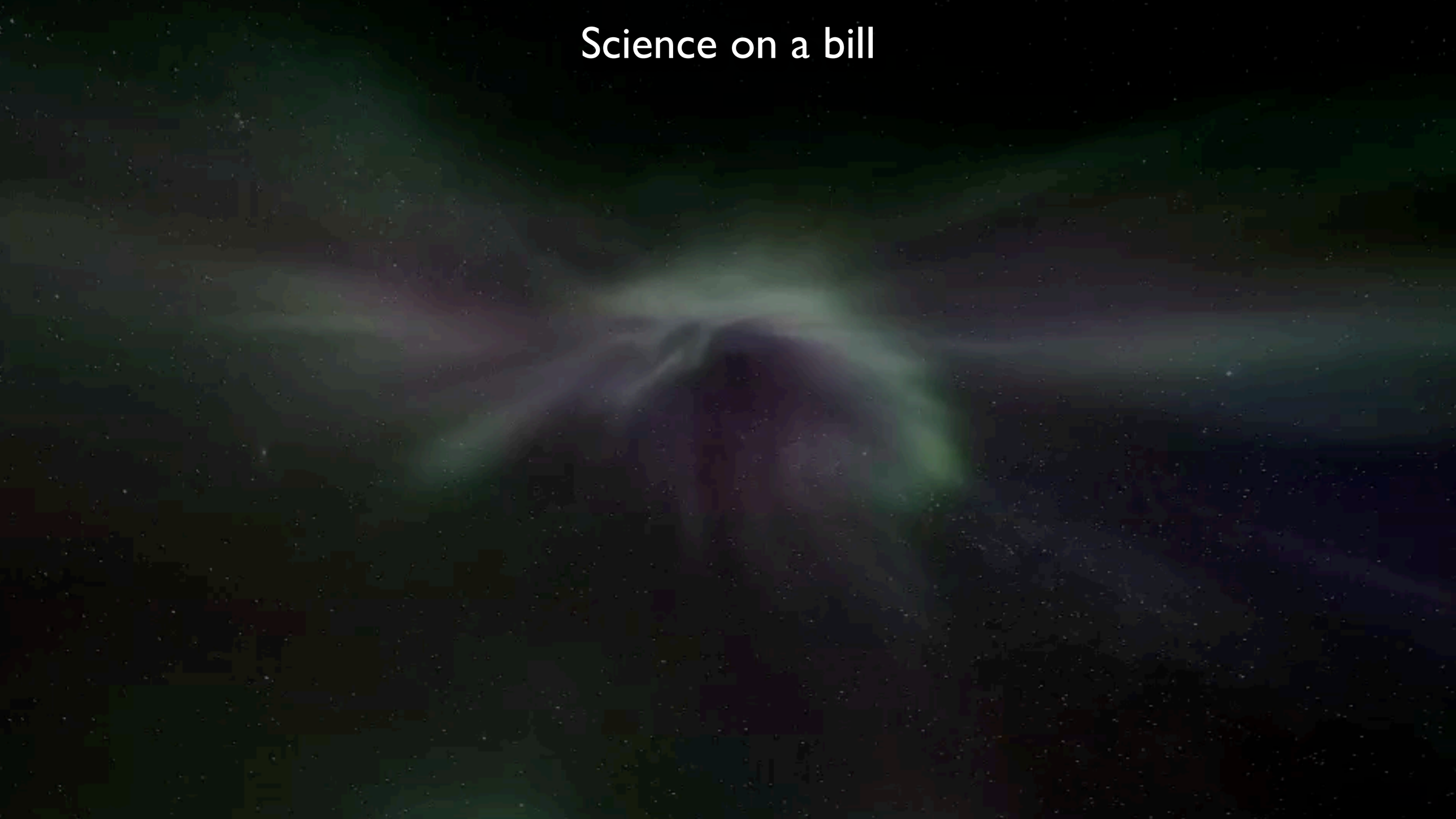
Solar wind and solar storms



Kristian Birkeland (1867 - 1917)



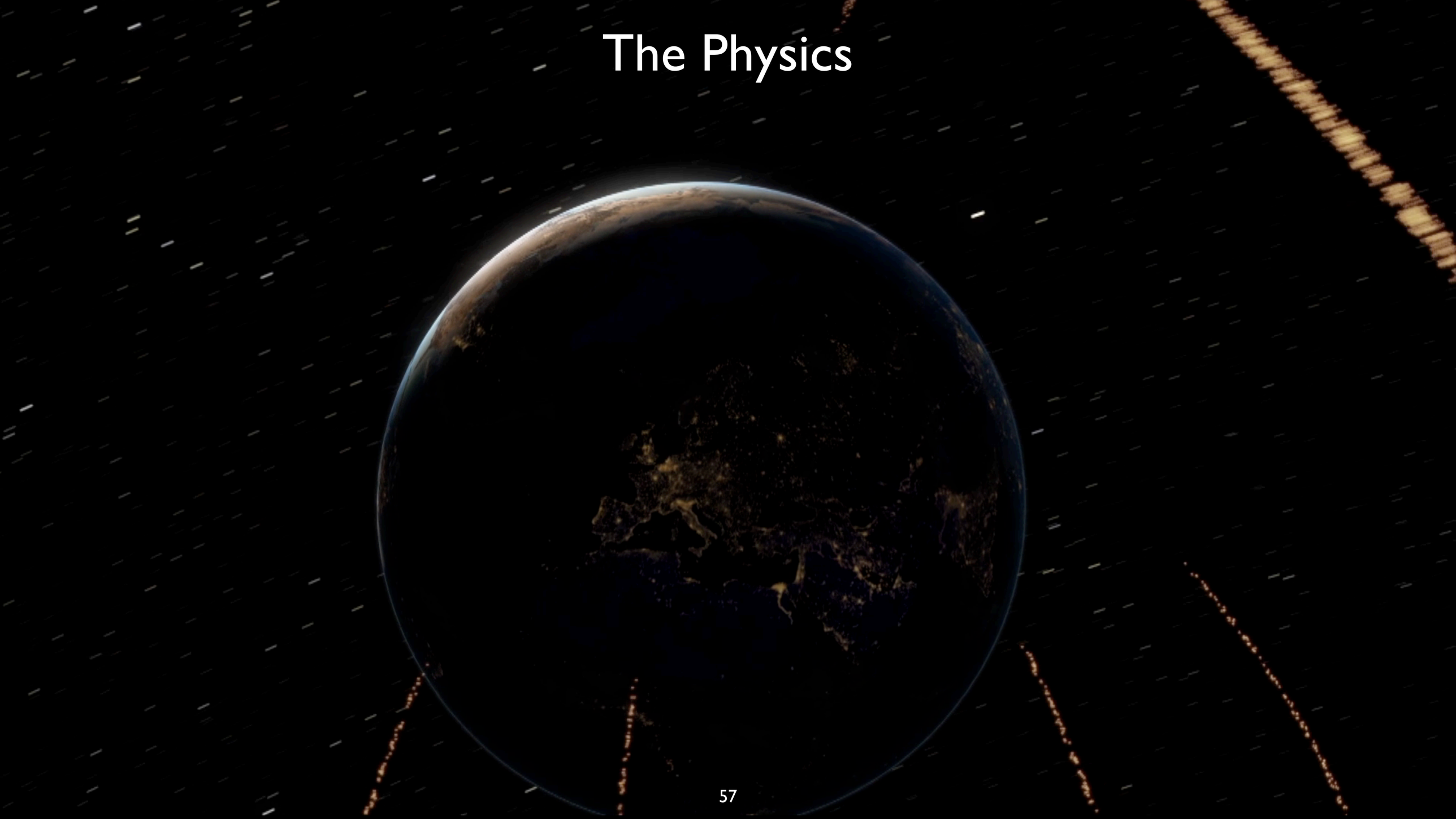
Science on a bill




NORGES BANK
200
TO HUNDRE
KRONER
07002009

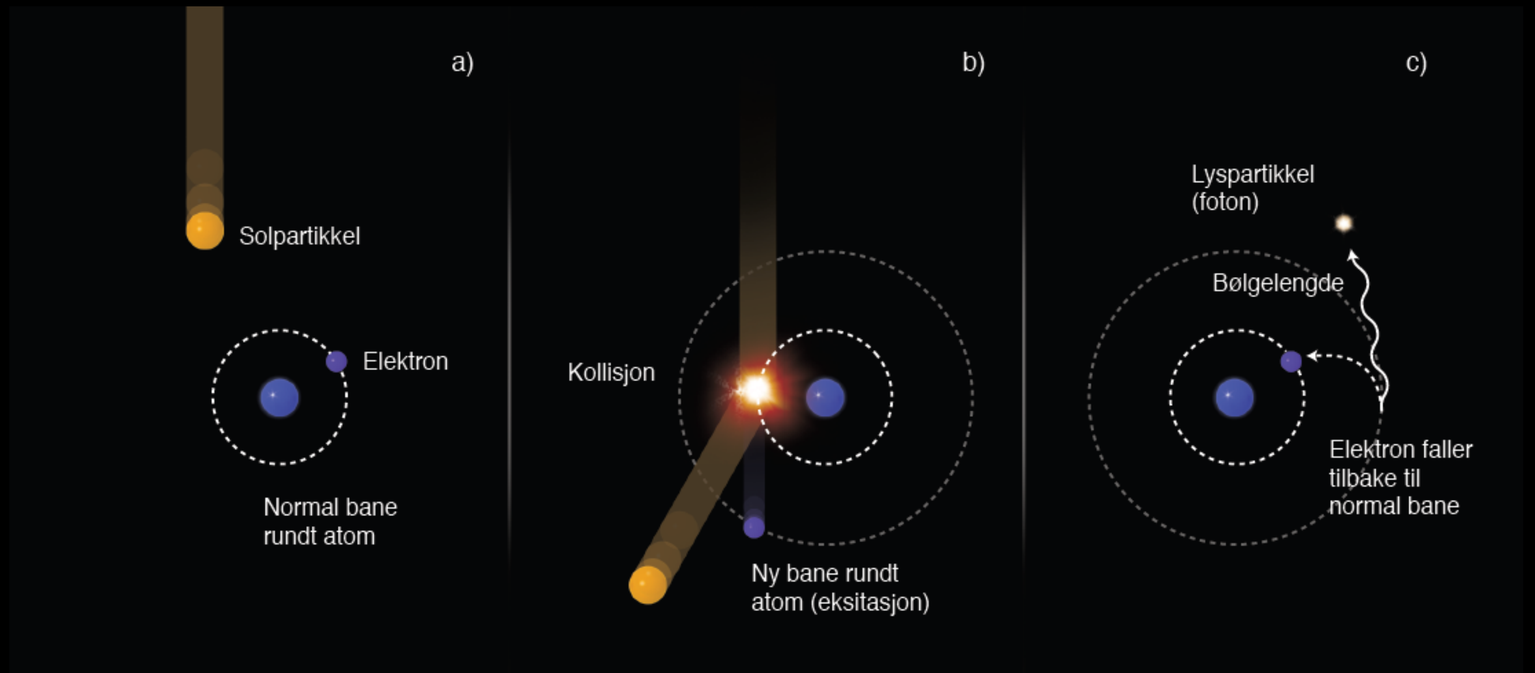
What causes the Northern Lights

The Physics

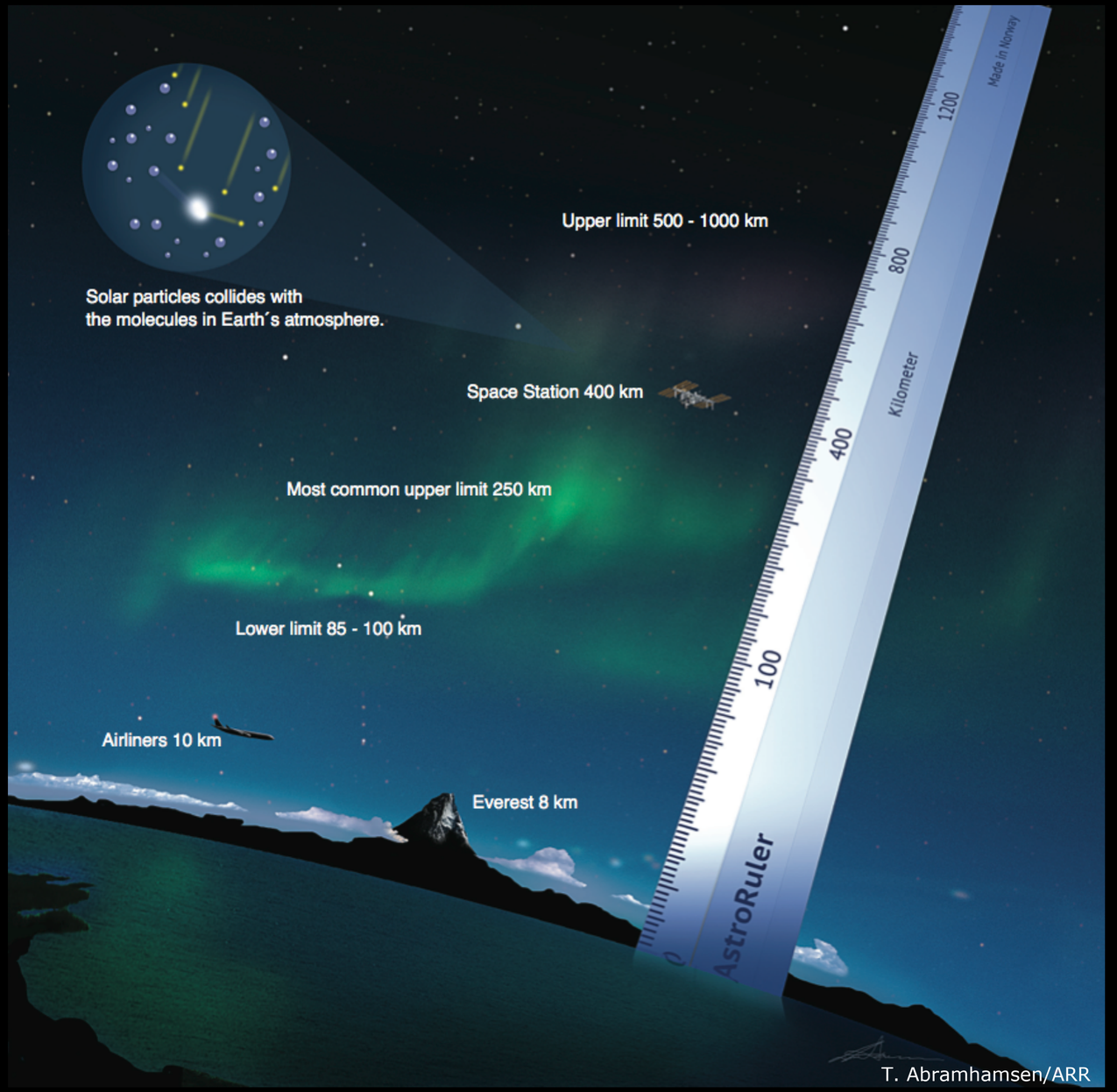


The Colors of the Aurora

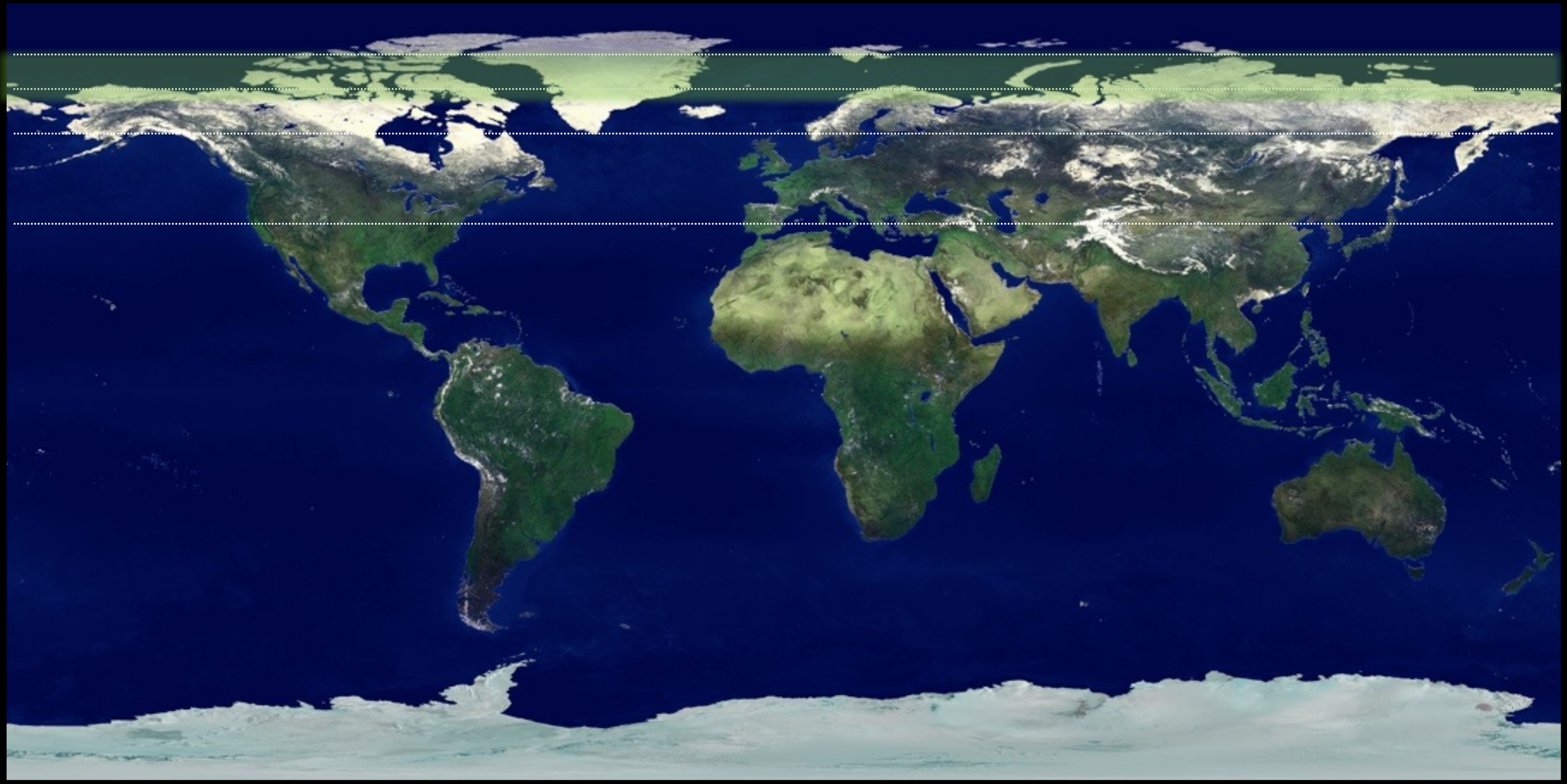
- The light from the Sun appears white but consist of all colors (e.g rainbow)
- The aurora light is composed of distinct colors that comes from certain gases in the Earths atmosphere.
- The colour composition of the aurora is the atmosphere's fingerprint.



The Height of the Aurora



Why Norway is the best place to see the Aurora



Modern Science Infrastructure

Poker Flat, Alaska

Kiruna Sweden

NORTH POLE

SVALBARD

Nobile Amundsen SBC

SvalRak

HOPEN

BJØRNØYA

Fiber-optical Cable

TROMSØ

Andøya Rocket Range

Circumpolar flights

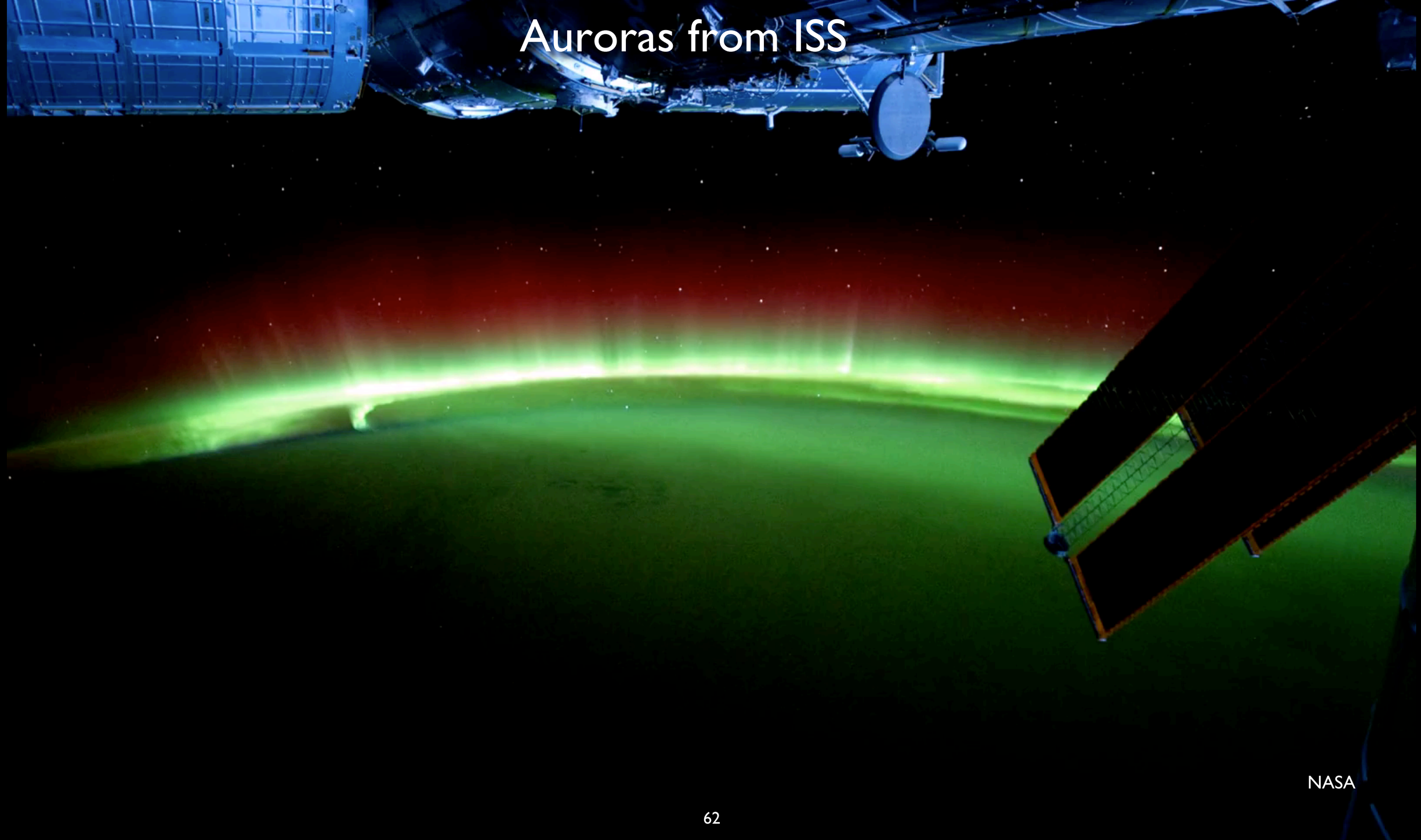
Impact Area

JAN MAYEN

GREENLAND

NORWAY

Auroras from ISS

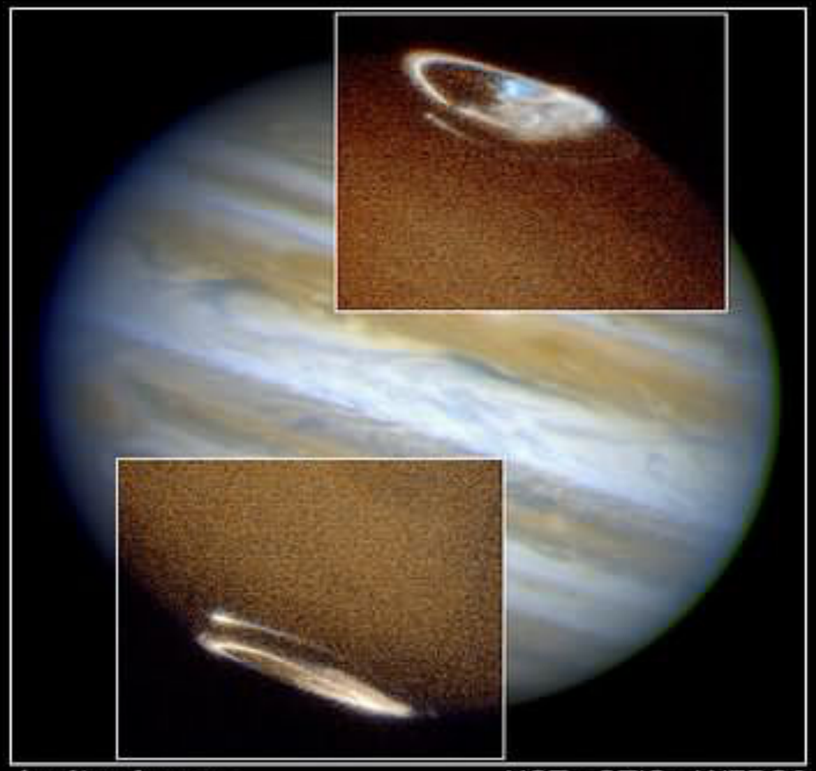


NASA

Aurora on other Planets

- Just like the northern and southern lights on earth, auroras also occur on other planets which have an atmosphere and a magnetic field.
  - In modern times auroras have been observed on several celestial bodies, such as, Earth, Saturn, Titan, Triton, Jupiter, Io, Uranus and Neptune.

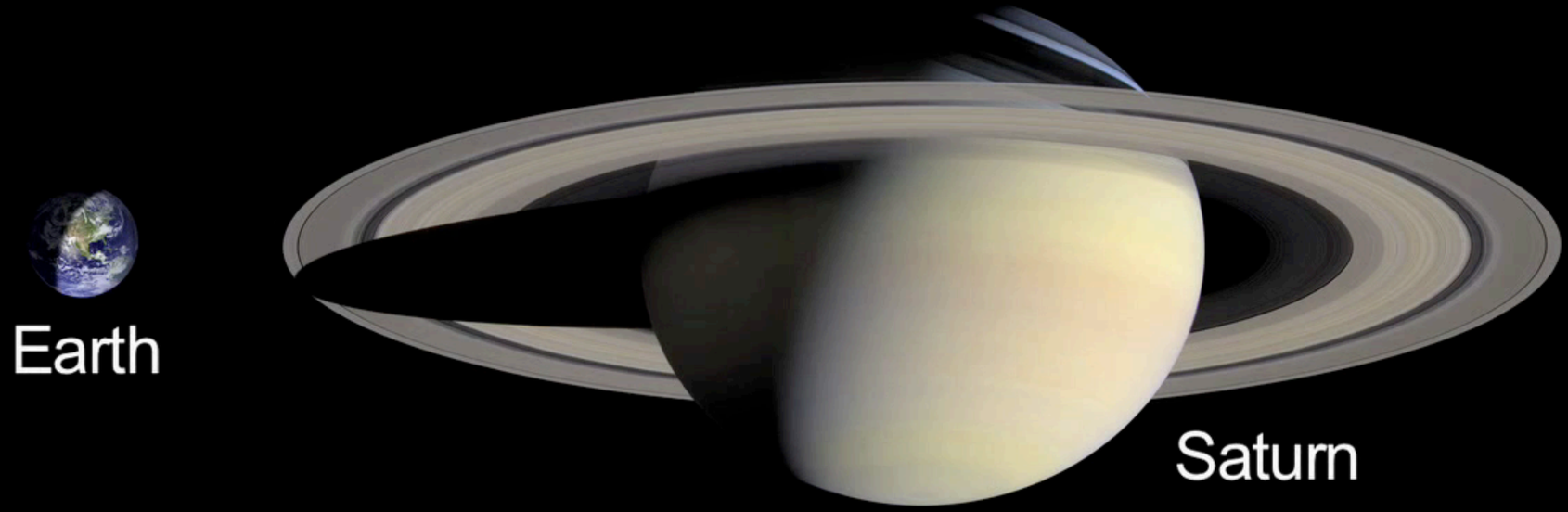
Aurora on Saturn
Credits: Hubble Space Telescope



Jupiter Aurora HST • STIS • WFPC2

PRC98-04 • ST ScI OPO • January 7, 1998
J. Clarke (University of Michigan) and NASA

Aurora on Saturn



(Actual relative sizes)

NASA

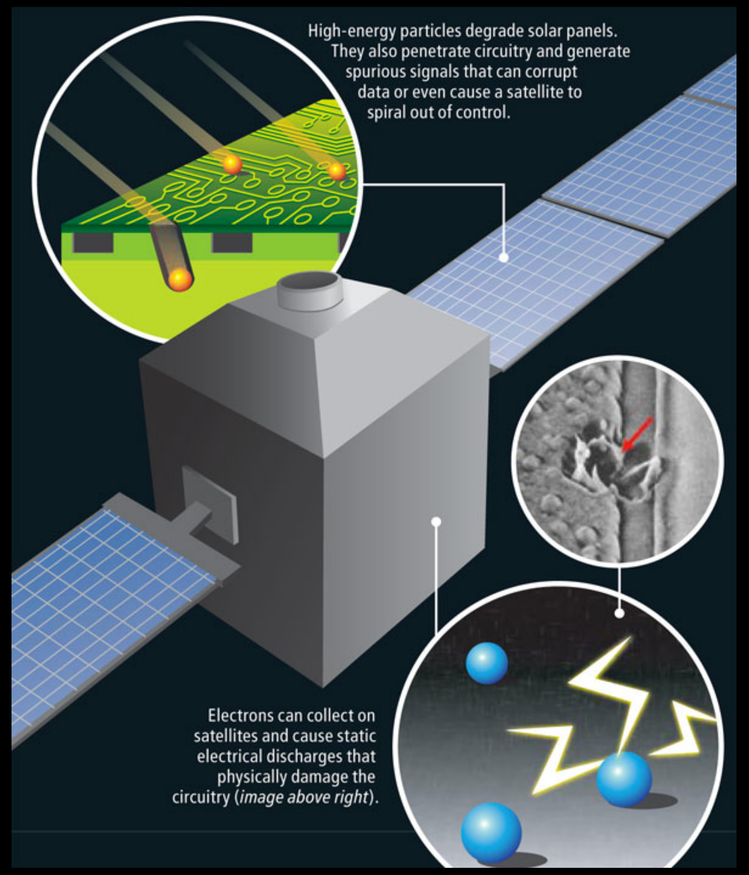
Space Weather

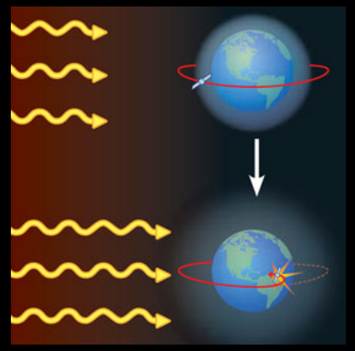
NASA

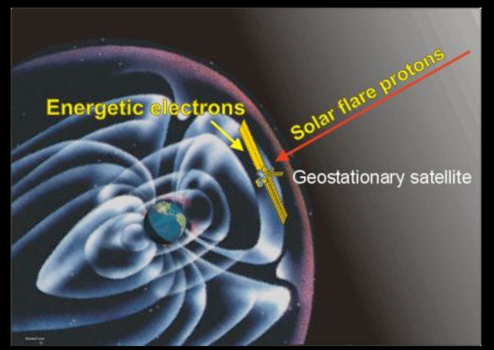
Effekter på satellitter

Eksempler på effekter:

- Overflateladning
- Single Evente Upset (fra høyenergetiske partikler
- Økt friskjon (Drag)
- Interferens og scintillasjon av signalet
- Romsøppel
- Orienteringsproblemer
- Støy på stjernetrackere/navigasjonssystemer
- Degradring av materialer/solpaneler
- Treff fra mikrometeoritter



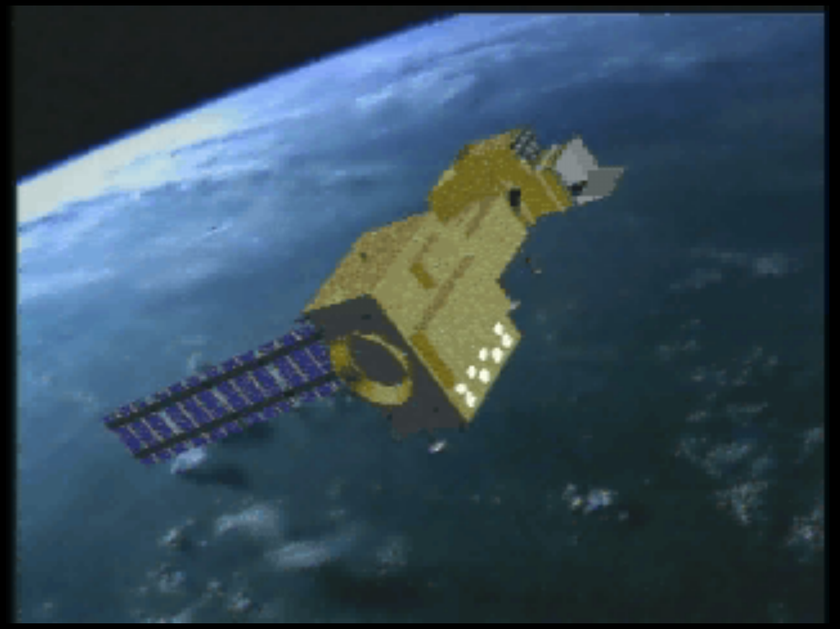


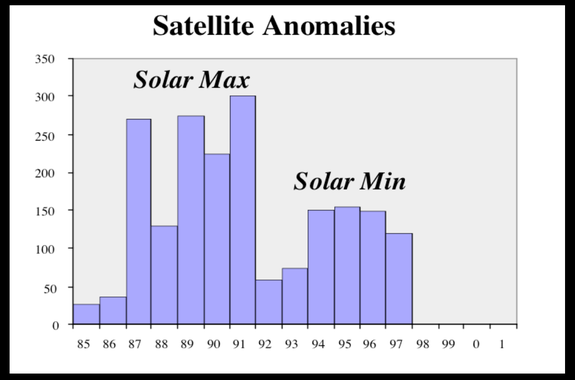


Damage to satellites

Some examples

- Telestar 401 (Jan 11 1997)
- Galaxy IV (1998) – cost 250 mill USD
  - 80% of all pagers in USA failed
  - PC-Direct (internet)
  - CBS's radio and TV feeds
  - CNN's Airport Network
- A number of satellites are damaged
- Annual loss can reach $500 millions

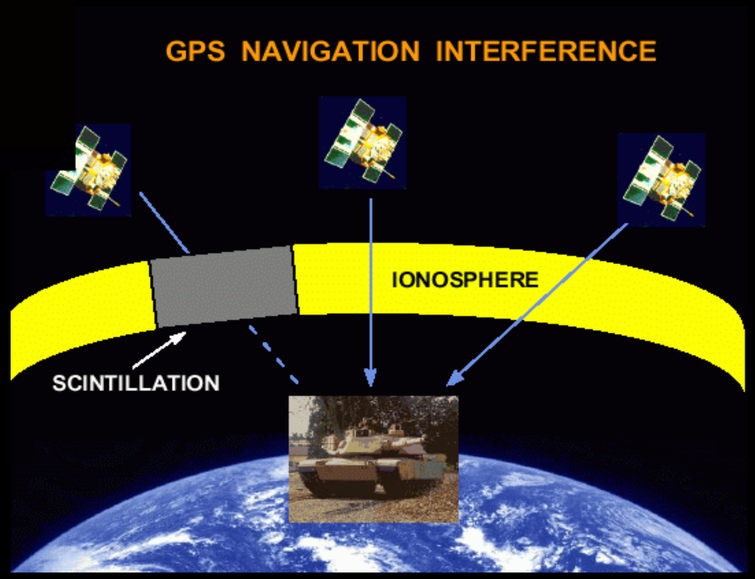


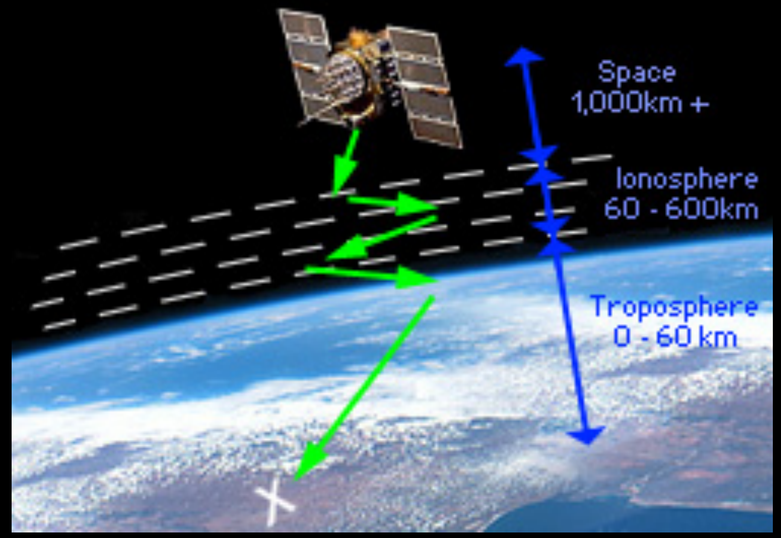


Navigation systems (GPS)

- Turbulence in the ionosphere causes scintillation in the satellite signal and can disrupt the reception.
- Total amount of electrons (TEC) along the path of the signal can introduce errors up to 100 meters.

- Radio bursts can «jam» the signals.



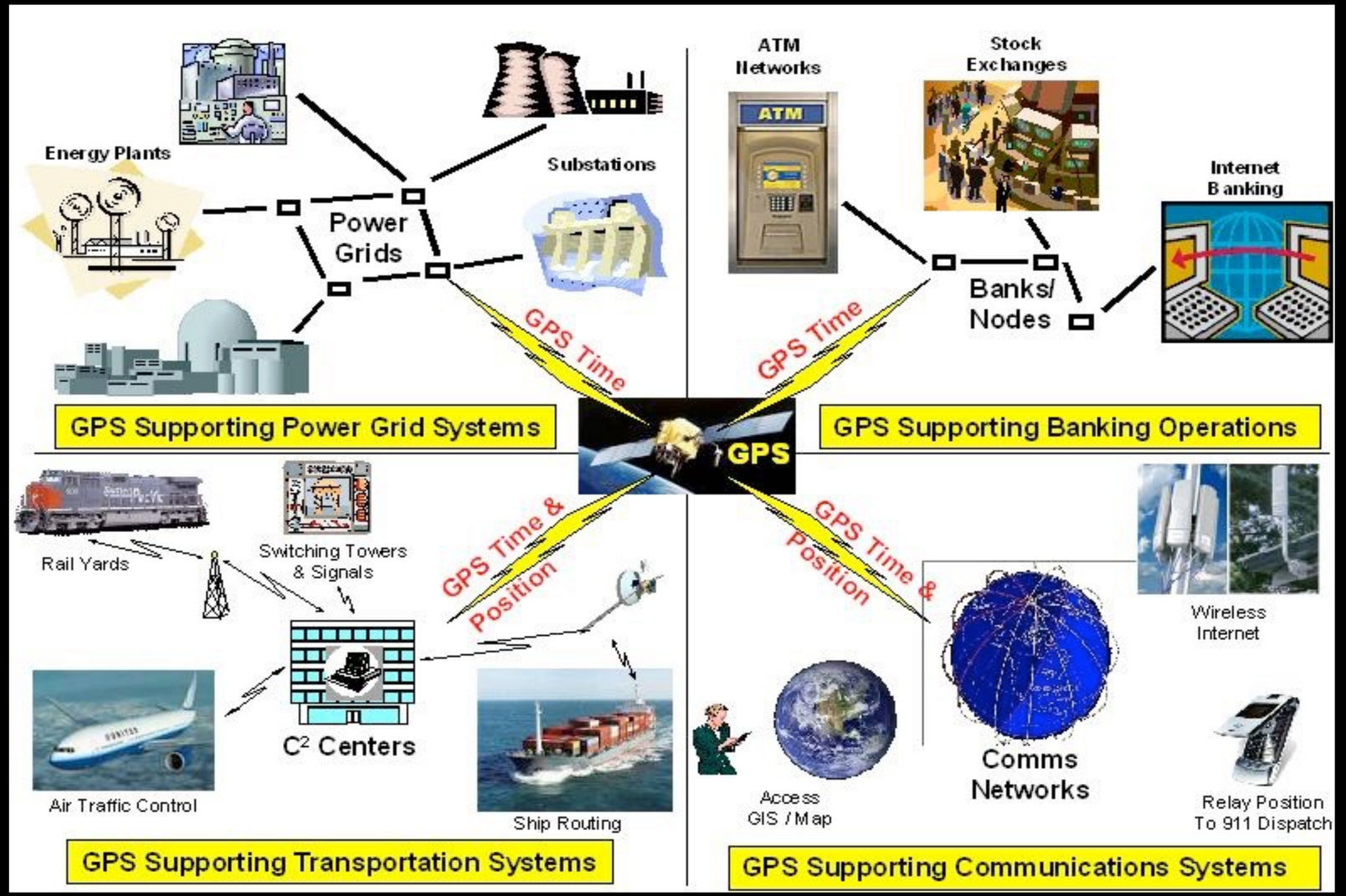


Some don´t care about GPS accuracy

For others it is critical

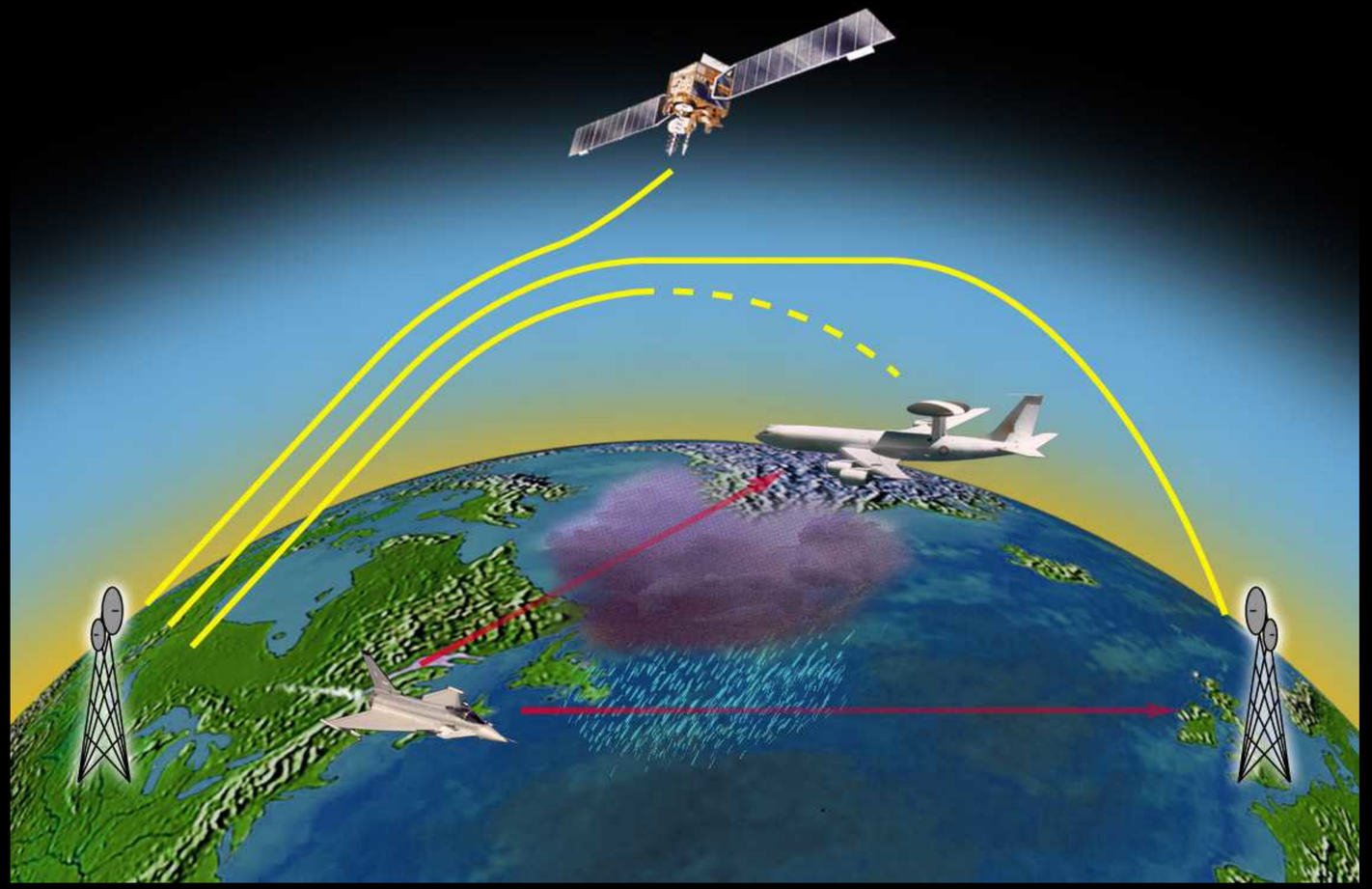
- Errors in GPS based systems can be a serious problem.

Extent of GPS Dependencies



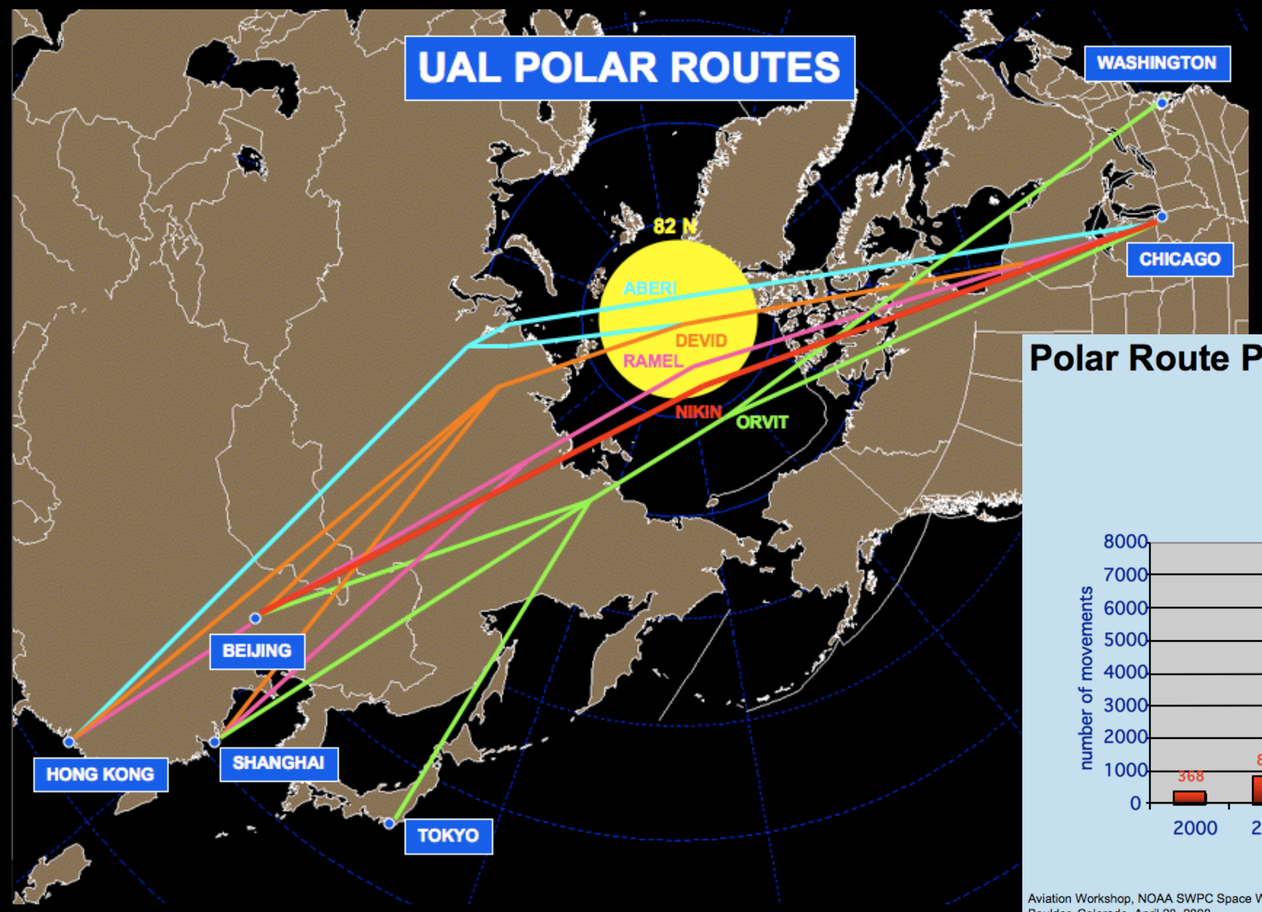
K. VanDyke, DOT

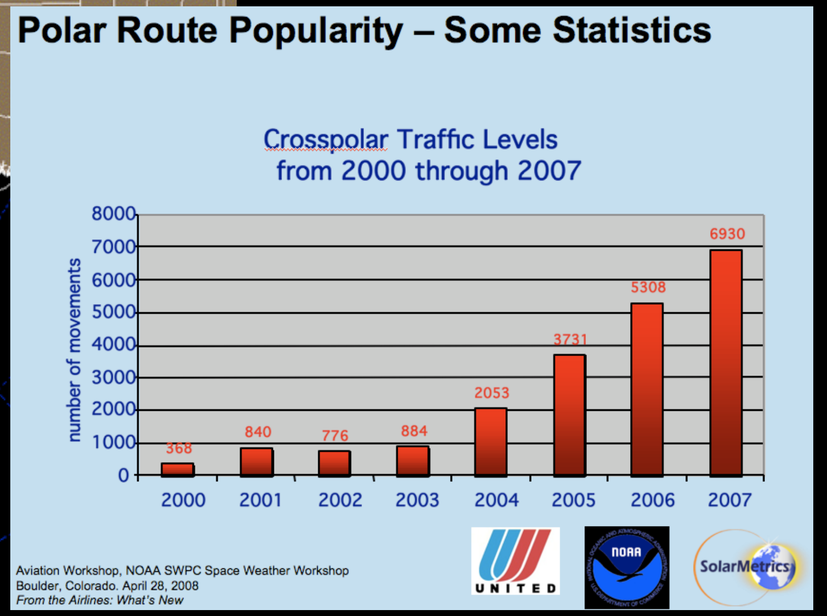
Radio communication i polar regions difficult



Effects on Aviation

- Polar routs: ca 8000 flights per year in 2800.
- No satellite communication works north of 82 degree N.

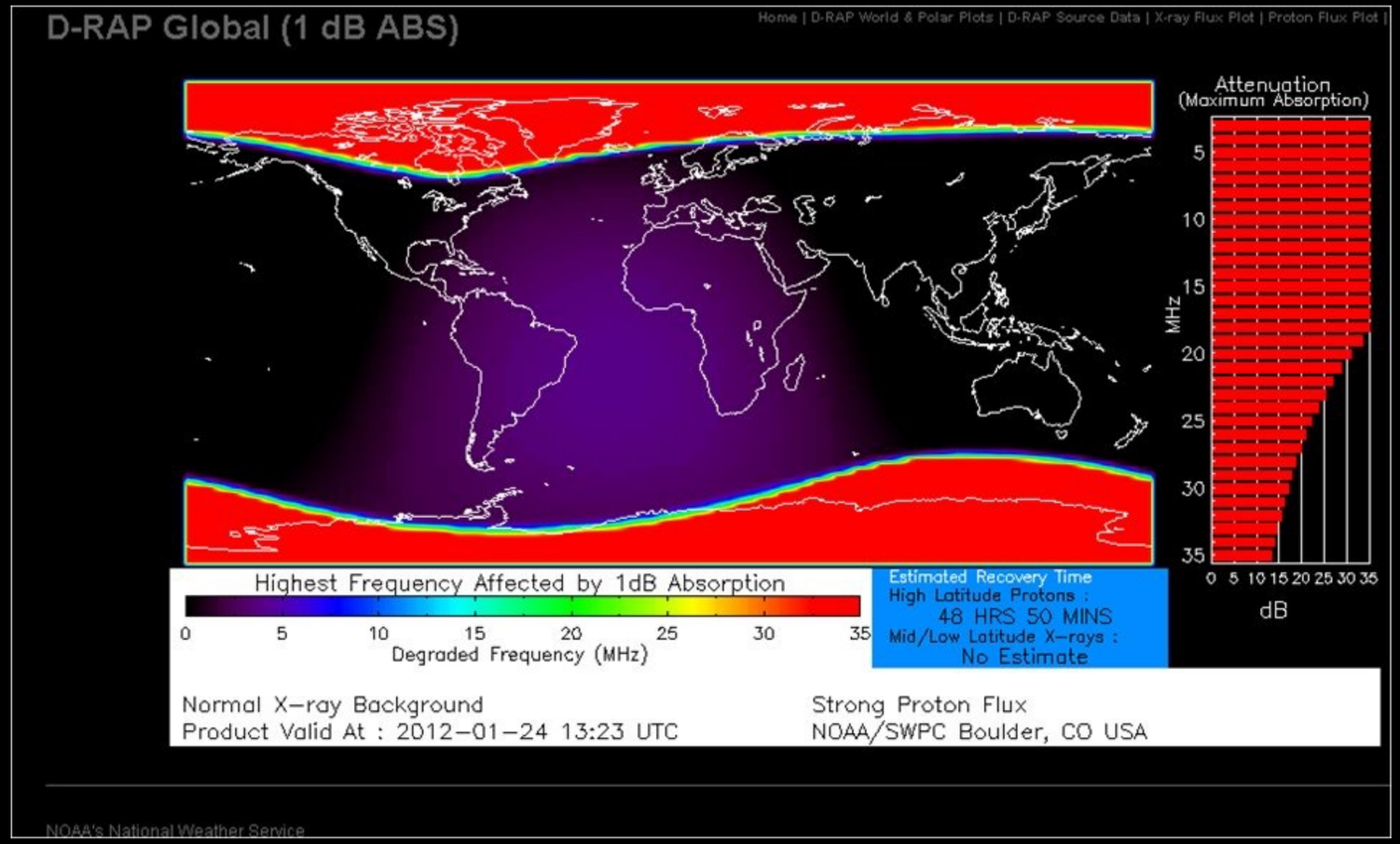




M.Stills, United Airlines

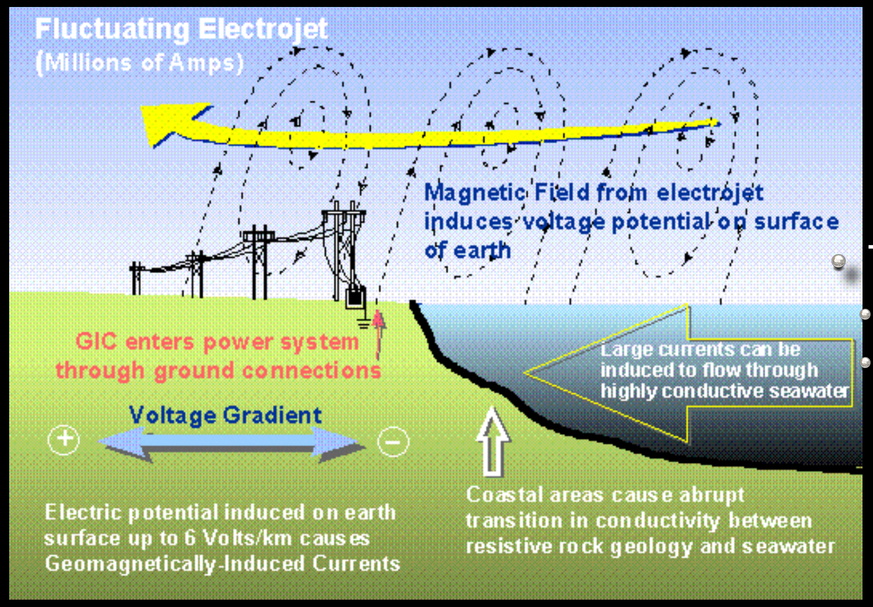
Flights were diverted

- Delte Airlines and United diverted some of their polar flights to avoid radio communication problems and increased radiation doses for the crew.
- The South pole was without radiocommunication for two days (where satellite communication is unavailable).



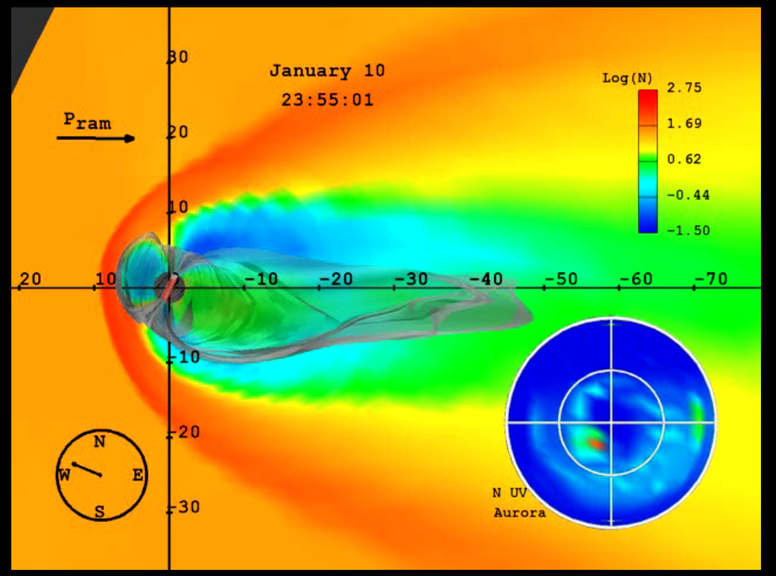
This graphic shows the energetic particles entering the D-region of the ionosphere. SWPC forecasters use this product to show where the energetic particles are entering and to give a visual to what is currently happening here at Earth. The red that can be seen at the poles is where the energetic particles enter and where airliners and spacecraft, should try to avoid.

Disruption of power grids



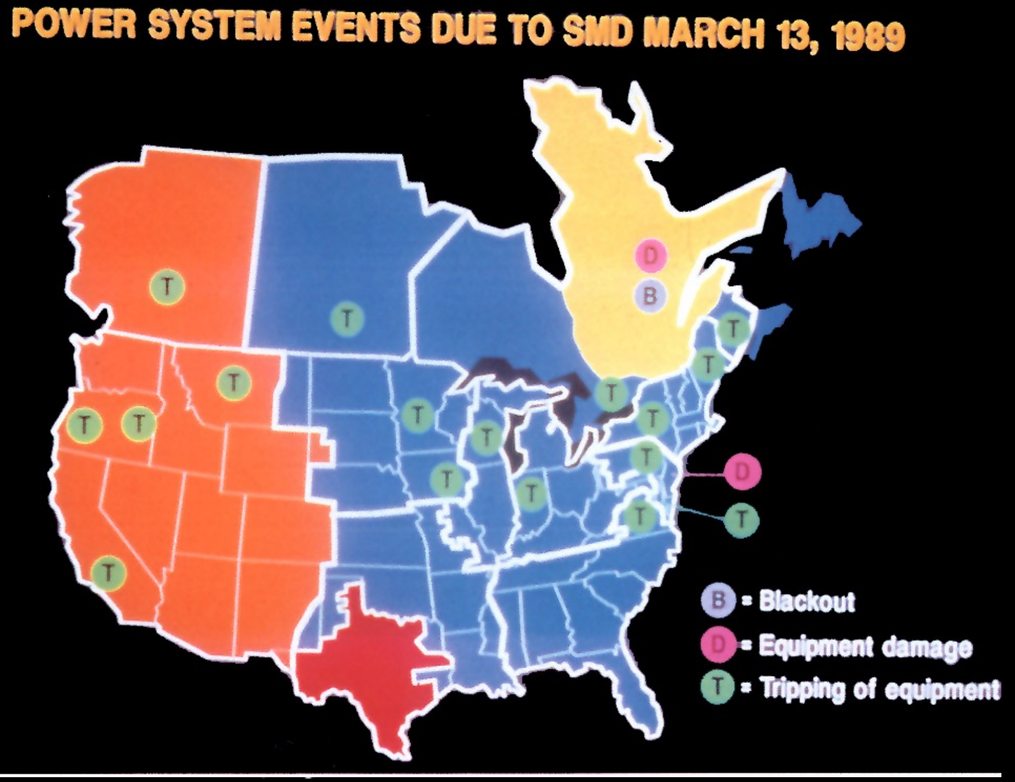
These currents leaks into all lang conductors:

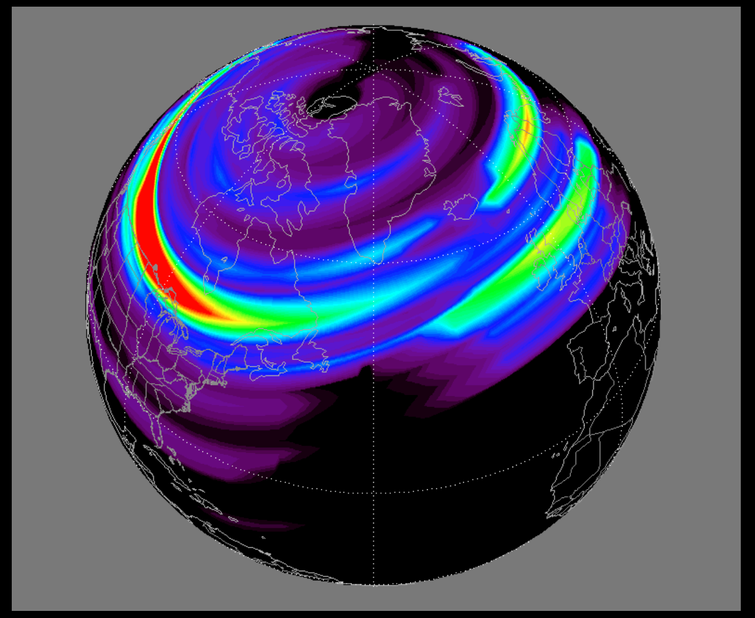
- Power grids
- Oil- and gas pipelines



Power failure March 1989

- The entire power grid in Quebec collapsed
- The collapse almoste spread into the NE USA
- Such a collapse would have had en estimated $3-6 billion impact on the US economy.

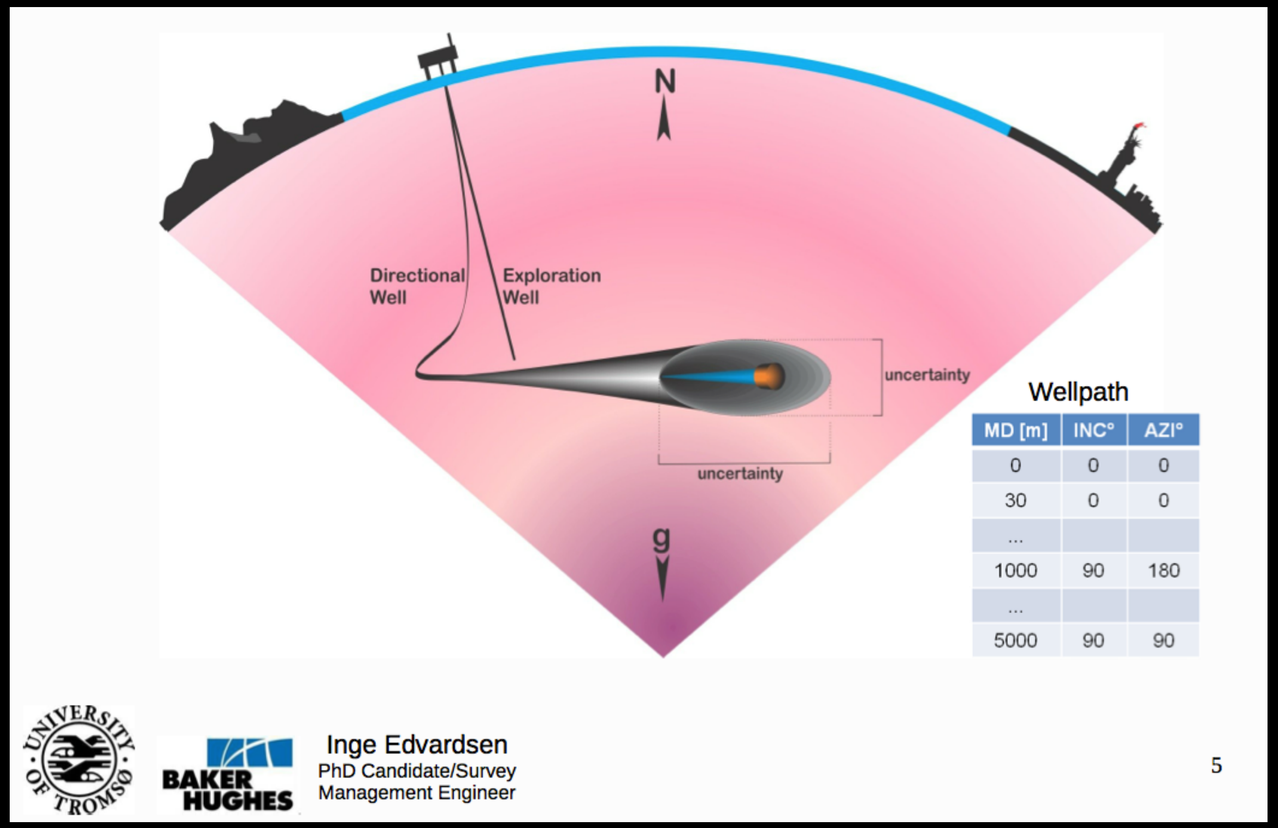




Directional drilling

Directional drilling

- Oil industry relies on geomagnetic maps to guide the drill and monitor the well direction.



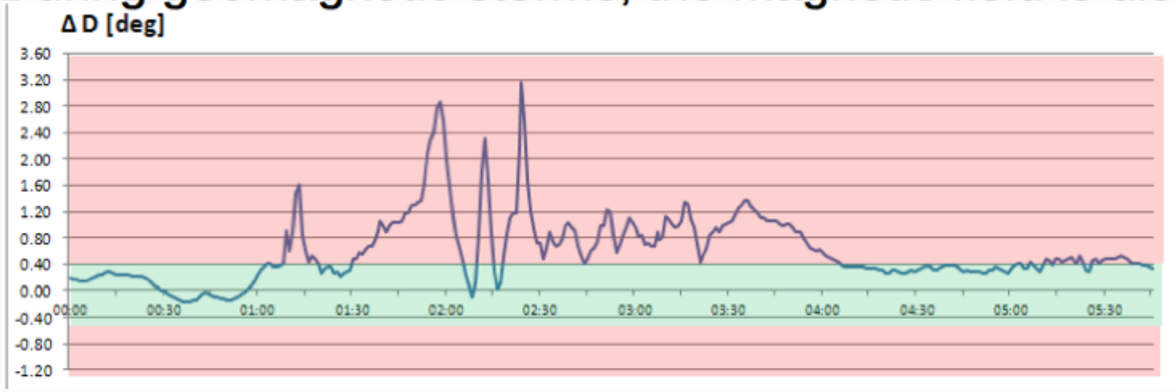
Wellpath

MD [m]	INC°	AZI°
0	0	0
30	0	0
...		
1000	90	180
...		
5000	90	90

Inge Edvardsen
PhD Candidate/Survey Management Engineer

Directional drilling

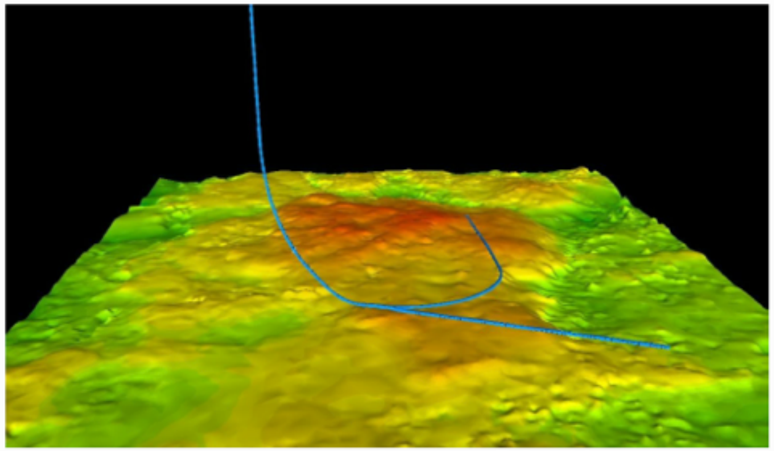
During geomagnetic storms, the magnetic field is disturbed:



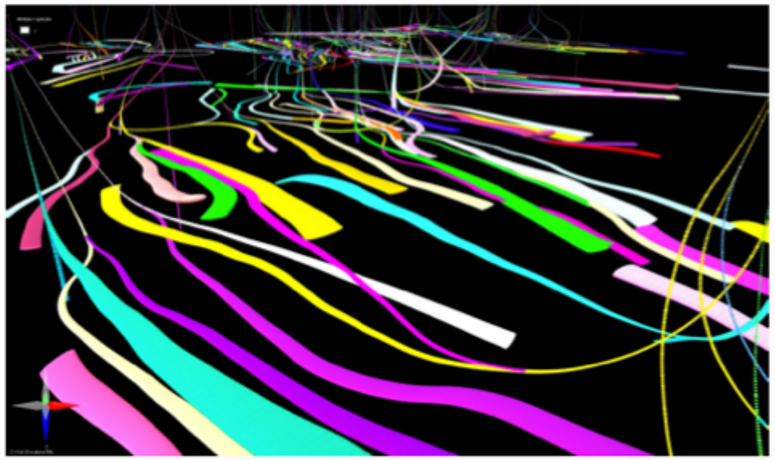
Error in compass needle direction

This has to be monitored and corrected for in order to:

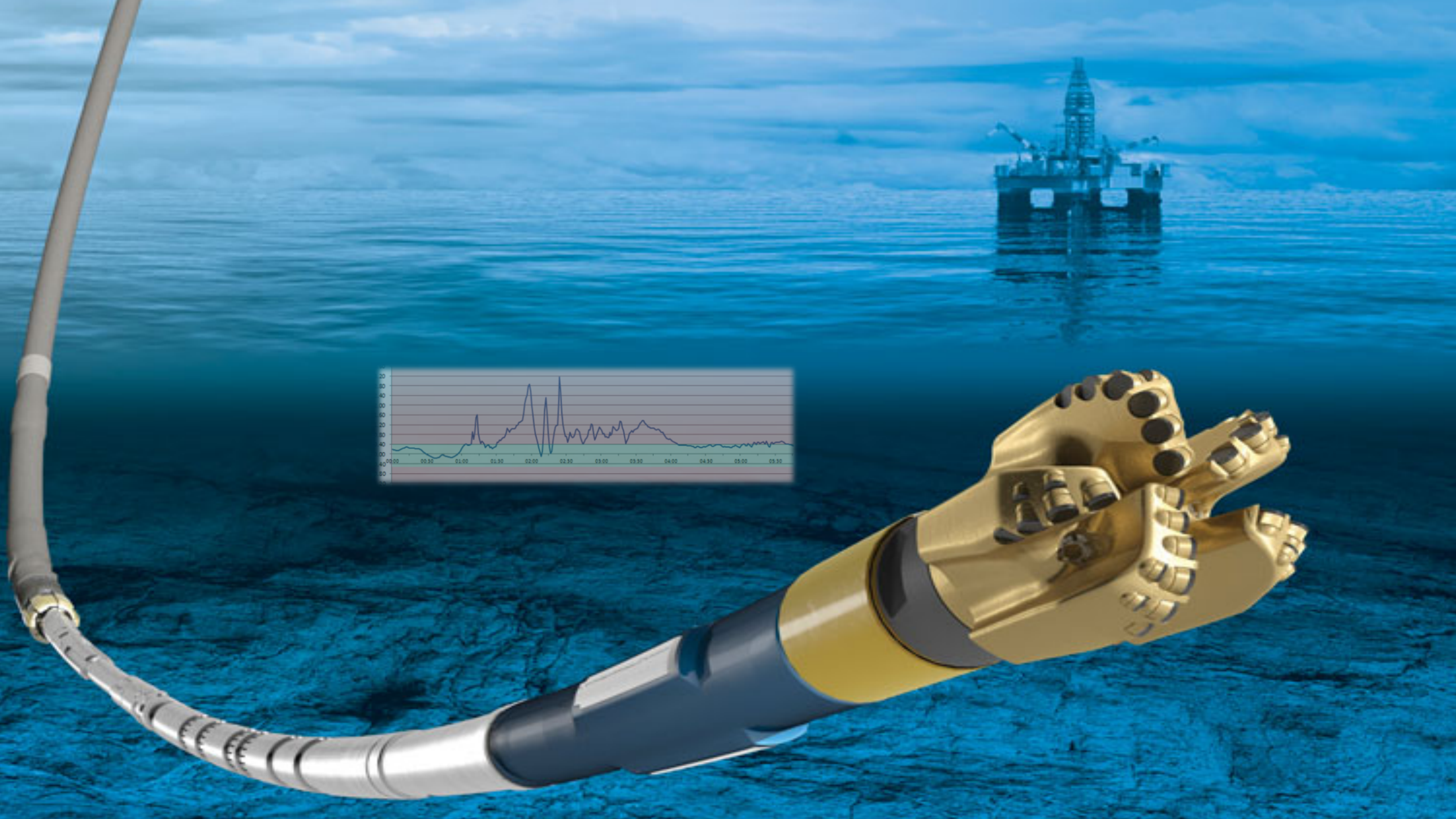
Hit the Geological Target
(& maximize recovery)



Avoid Other Wells



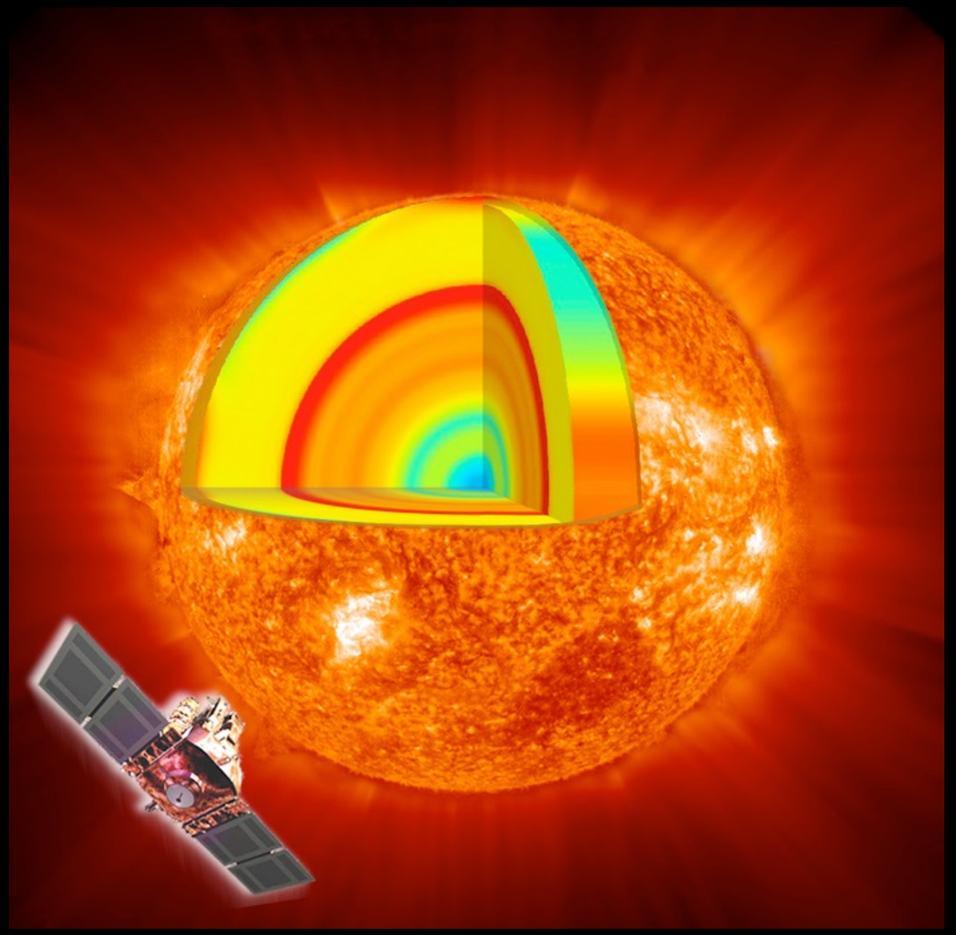
Inge Edvardsen
PhD Candidate/Survey
Management Engineer

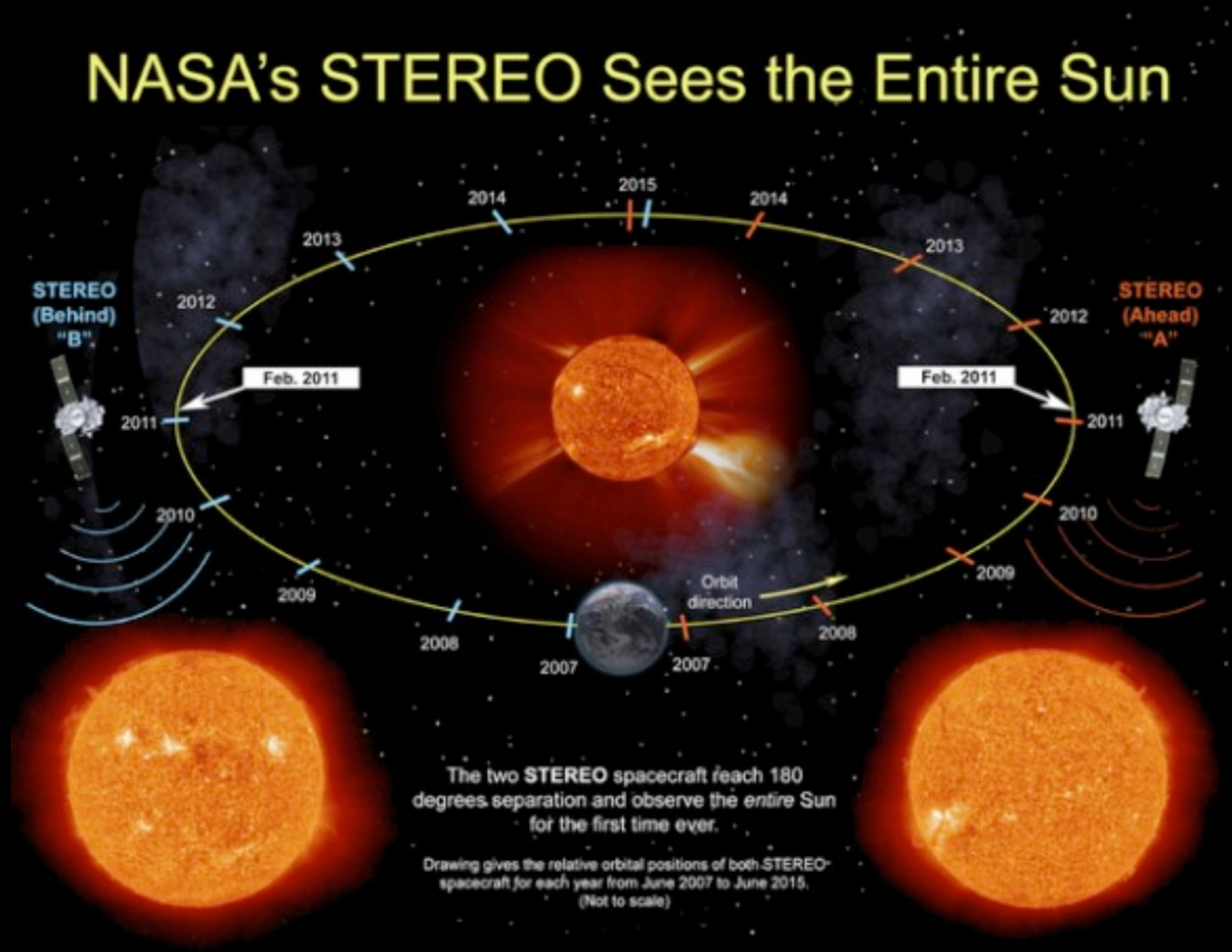


Impacts on animals

- The navigational abilities of homing pigeons are affected by geomagnetic storms
- Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells.

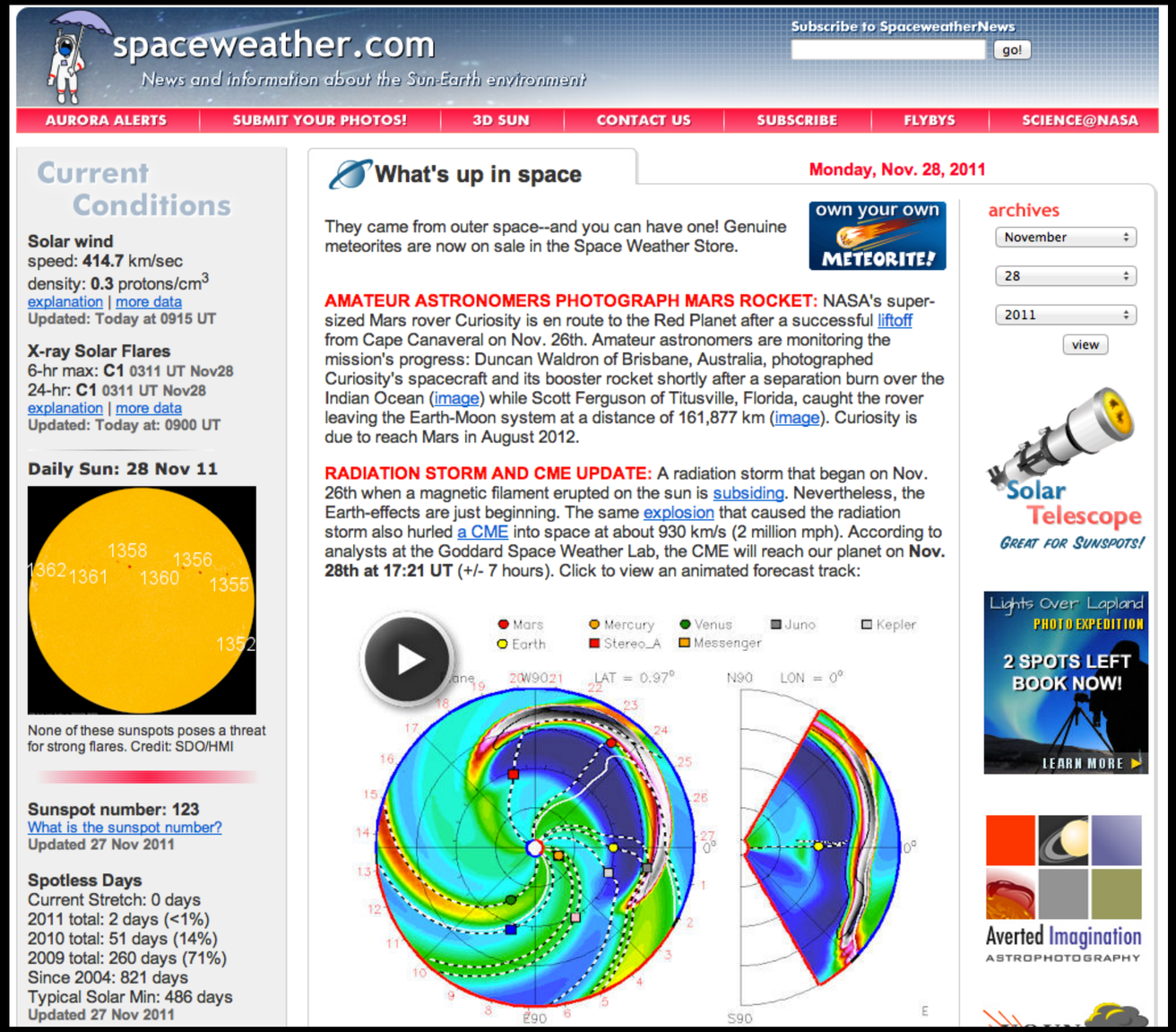
Aurora forecast: Monitoring the Sun





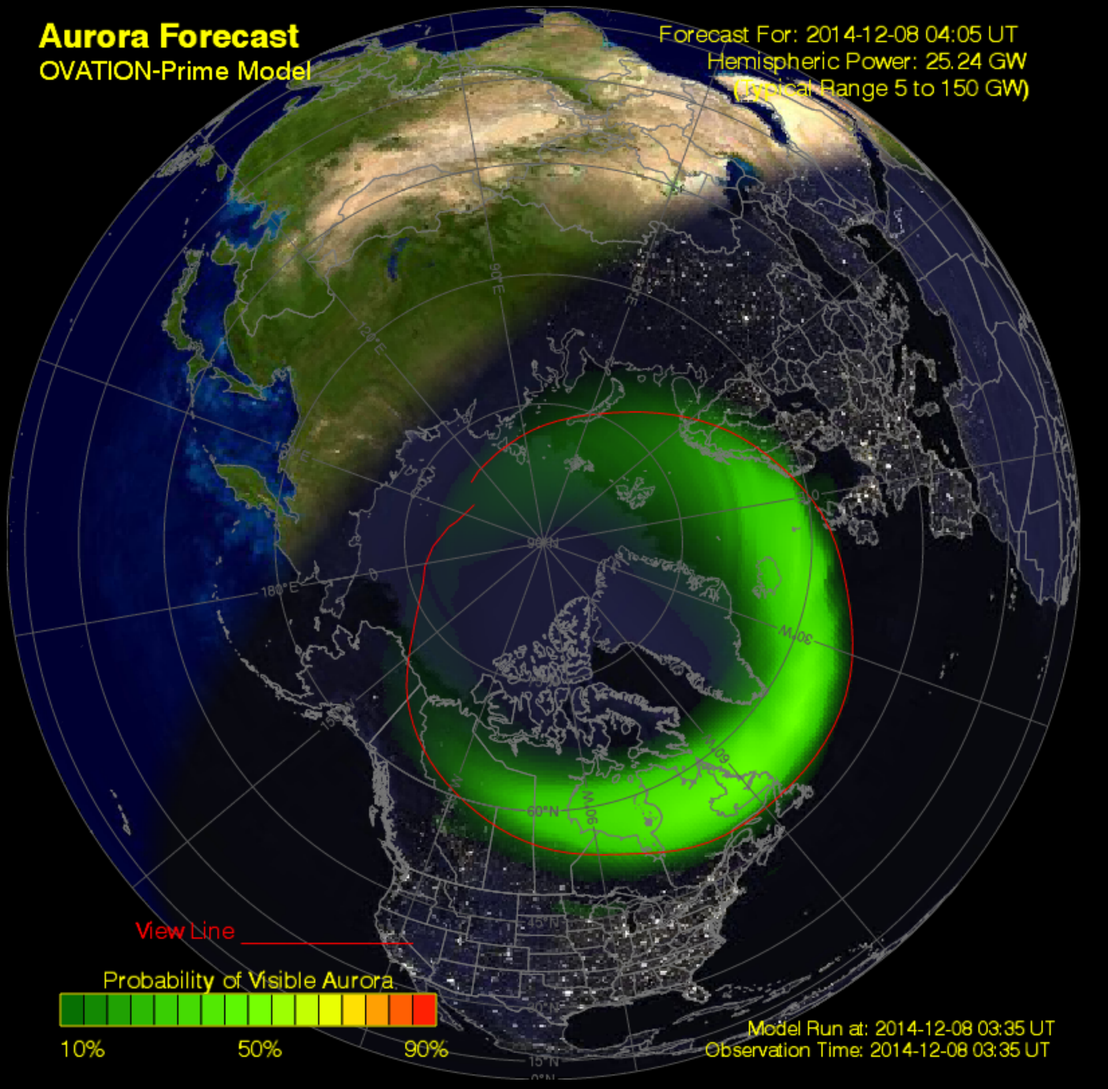
General Aurora Forecasting

www.spaceweather.com



http://helios.swpc.noaa.gov/ovation/

http://mms.rice.edu/realtime/forecast.html



University of Alaska

http://www.gi.alaska.edu/AuroraForecast/Europe/20150928

UNIVERSITY OF ALASKA FAIRBANKS

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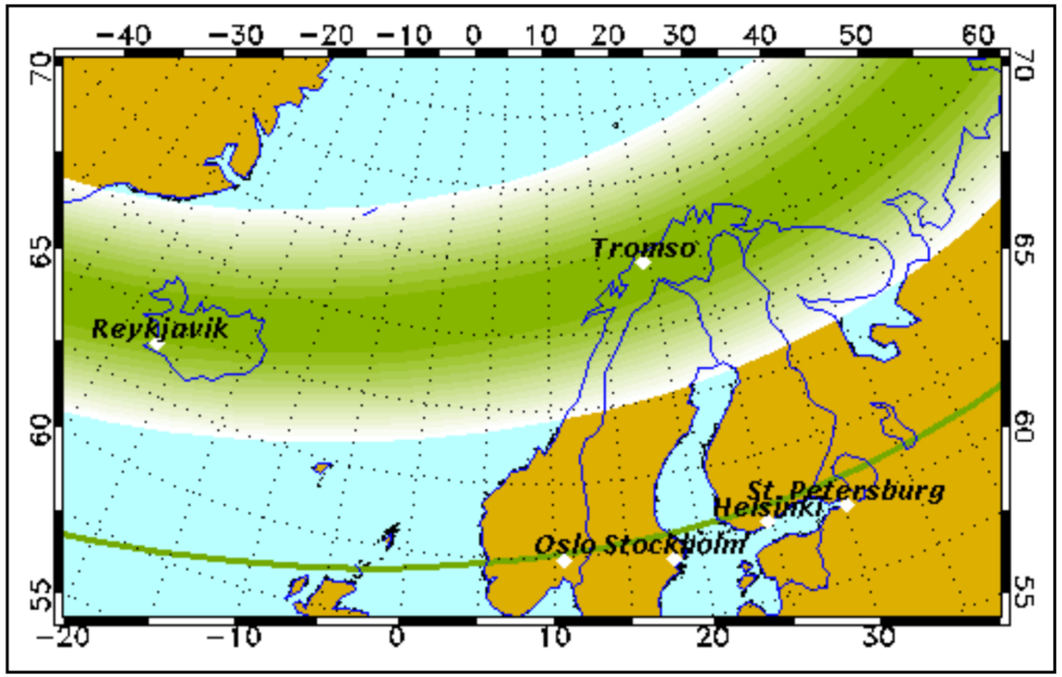
Aurora Forecast for Monday, September 28, 2015



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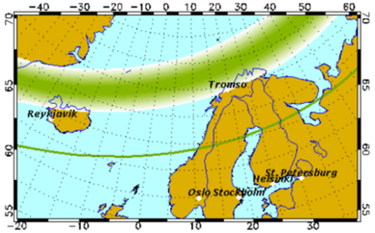
- Can I See the Aurora?
- Viewing Aurora in the Northern Summer
- Traveler's Guide to the Aurora
- FAQ
- Links

Short-Term (1-hour) Forecast

Sep 29, 2015 04:45 GMT
(September 28, 2015 20:45 ADT)

Quiet:

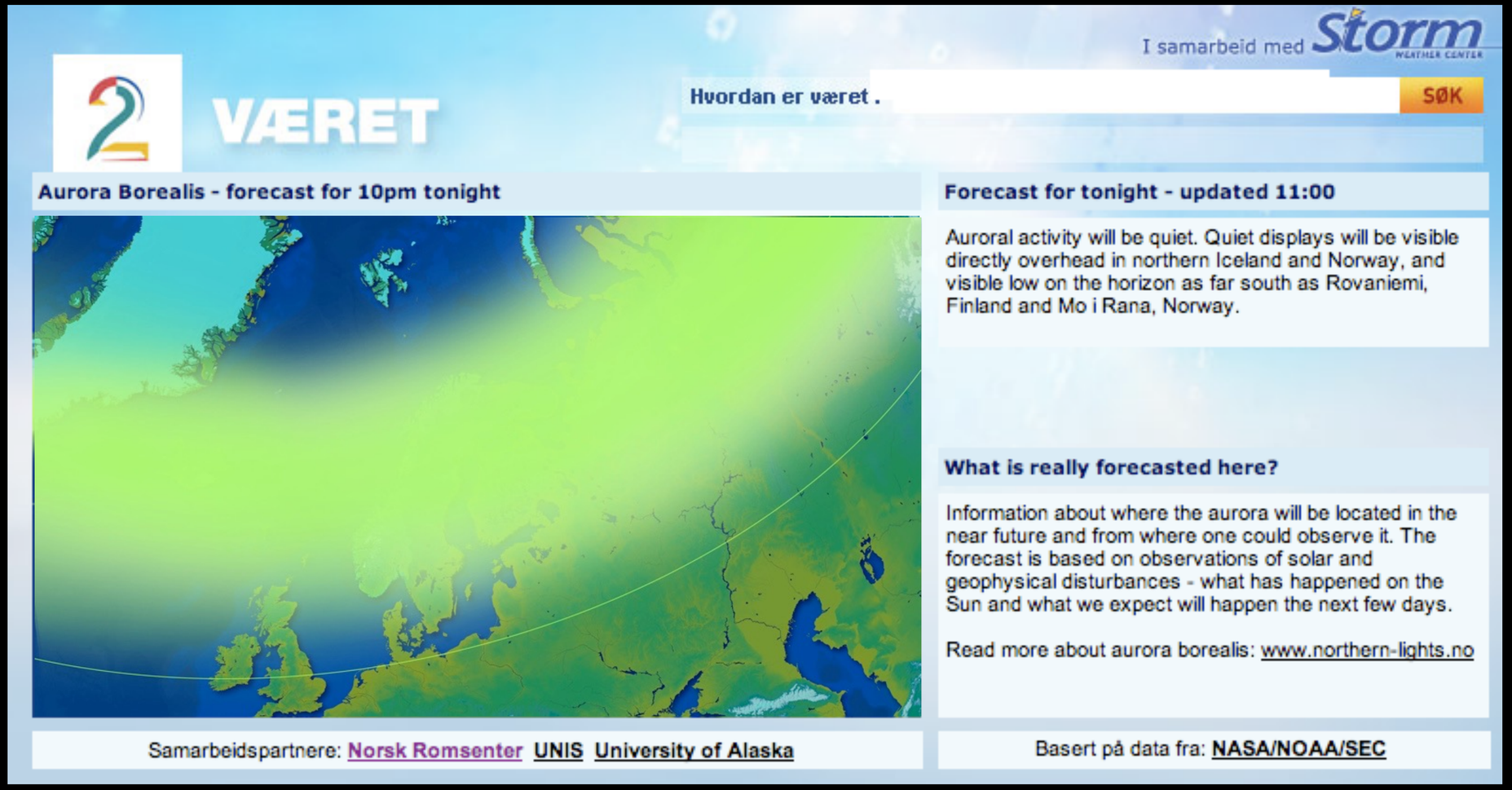


Moderate: 0 1 2 **3** 4 5 6 7 8 9

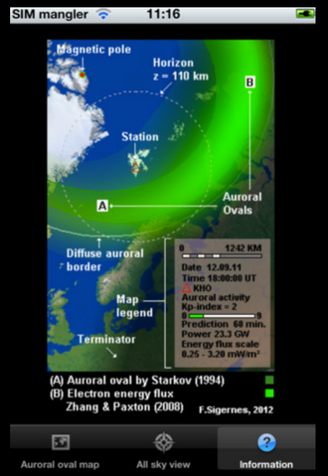
Forecast: Auroral activity will be moderate. Weather permitting, moderate displays will

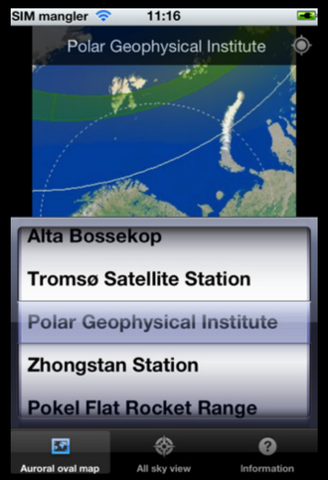
Aurora Forecaster in Norway

http://www.storm.no/nordlys/

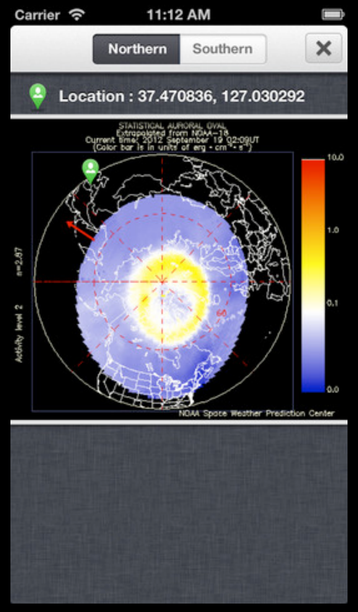


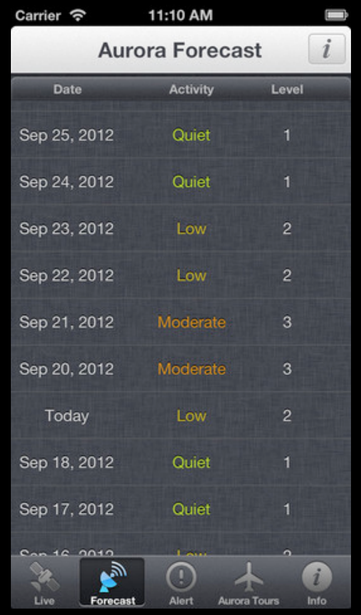
Smart Phone - Aurora Forecaster





«Auroral Forecast»





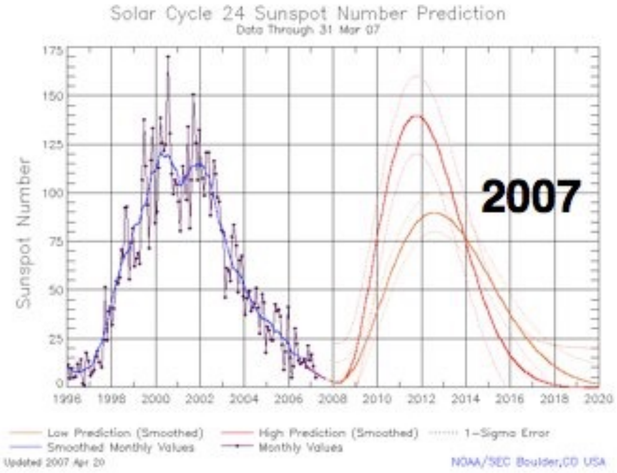
«Aurora Forecast»

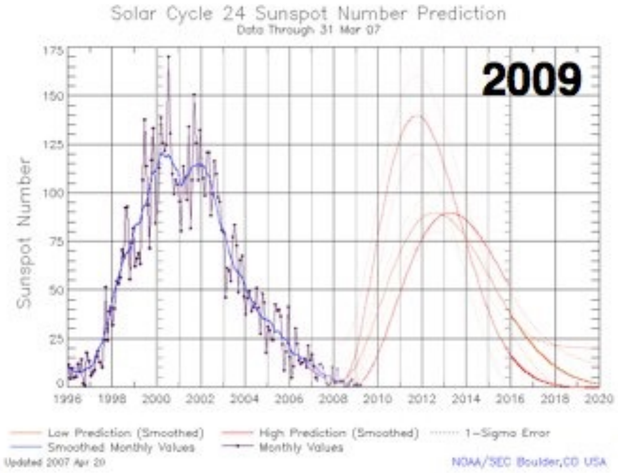
Predictability

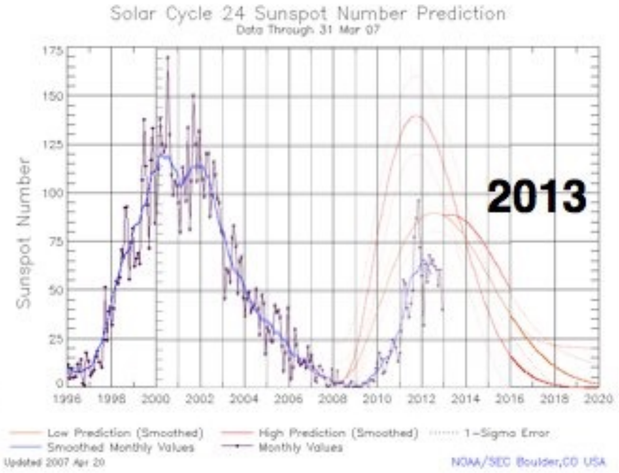
pre·dict·a·bil·i·ty [prih-dik-t*uh*-**bil**-i-tee]

noun

1.
consistent repetition of a state, course of action, behavior, or the like, making it possible to know in advance what to expect: *The predictability of their daily lives was both comforting and boring.*



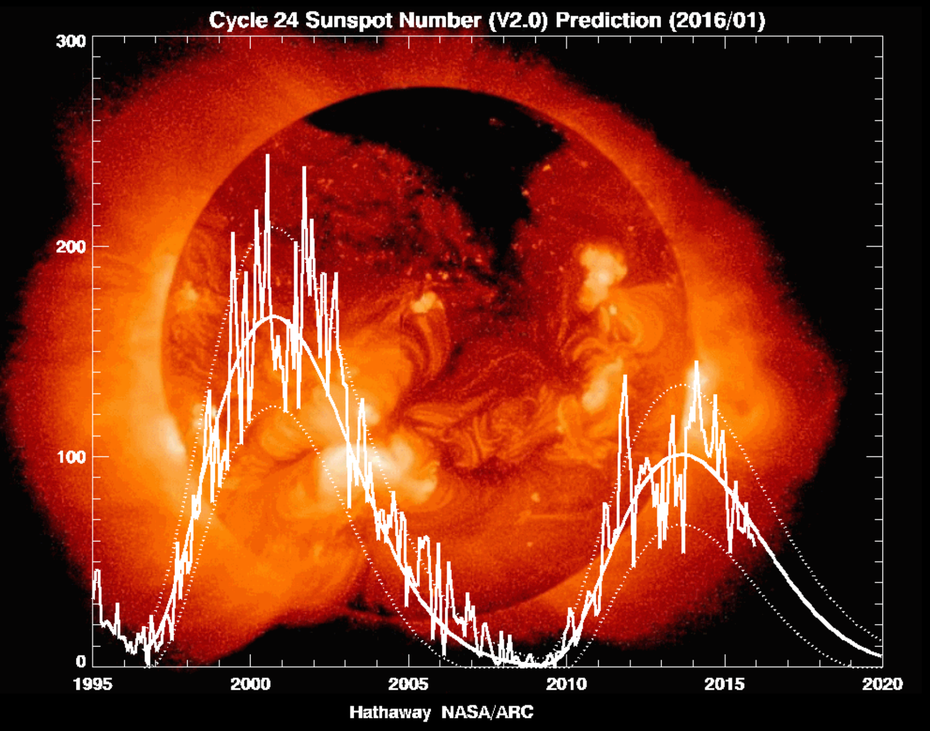


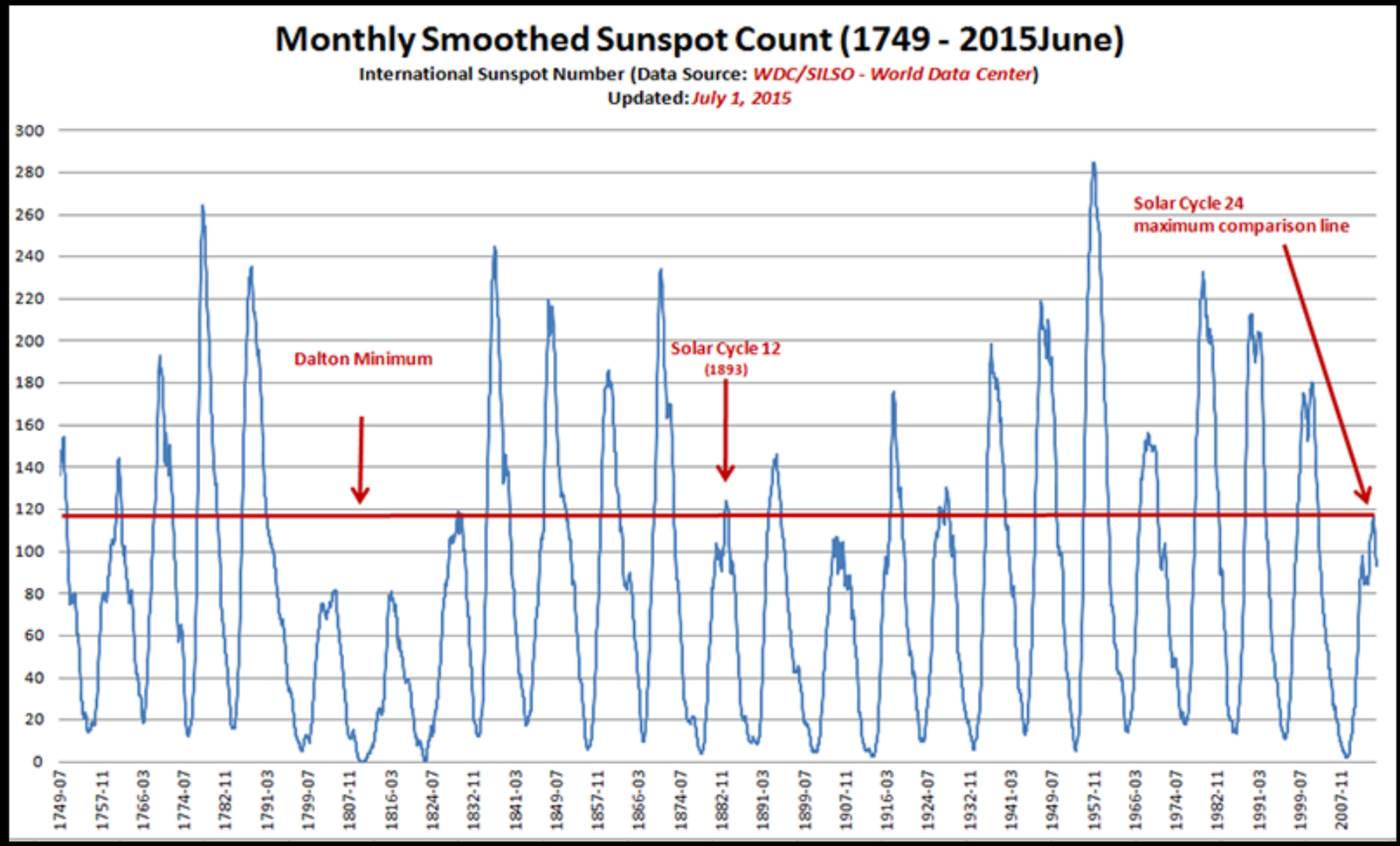


Sometimes we just don't understand something all that well.....

The moral: aim low!

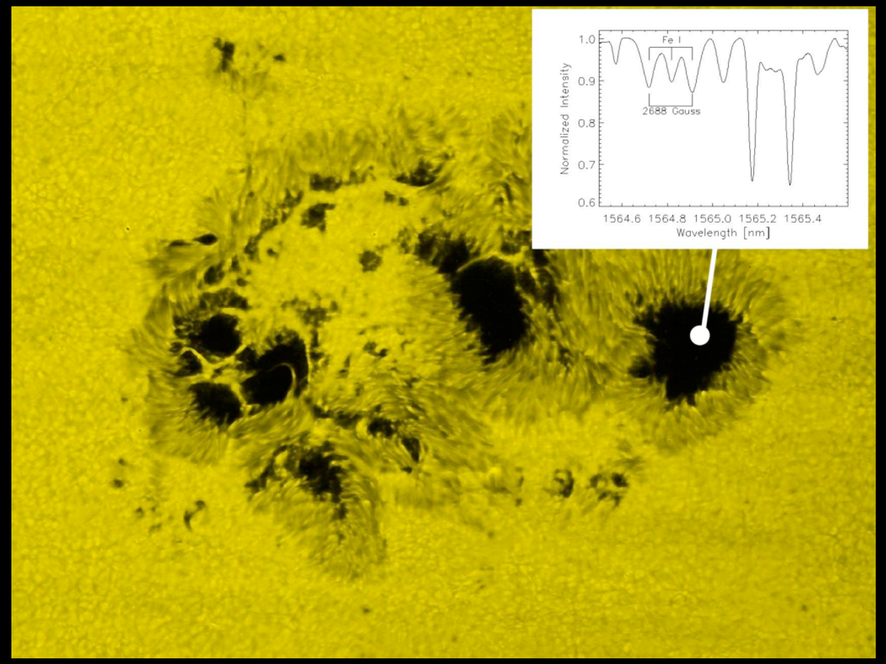
Weak Solar Cycle

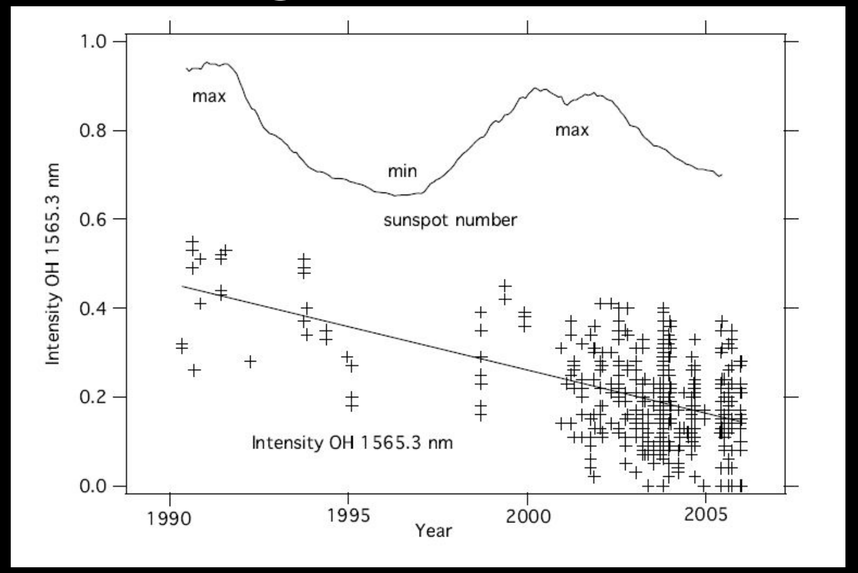


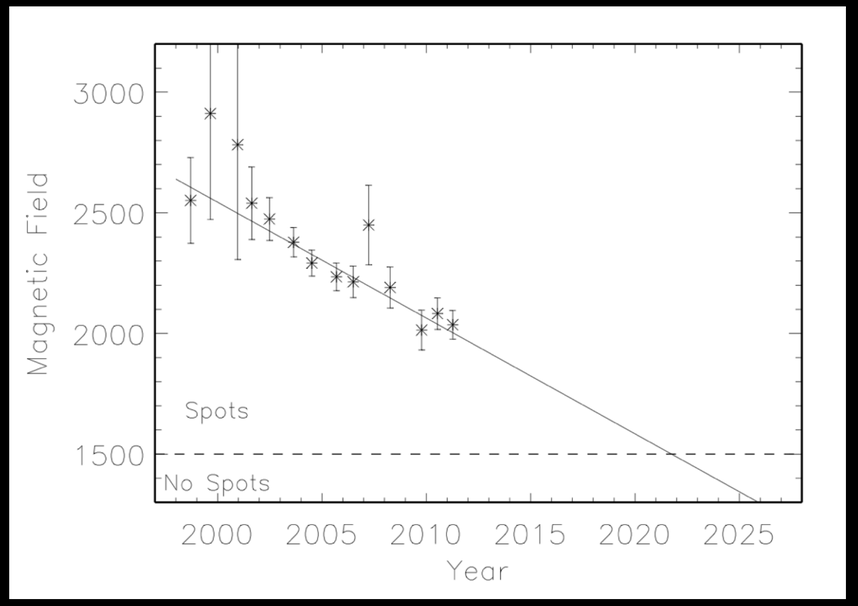


What about our future Sun?

Are Sunspots weakening?







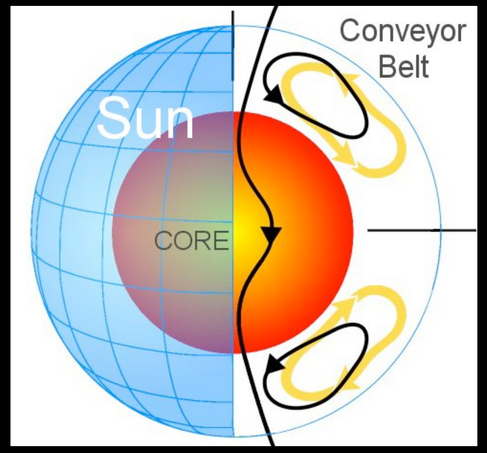
"Sunspots may vanish by 2015" - William Livingston and

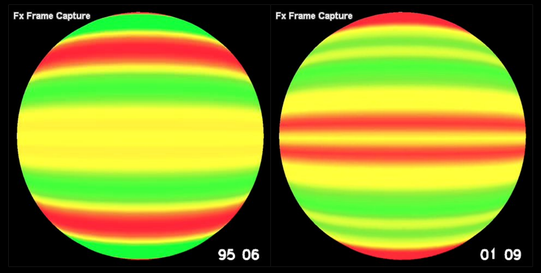
Matthew Penn, National Solar Observatory at Kitt Peak

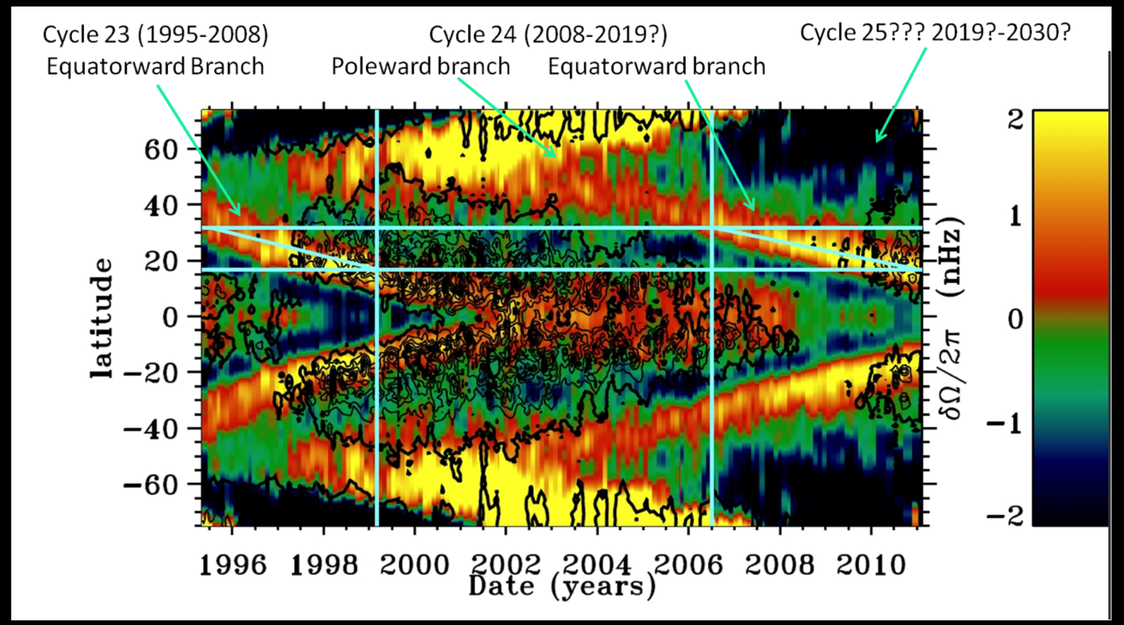
What is happening with the Sun?

A missing jet stream, fading spots, and slower activity near the poles say that our Sun is heading for a rest period

Latitude-time plots of jet streams under the Sun's surface show the surprising shutdown of the solar cycle mechanism. New jet streams associated with a future 2018-2020 solar maximum were expected to form by 2008 but are not present even now, indicating a delayed or missing Cycle 25.





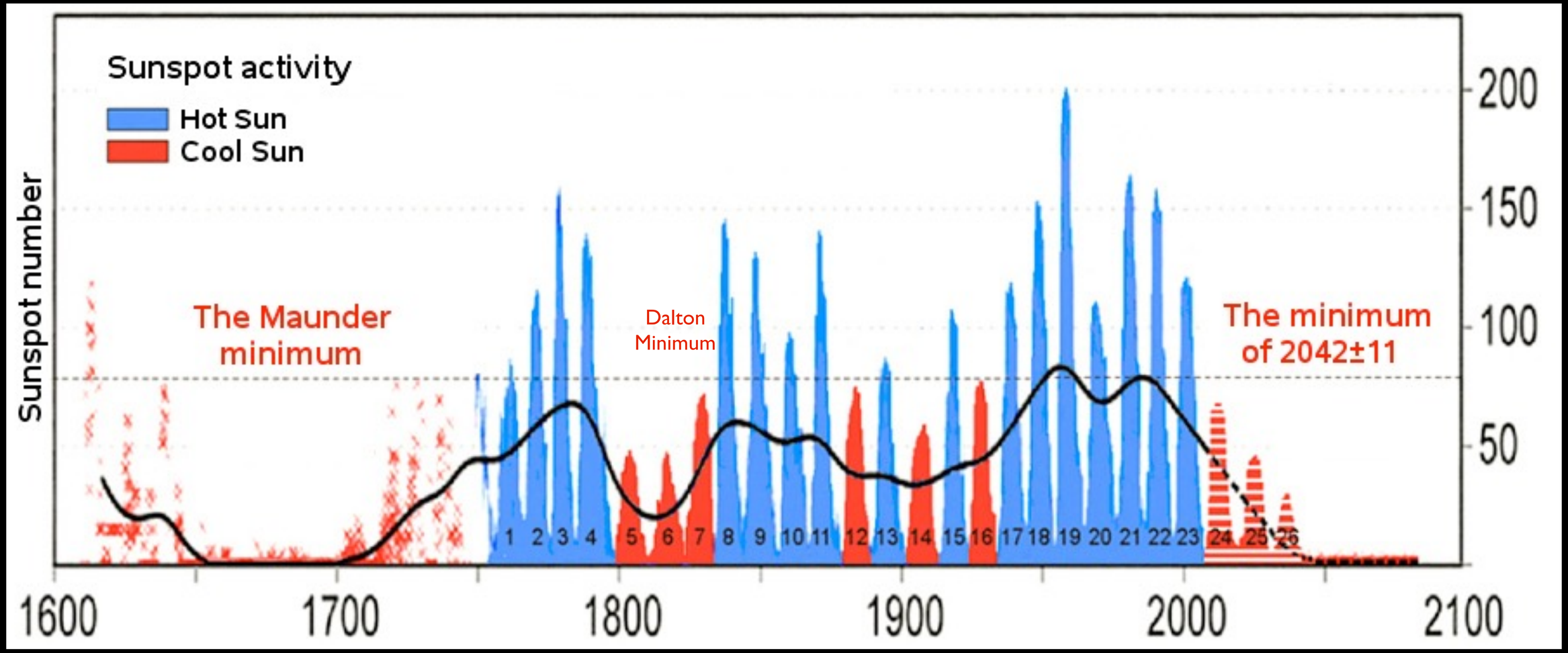


"Large-Scale Zonal Flows During the Solar Minimum -- Where Is Cycle 25?" by Frank Hill, R. Howe, R. Komm, J. Christensen-Dalsgaard, T.P. Larson, J. Schou & M. J. Thompson.

"Whither Goes Cycle 24? A View from the Fe XIV Corona" by R. C. Altrock.

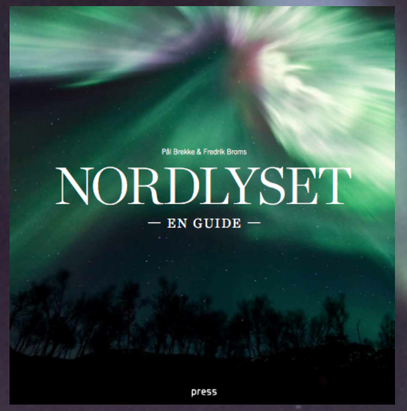
"A Decade of Diminishing Sunspot Vigor" by W. C. Livingston, M. Penn & L. Svalgard.

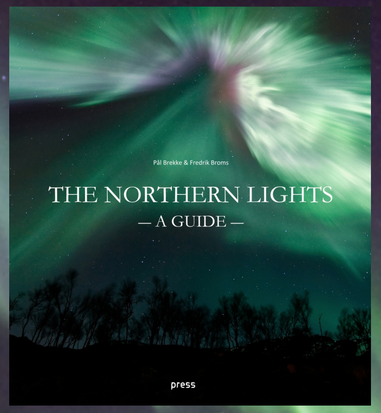
What will the Sun do in the future?

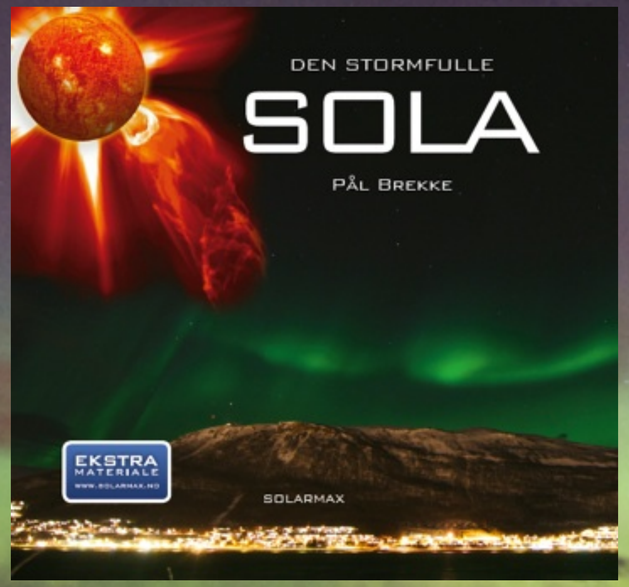


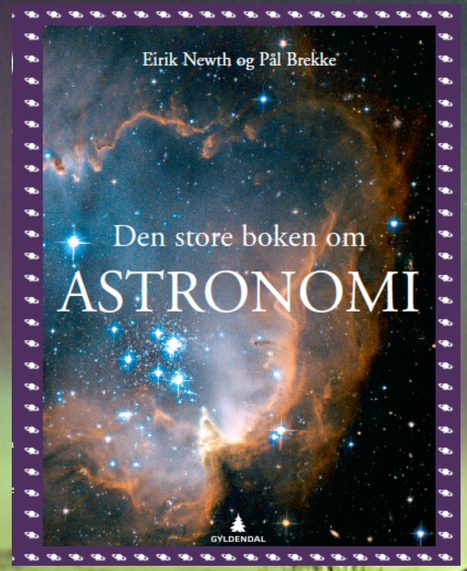
E.g. H. Abdussamatov (2009), Lockwood et al. (2009)

Lær mer om Sola og Nordlyset



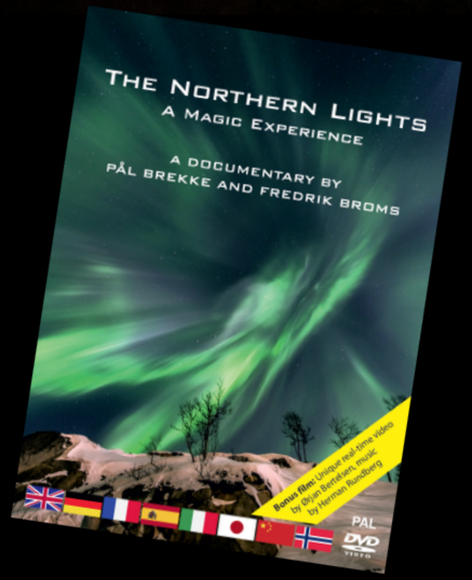






Info: www.solarmax.no/Aurora/ paal@spacecentre.no

Fredrik Broms



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