



On Becoming a Scientist, Studying the Earth and the Sun

Leif Svalgaard



Stanford University

陸別 (Rikubetsu), November, 2012

陸別 Rikubetsu

Today, I am here.
Science spans the globe



Places



København Univ.

Founded in year 1479

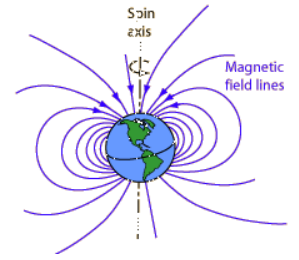


Greenland



As a student I went to Greenland to observe the Earth's magnetic field in 1967

The 'house' for some of my instruments looked like this [an Igloo: I made it myself; my first try collapsed...]



In 1972 I was invited to work at Stanford University in California

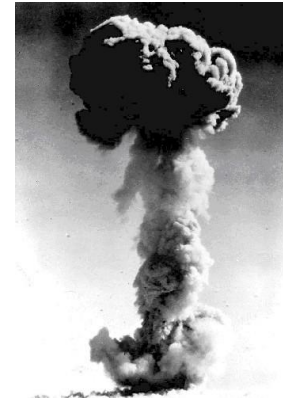


Stanford Univ.

“The Earth is a Great Magnet”

Gilbert, 1600

Getting to the Station on the Ice

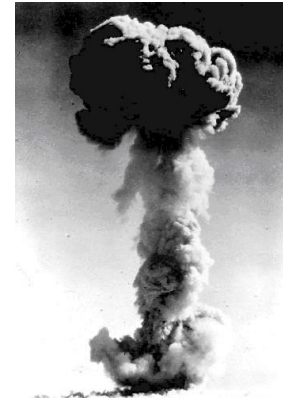


Low seismic 'noise', good for detection of Atomic Bombs



Inge Lehman Station 77.92°N 39.23°W, 2400 m (7900 ft), 1966-1967

Getting to the Station on the Ice

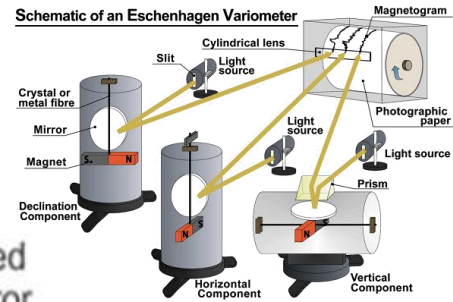
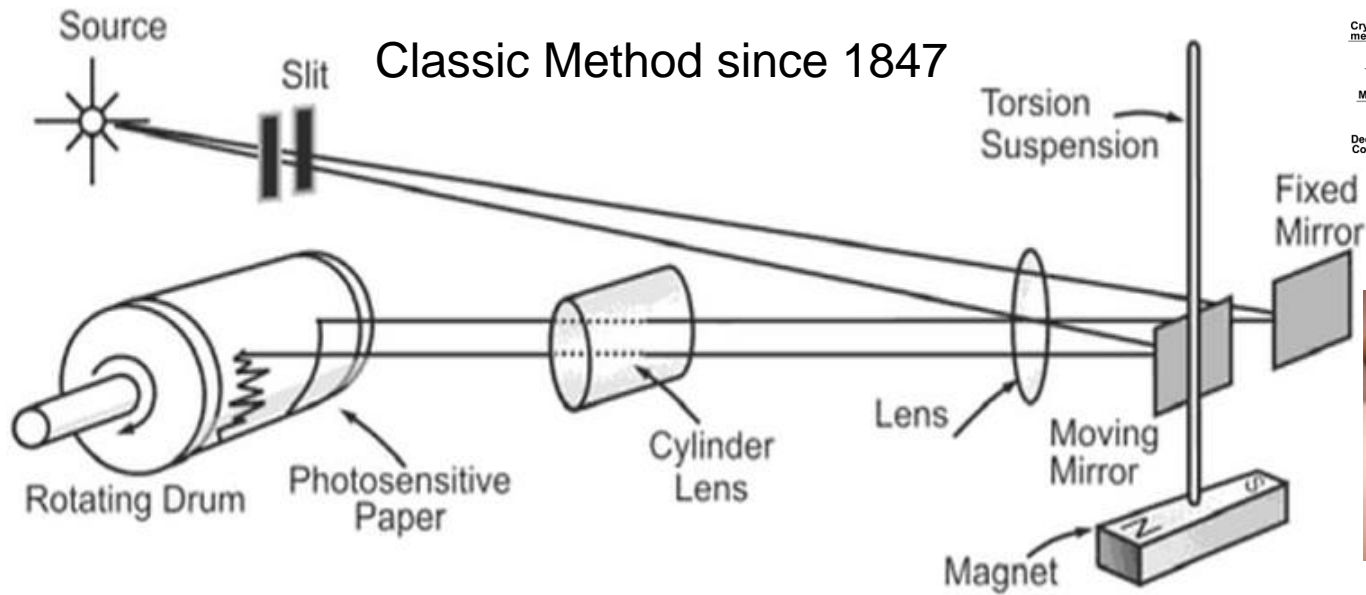


Low seismic 'noise', good for detection of Atomic Bombs

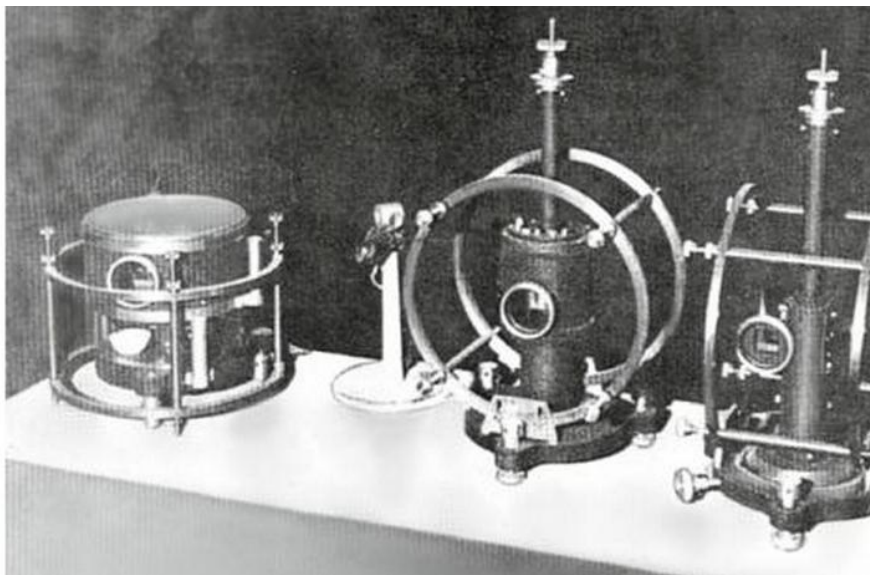
But my job was to make magnetic observations...



Inge Lehman Station 77.92°N 39.23°W, 2400 m (7900 ft), 1966-1967



Compass shows the Direction of the Earth's Magnetic Field



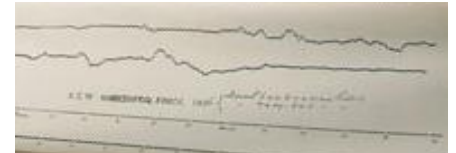
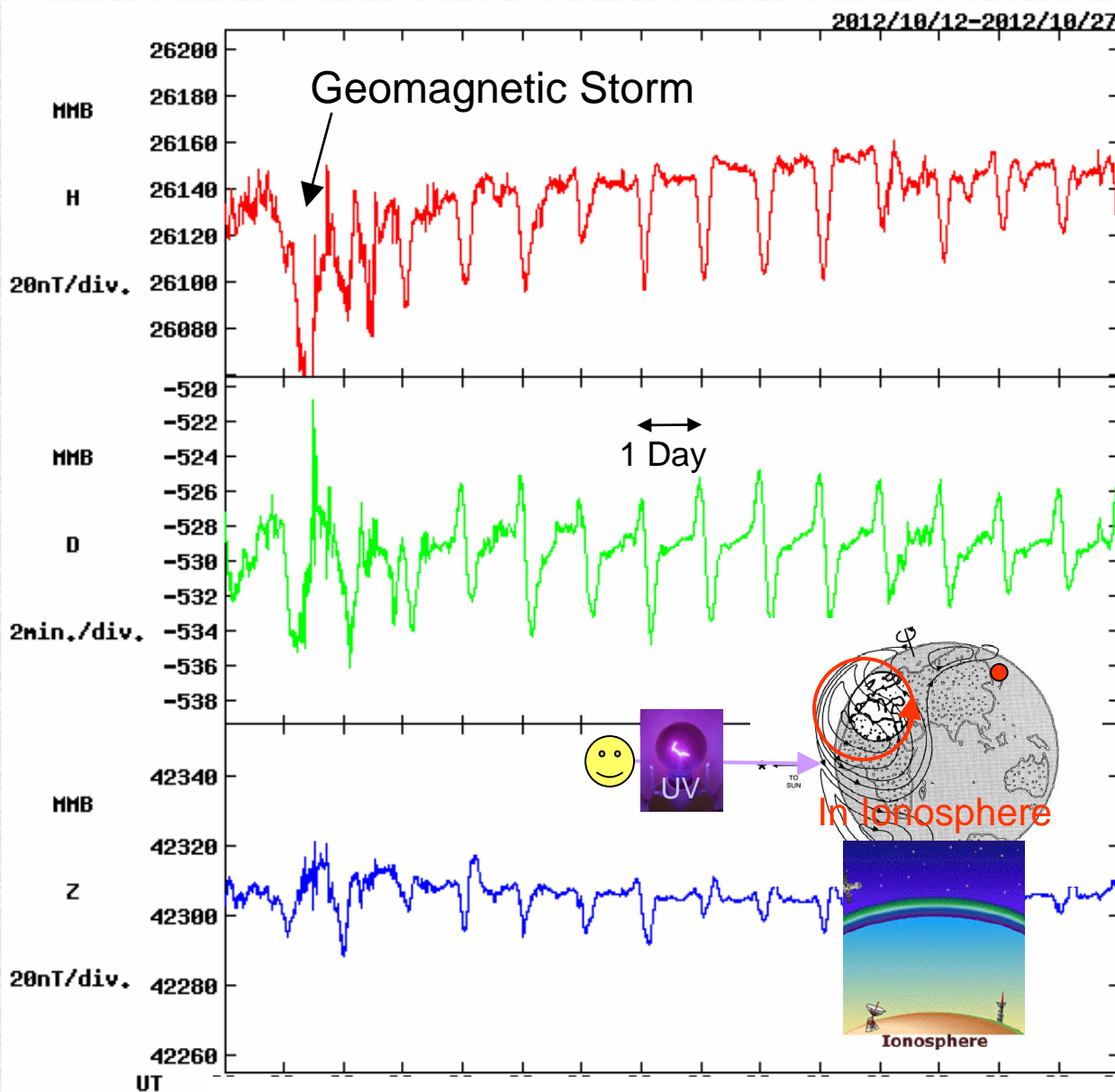
I used the Classic Instruments

Magnetic Recorders



Modern Instrument

Magnetic Recordings



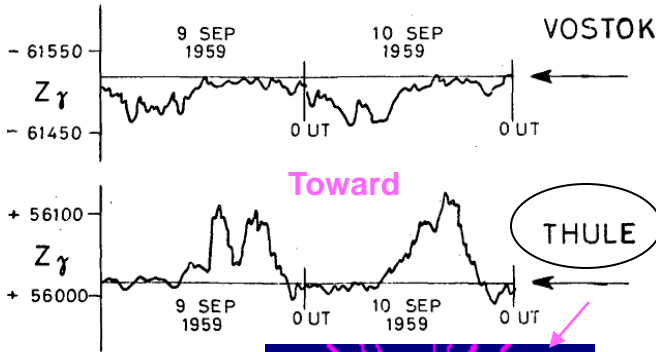
During a magnetic storm
Aurorae become active:



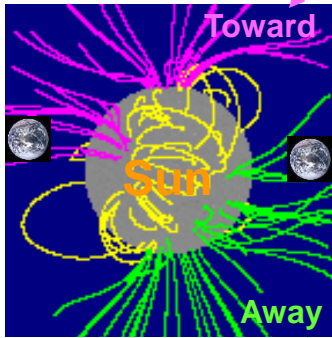
And seen from Space

Magnetic Fields on Earth and in Space

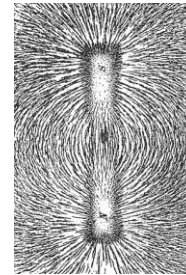
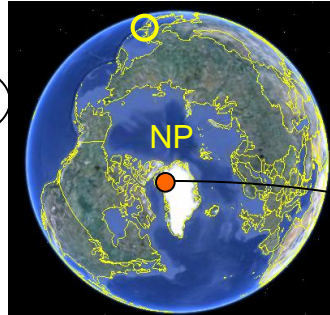
The solar system is permeated by magnetic fields coming from the Sun with the **Solar Wind** and connecting with the field of the Earth [and other planets]



The records from Earth's polar regions show the Sun's fields

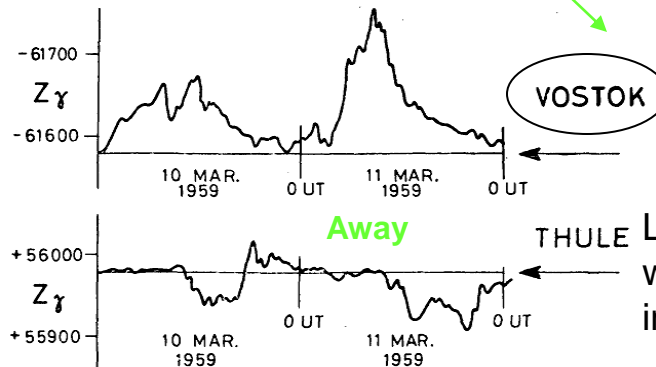
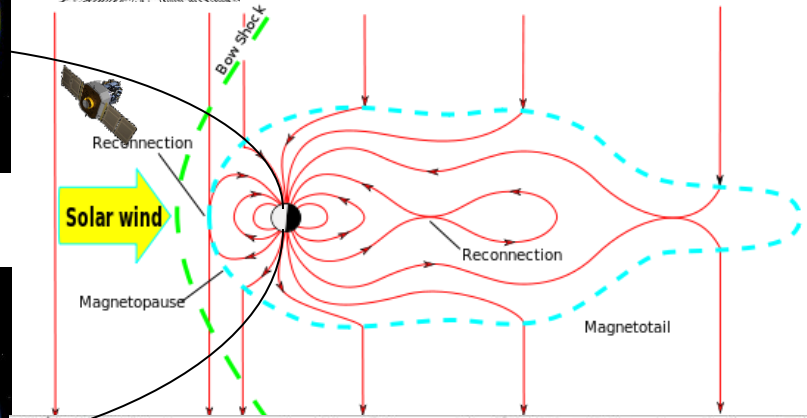
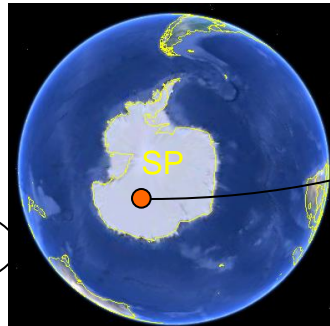


Svalgaard, 1968

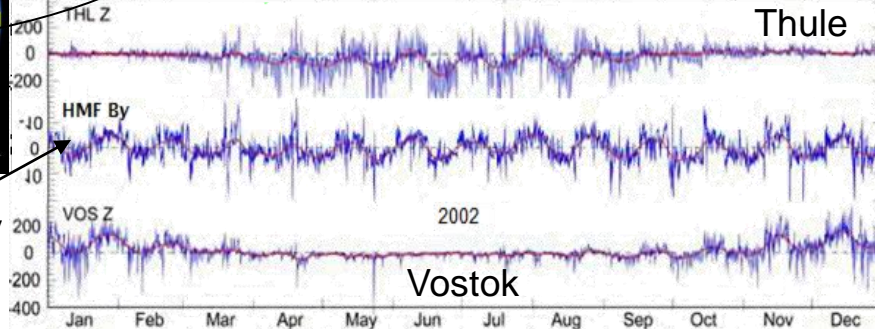


Magnetic field lines show the direction of the magnetic field

Mansurov, 1969



Look how accurately we can see the field in space from Earth



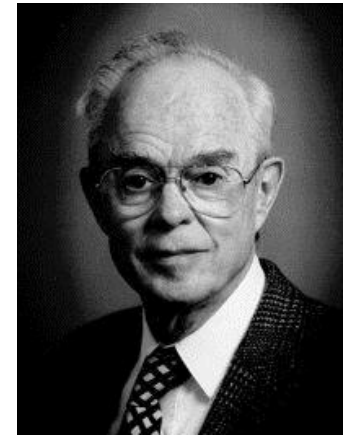
The Solar Wind

“Blows” all the time and is the expansion of the extremely hot atmosphere into space, visible near the Sun as the ‘Corona’:



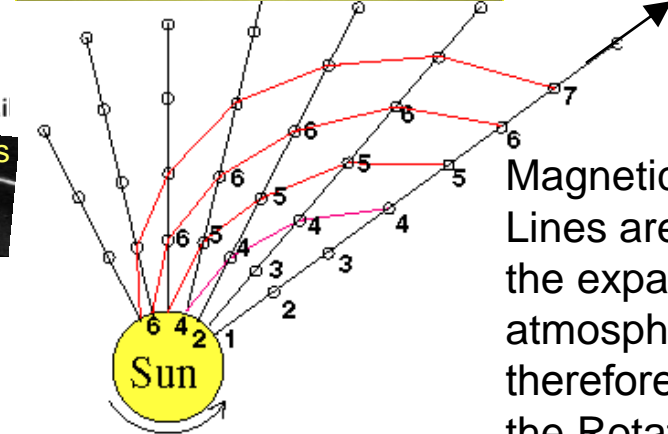
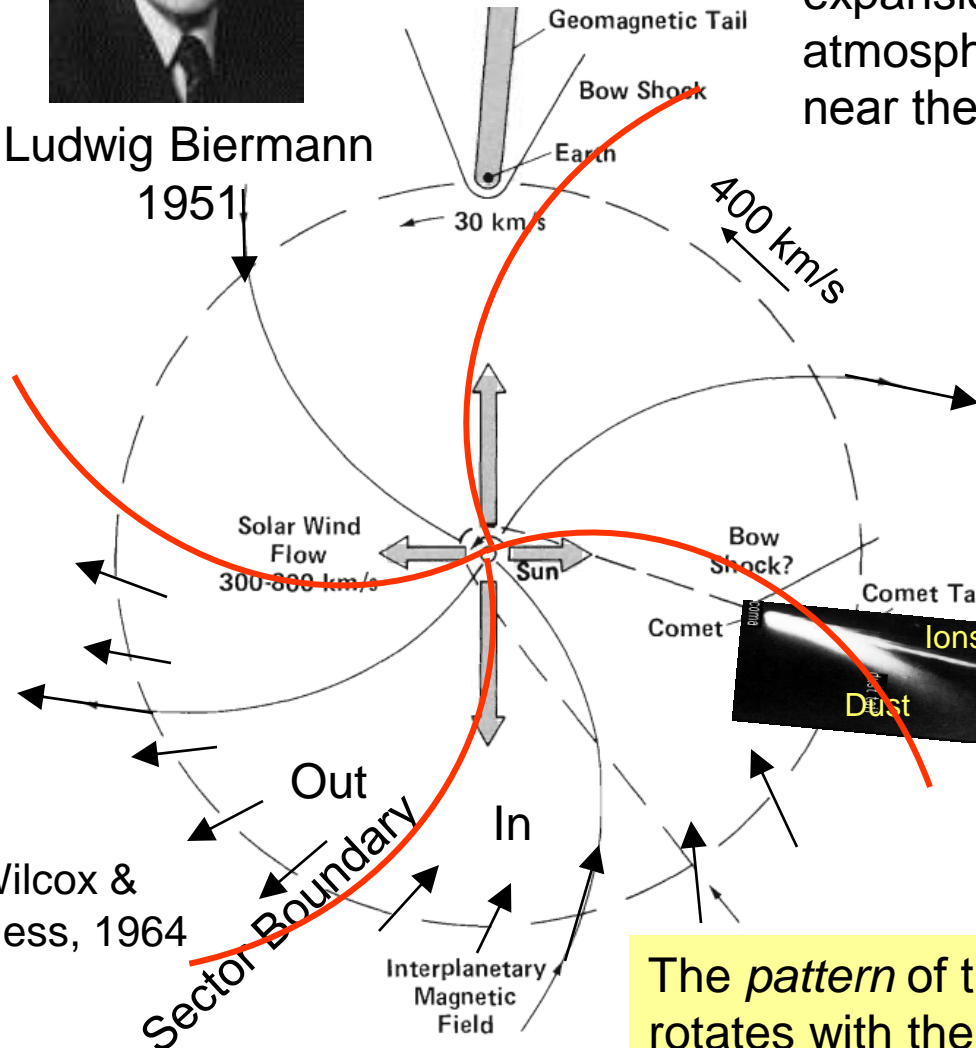
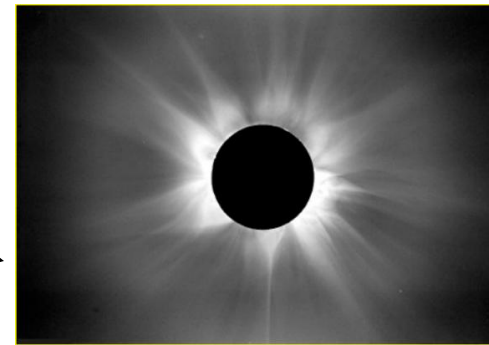
Ludwig Biermann

1951



Gene Parker
1958

Expansion is radially outwards

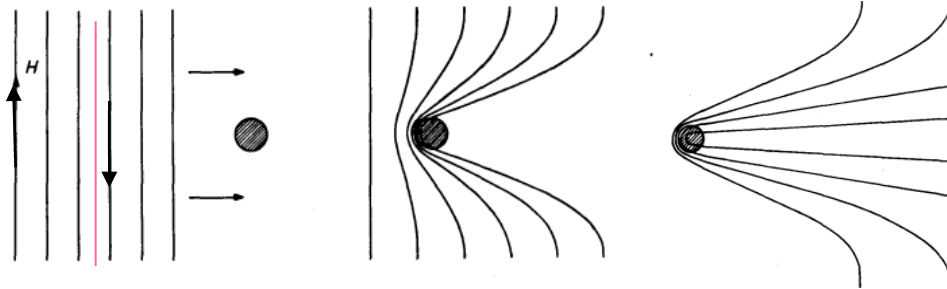


Magnetic Field Lines are tied to the expanding atmosphere and therefore ‘rooted’ in the Rotating Sun

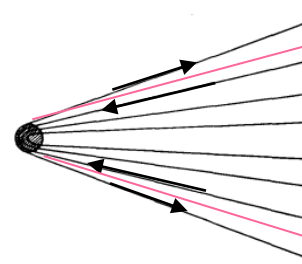
The *pattern* of the magnetic ‘spiral’ rotates with the Sun once in 25 days

Solar Wind Stealing a Comet Tail

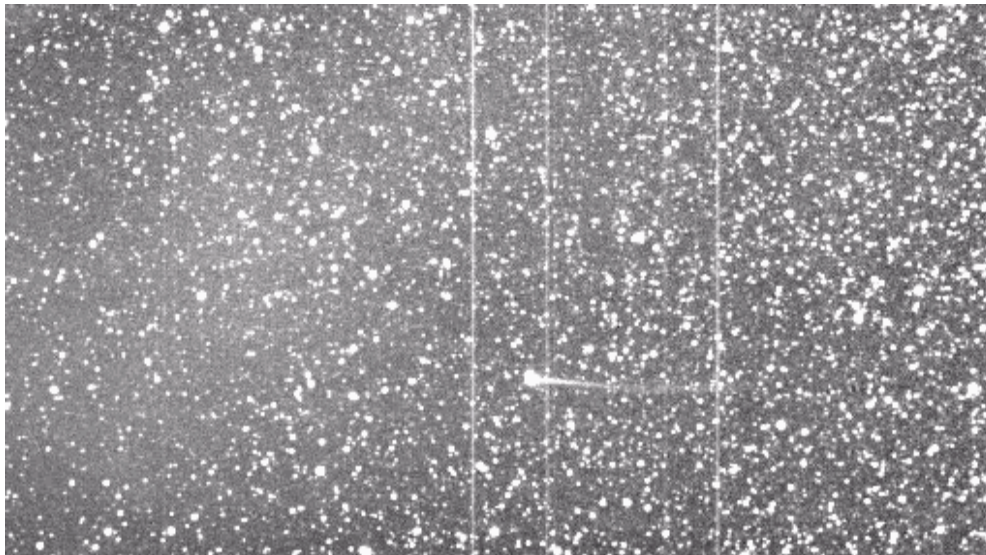
Sector Boundary



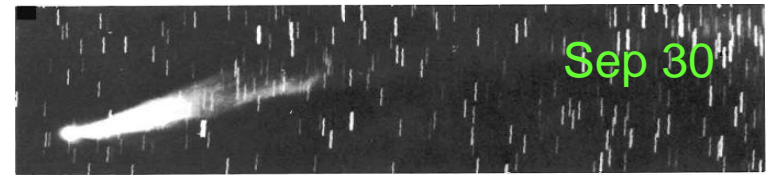
Reconnection



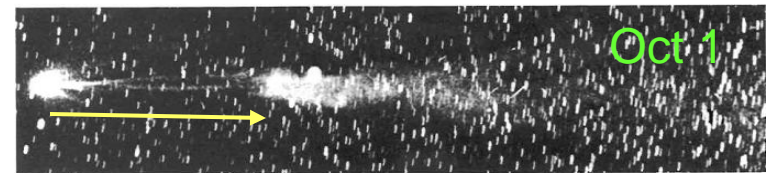
Fragile: Comet ion tail inside



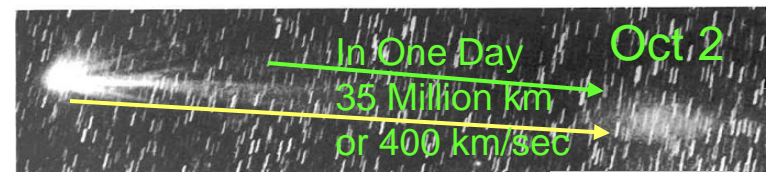
Comet Encke, 2007/04/20



Sep 30



Oct 1



Oct 2

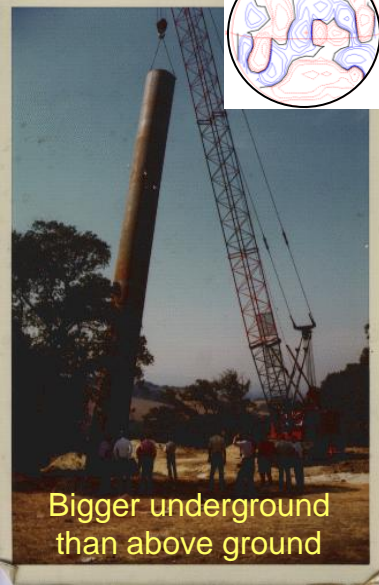
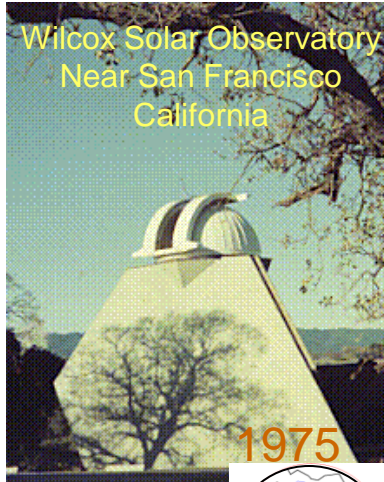
In One Day
35 Million Km
or 400 km/sec

Comet Morehouse, 1908

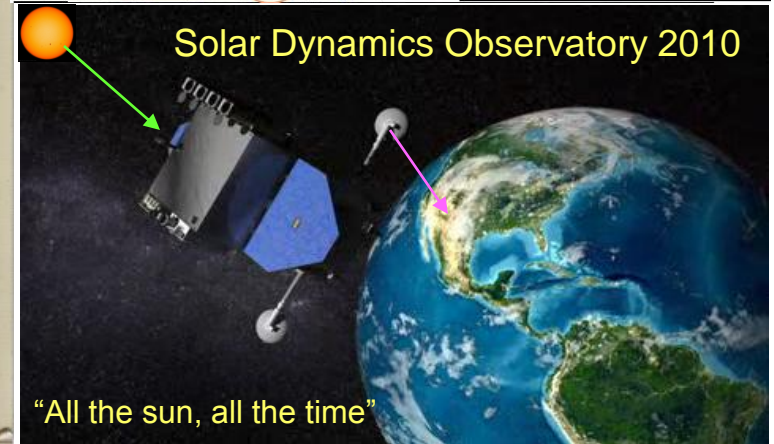
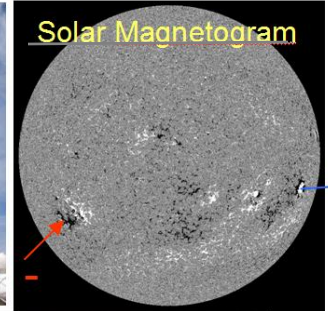


Where Does the Magnetized Solar Wind Come From?

To find out we build Solar Magnetic Field Observatories !

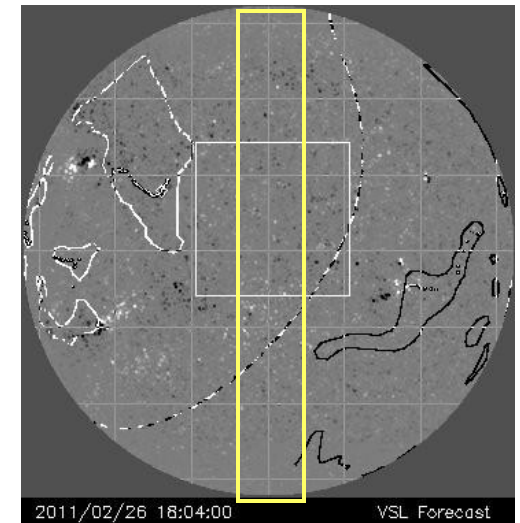
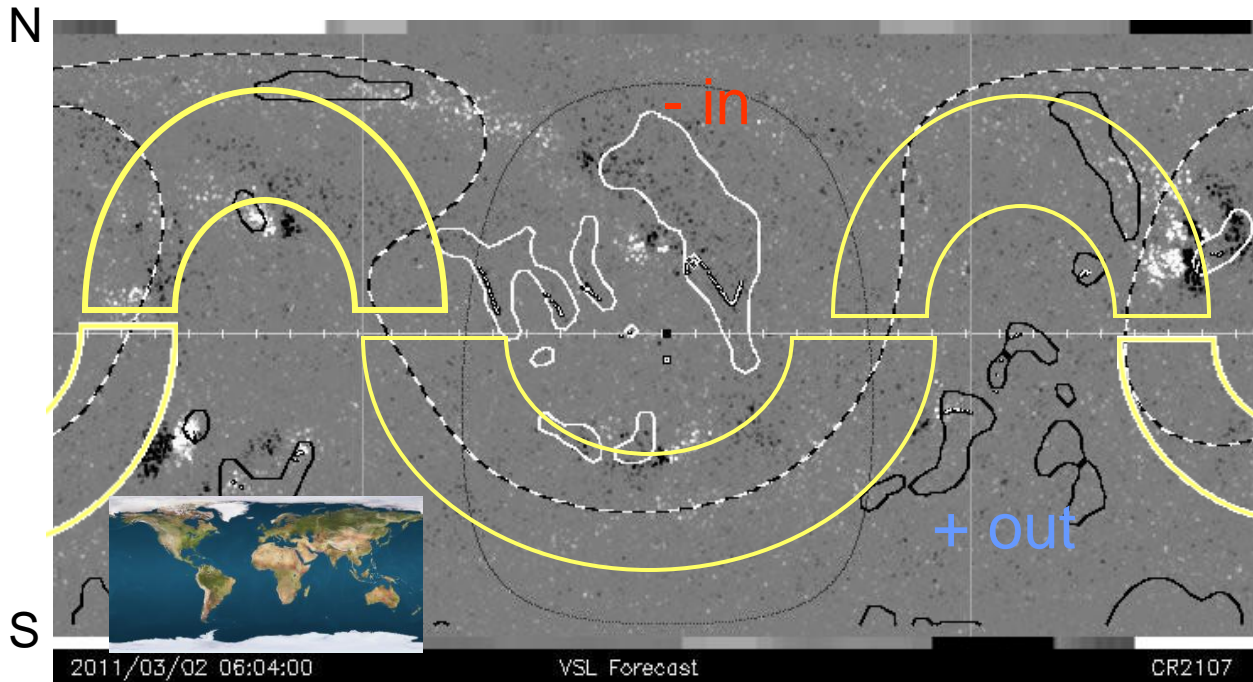
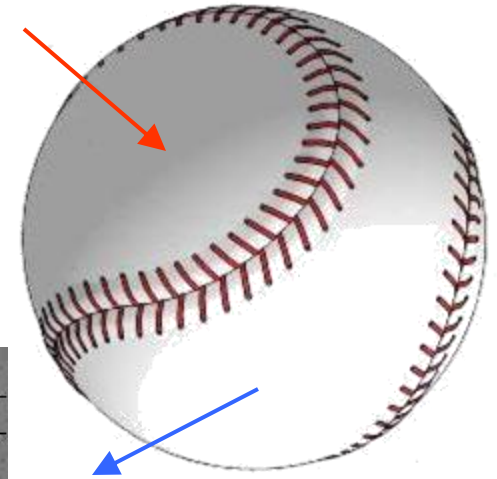


So, from the ice in Greenland I went to sunny California to study the Sun



Sector Boundaries on the Sun

From the measured magnetic field we can **calculate** where the boundary between opposite polarities is. It winds its way across the surface looking like the seam of a baseball

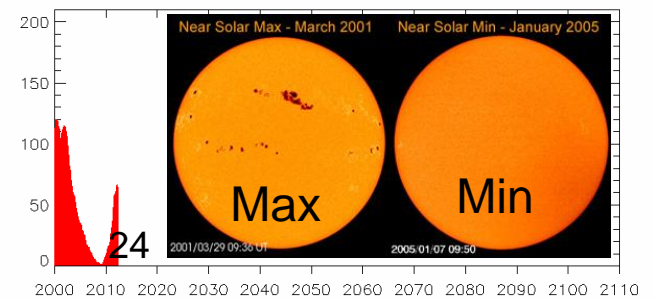
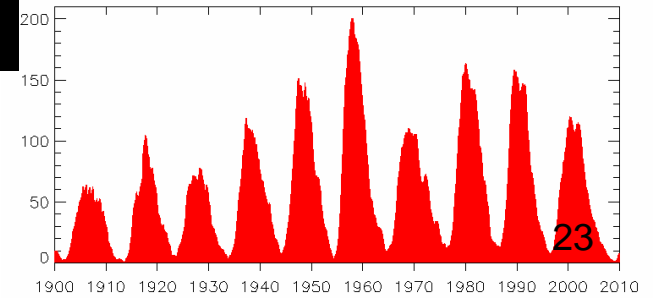
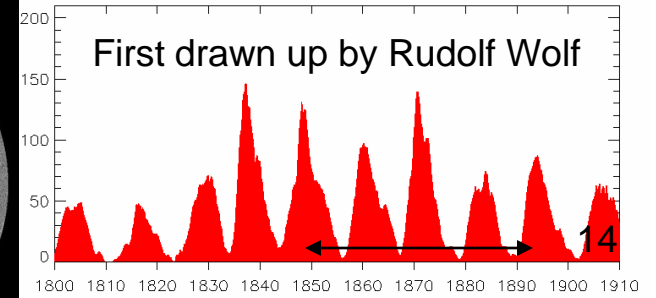
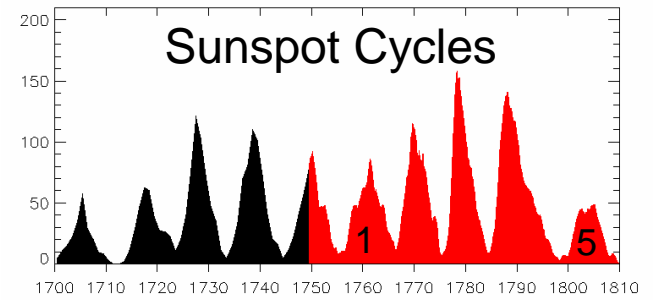
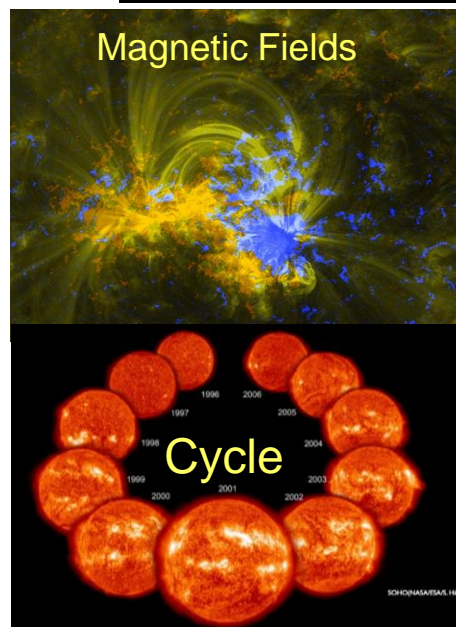
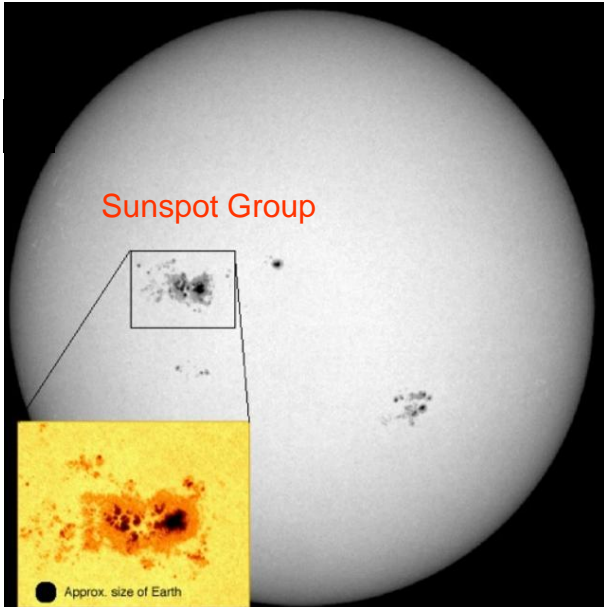
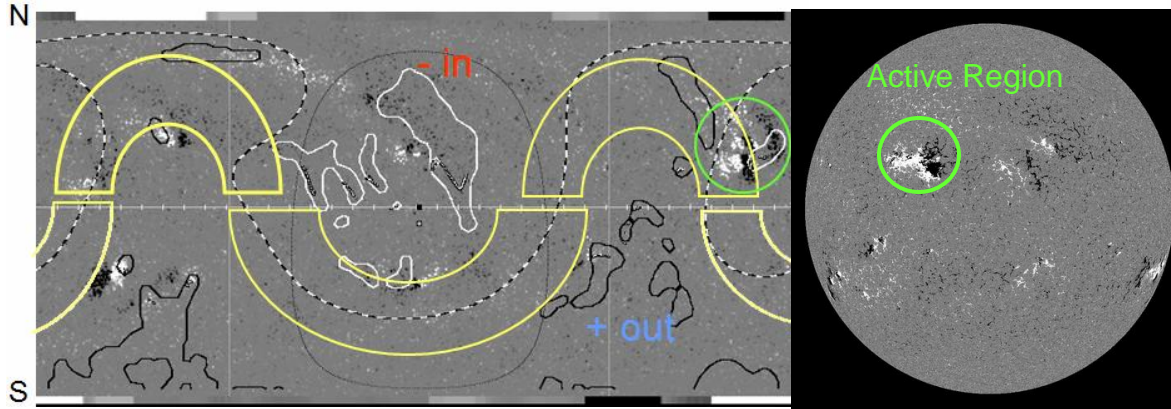


'Synoptic' map from 27 daily strips showing the whole Sun

Disk Magnetogram

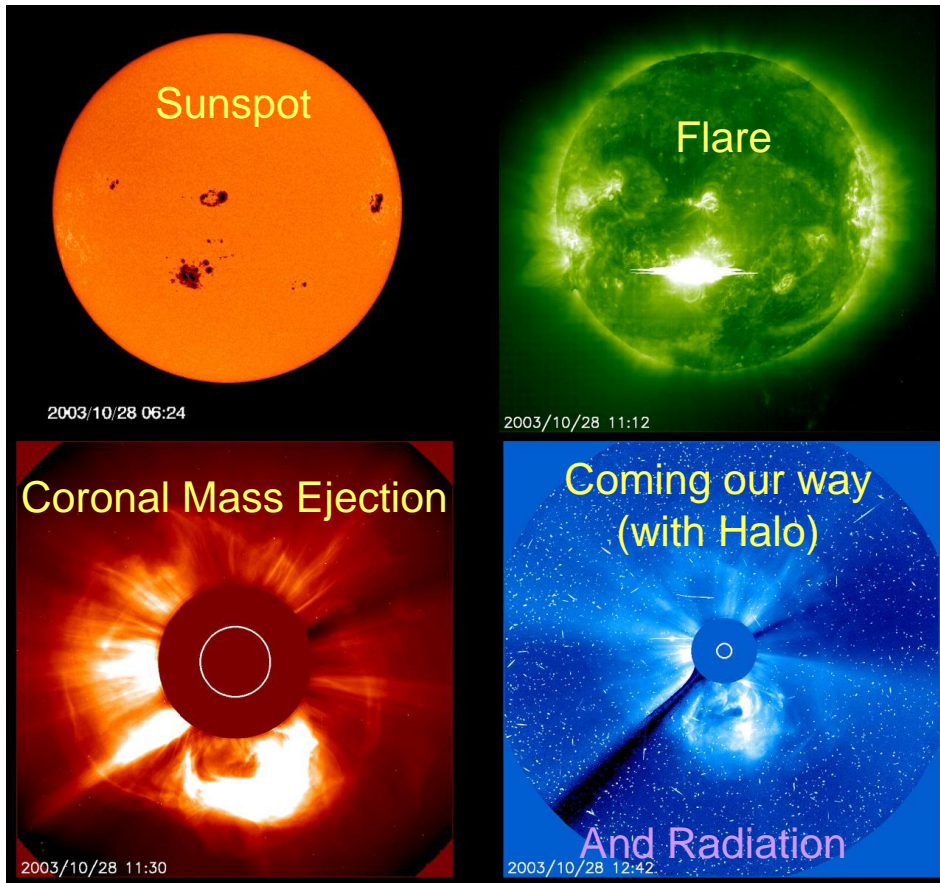
The 11-yr Solar Cycle

An 'Active Region' = Lots of Magnetic Fields



Solar Storms and Consequences

The energy stored in twisted Active Regions can be released explosively causing dangerous radiation and plasma hurled into space. If Earth-directed, this 'debris' from the explosions can have damaging and disturbing effects on our technological infrastructure

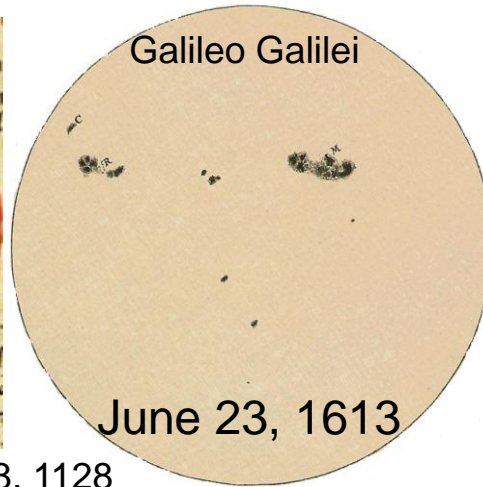


Centuries of Sunspot Observing

We have observed sunspots with telescopes for 400 years

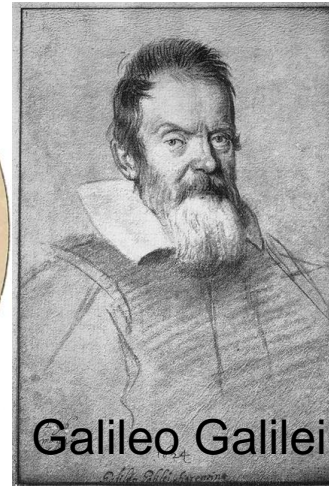


John of Worcester Dec. 8, 1128



Galileo Galilei

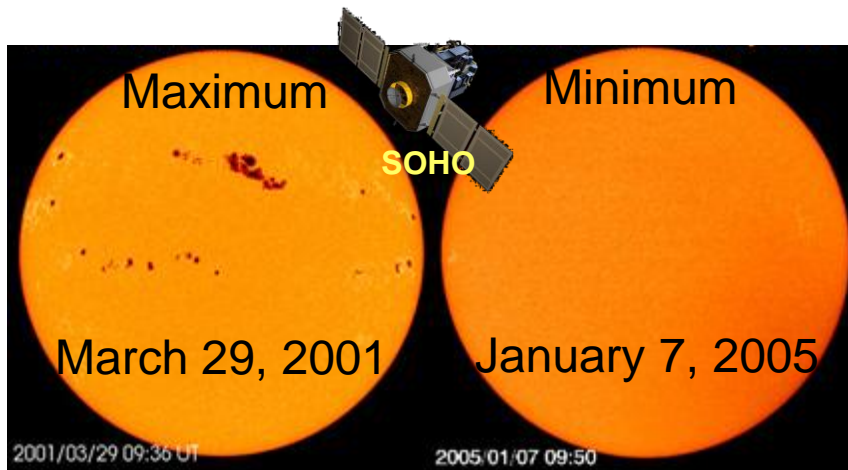
June 23, 1613



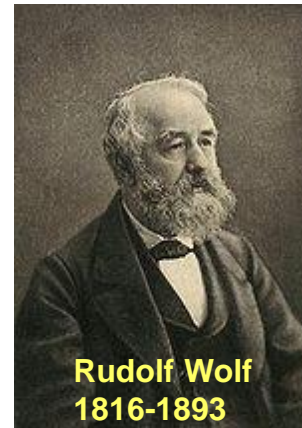
Galileo Galilei



Galileo's Telescope



Sunspots observed by Spacecraft



Rudolf Wolf
1816-1893



Wolf's Telescope

Still used today

'Compiler' of Sunspot Number

The sunspot number is always determined using small telescopes

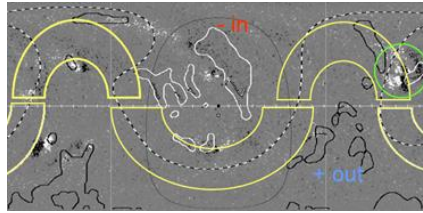
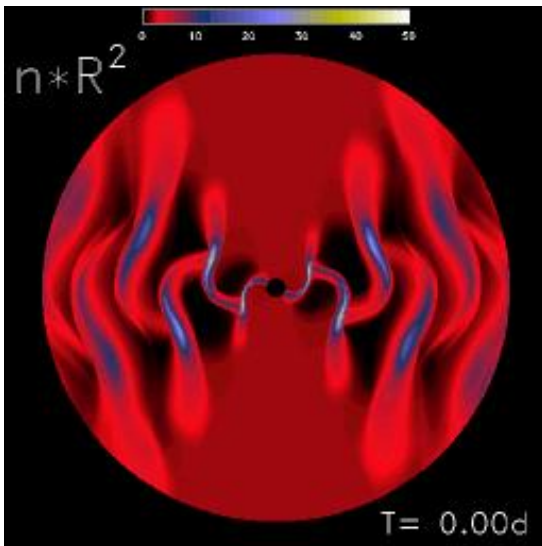
Returning to Solar Wind...

Schulz; Svalgaard; Saito (1974)



'Vertical' cut through the sweeping boundary:

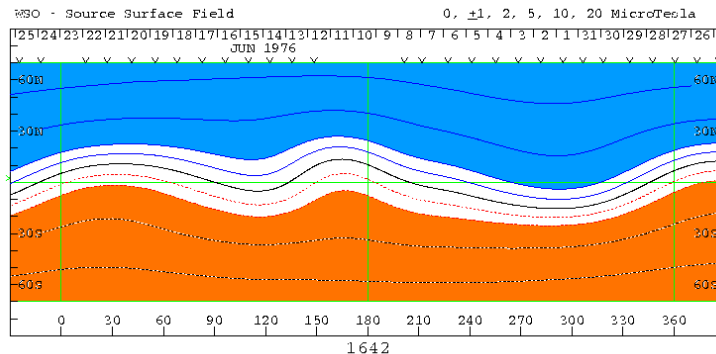
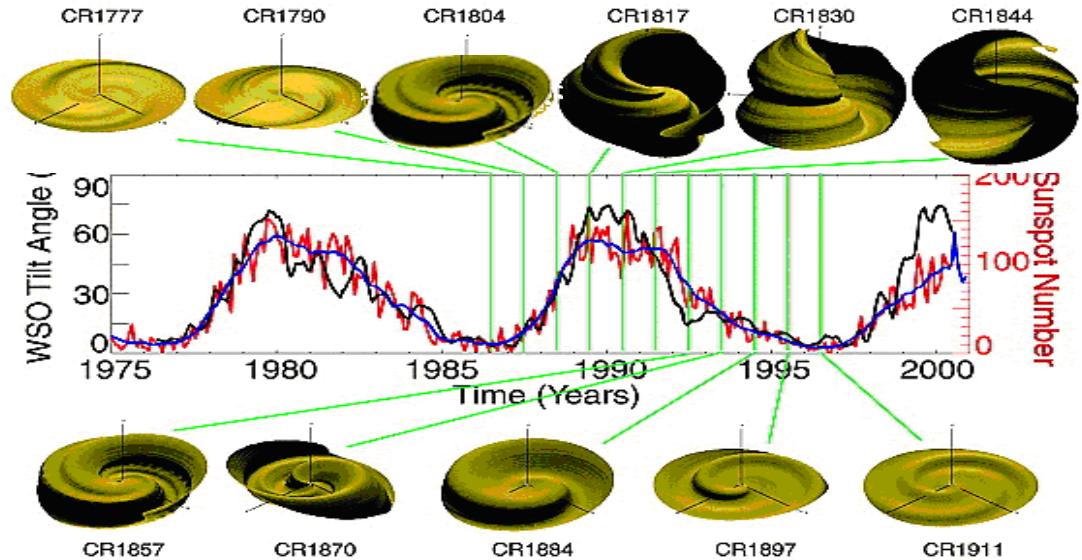
← 50 AU →



Sector boundary

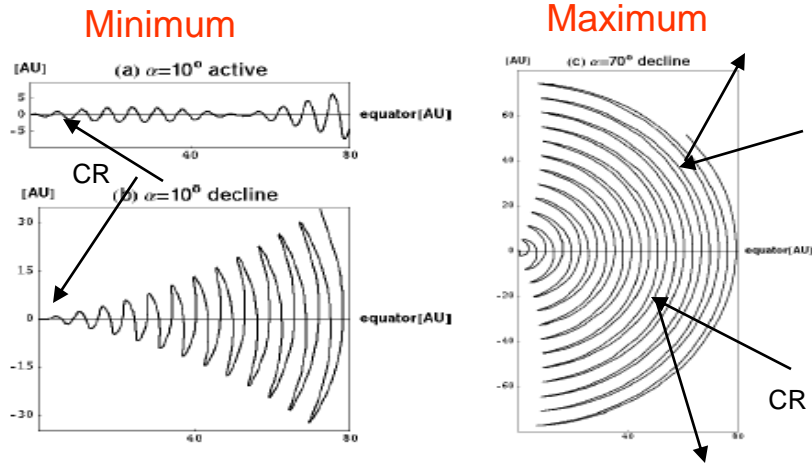
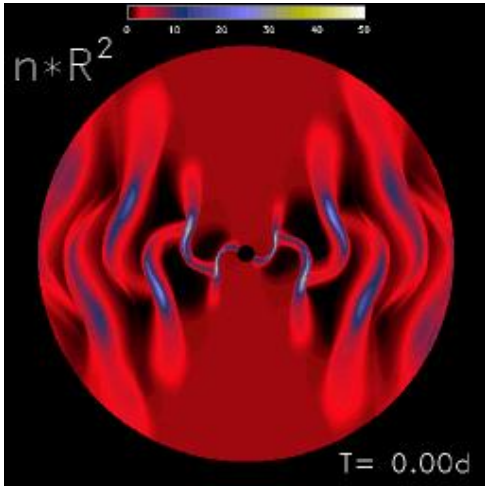
The Boundary through the Cycle

Near the sector boundary the solar wind is denser and slower. As the Sun rotates this builds up spiraling layers of denser plasma wrapping around the Sun many times:



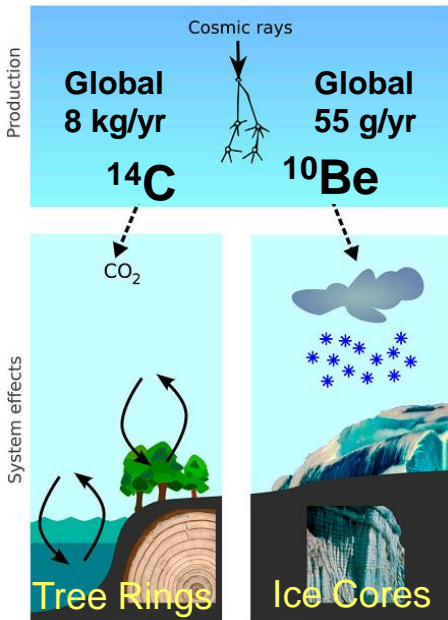
The 'flapping' sector boundary in time. Note the changing extent

Cosmic Rays from the Milky Way Galaxy



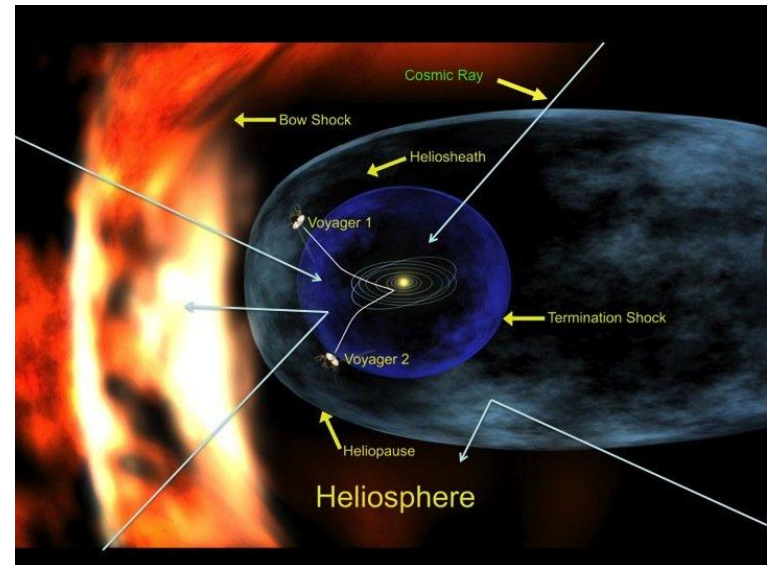
Cosmic Ray Modulation caused by solar cycle variation of current sheet extent and of solar storms

At maximum, more Cosmic Rays are deflected out of the solar system and do not reach the Earth:



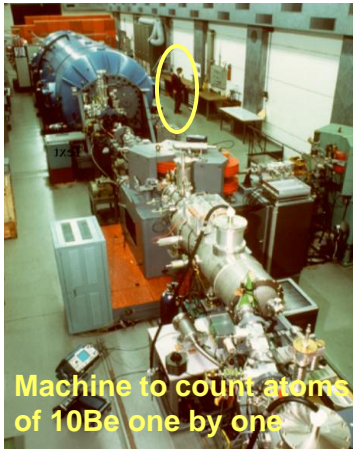
About 30 [secondary] cosmic rays fly through your body every second

When hitting the atmosphere Cosmic Rays produce **radioactive** Carbon14 and Beryllium10 isotopes

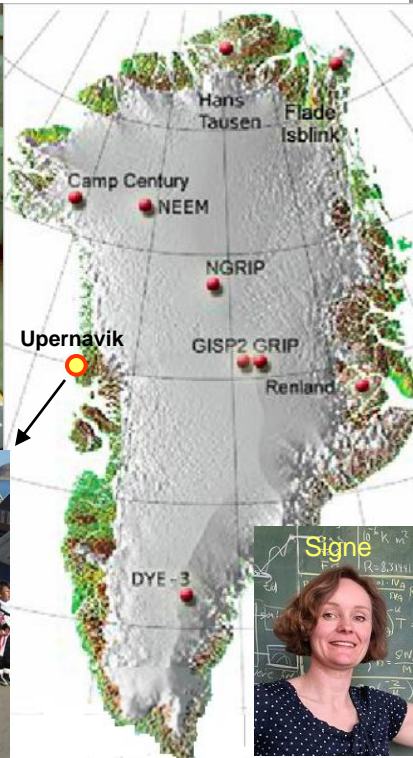


Drilling for Ice Cores

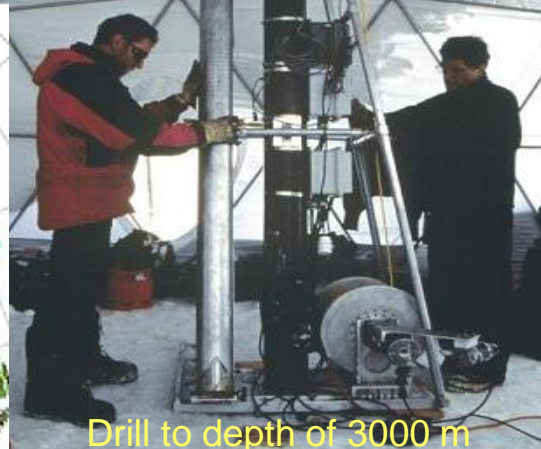
To measure the ^{10}Be concentration and thus the Cosmic Rays thousands of years back in time



Machine to count atoms of ^{10}Be one by one



Signe



Drill to depth of 3000 m



Be-10

Quelcaya glacier

Annual Layers in the Ice

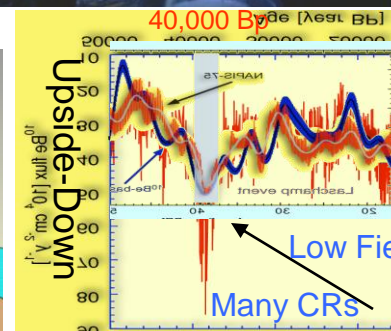
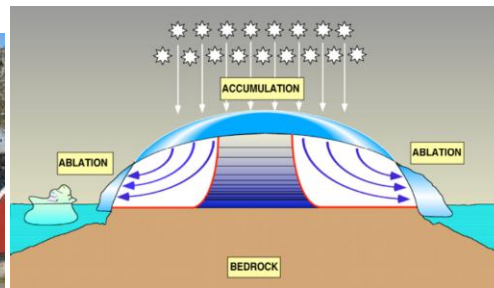


First day of school

Upernavik, 1130 inh



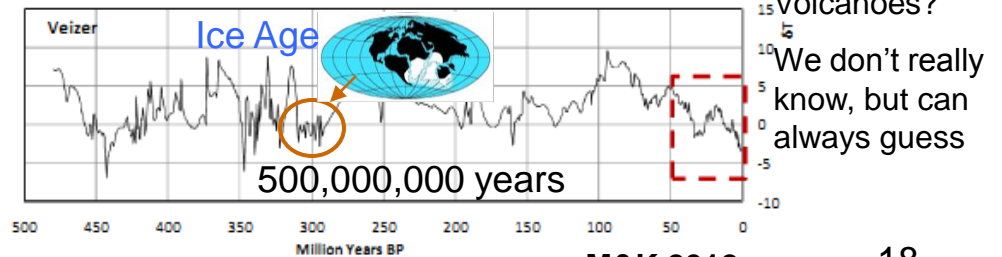
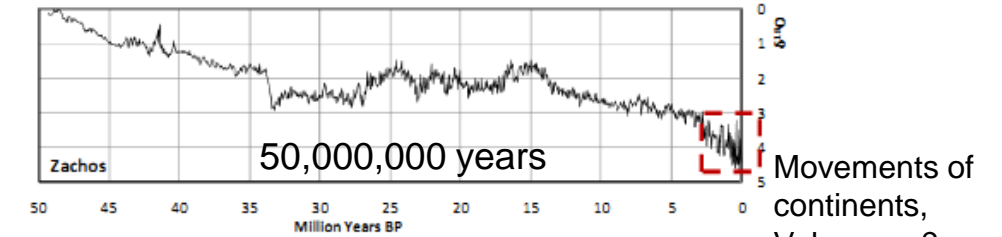
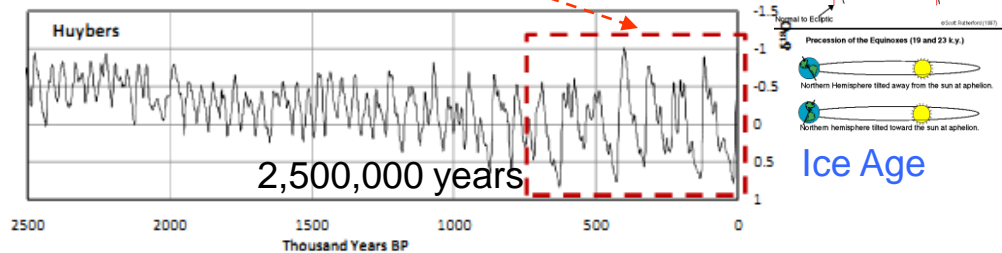
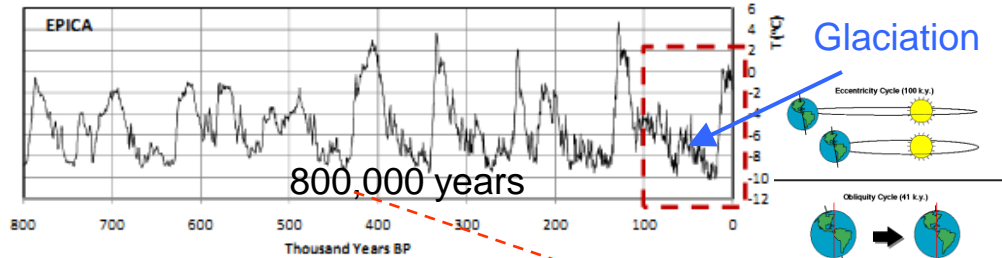
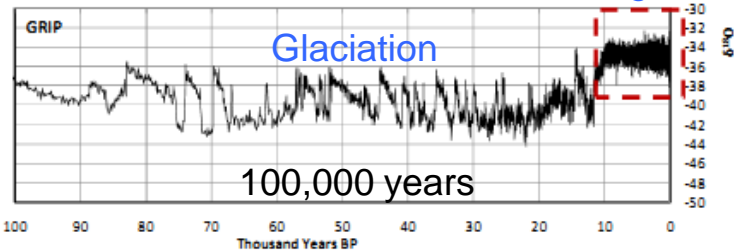
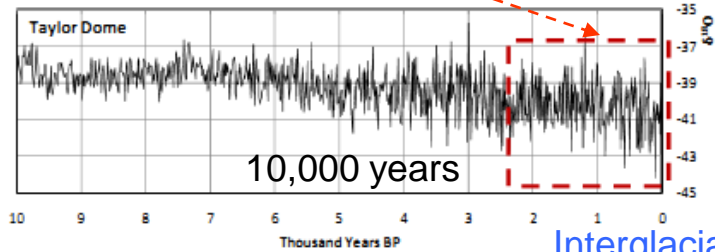
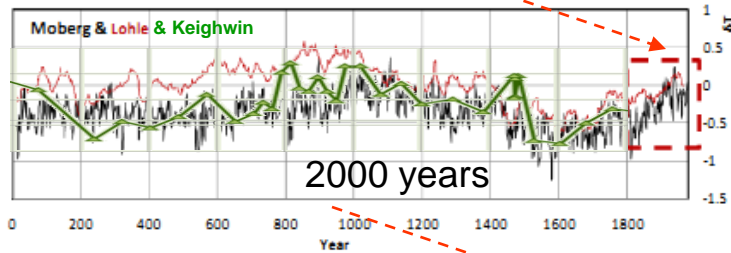
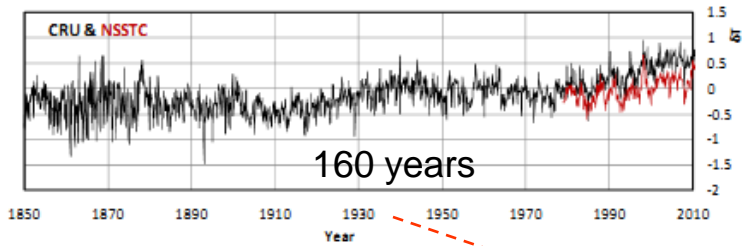
Greenland グリーンランド



Cosmic Ray counts are also influenced by the Earth's magnetic field. We can correct for that. 17

Large Climate Variation over Time

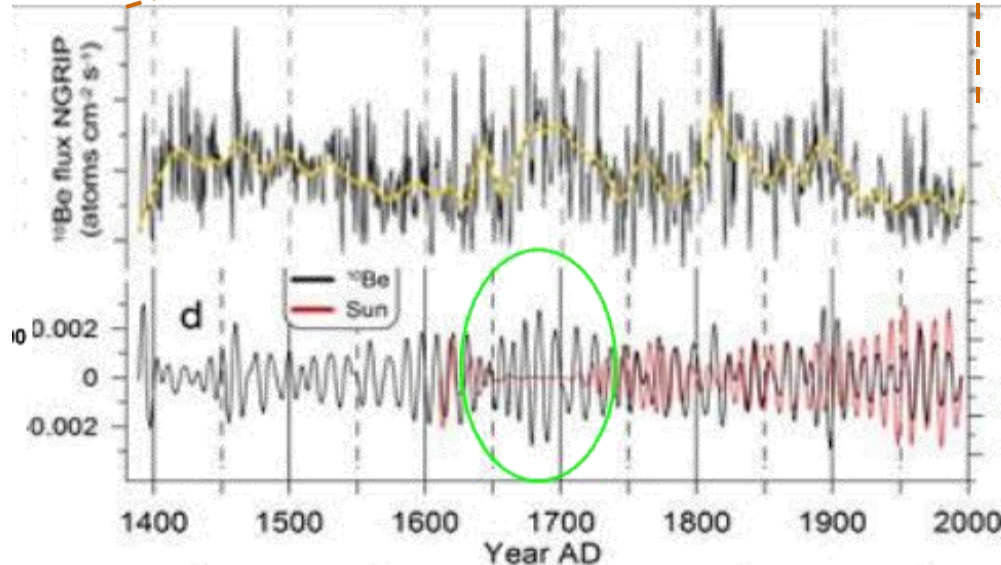
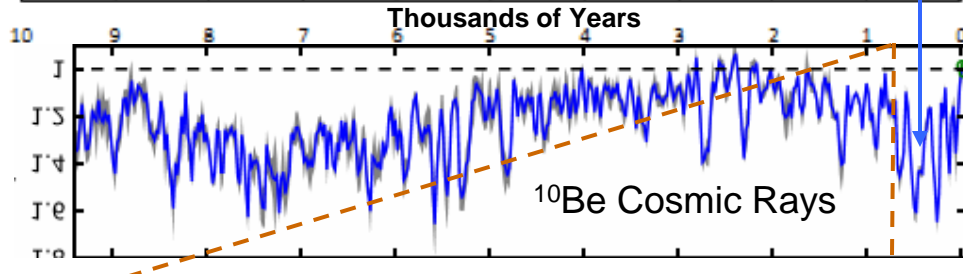
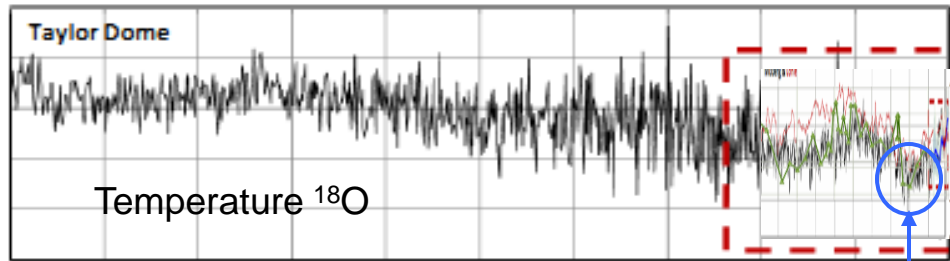
Is the variable Sun the cause of climate variation? **Not** of the large variations



Movements of continents,
Volcanoes?

We don't really know, but can always guess

But surely, the Shorter Term Variations Must be Controlled Mainly by the Sun?

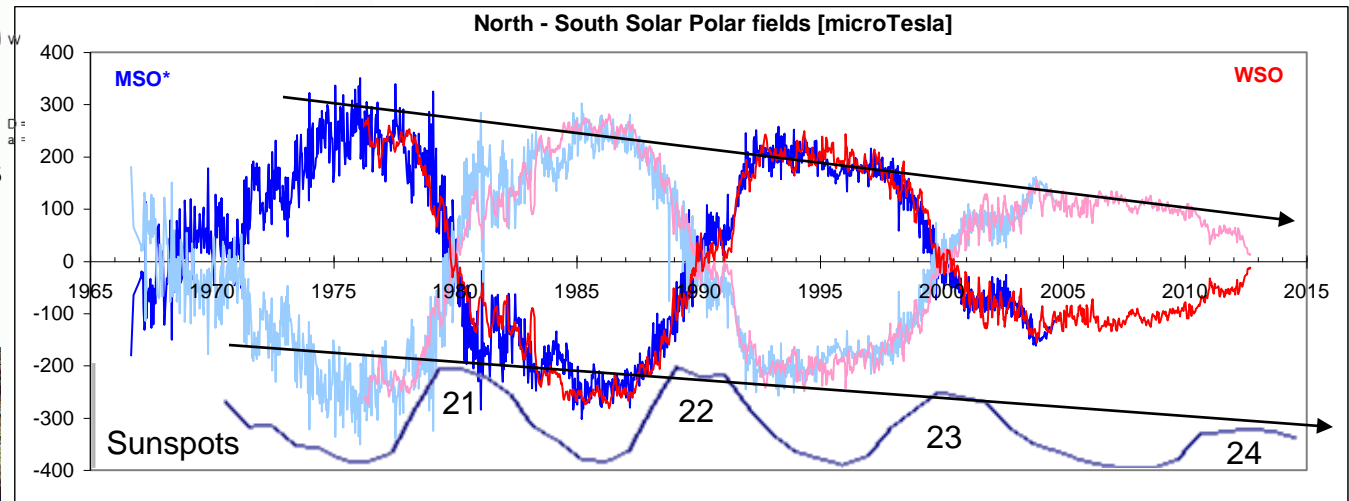
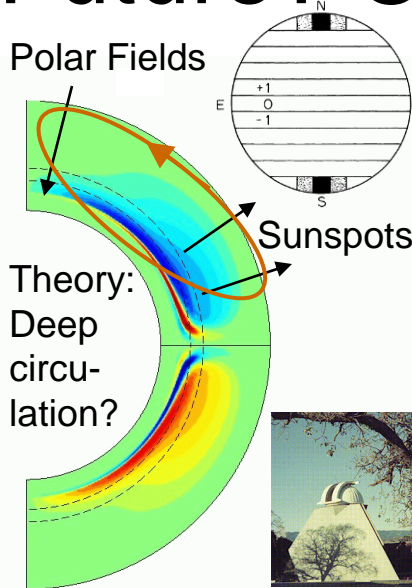


Much has been made of the period 1645-1715 [called the Maunder Minimum] where it was cold and solar activity was low

But if we compare the temperature over the past 10,000 years with the ^{10}Be concentration there is very little convincing correlation

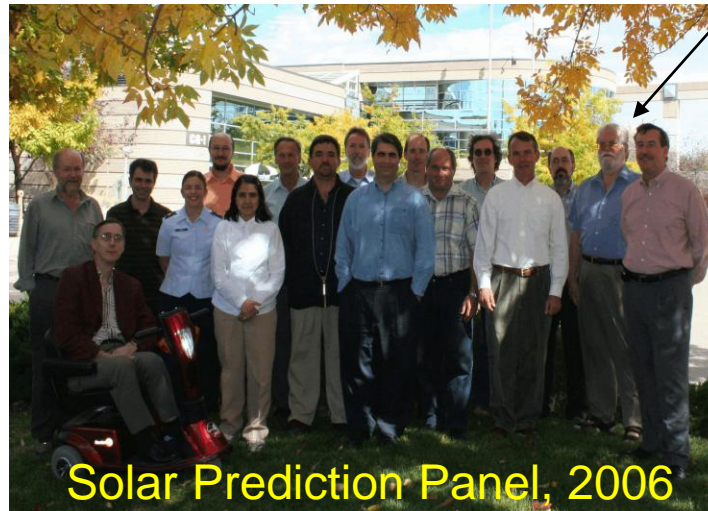
During the Maunder Minimum the modulation of Cosmic Rays was strong and healthy, but almost no sunspots were observed. The reason for this is not known, but there are tantalizing hints that such a situation may arise in the next few decades.

So, what will Solar Activity be in the Future? Can we predict Solar Activity?



Many uncertainties remain. Expect SDO to tell us more about the interior of the Sun

Observations seem to indicate a Shallow Circulation

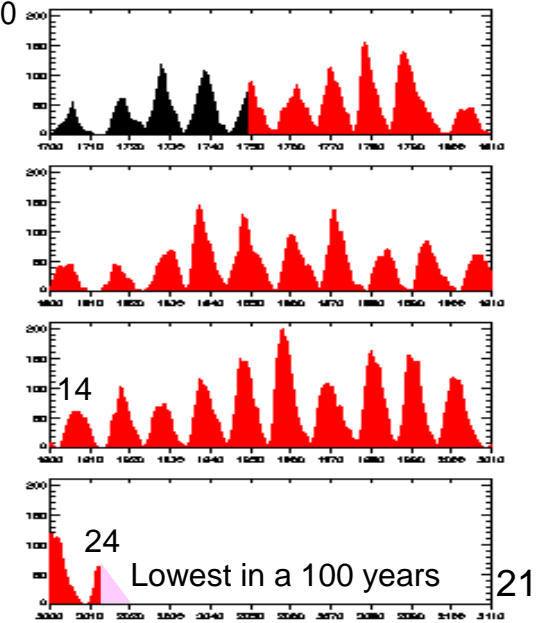
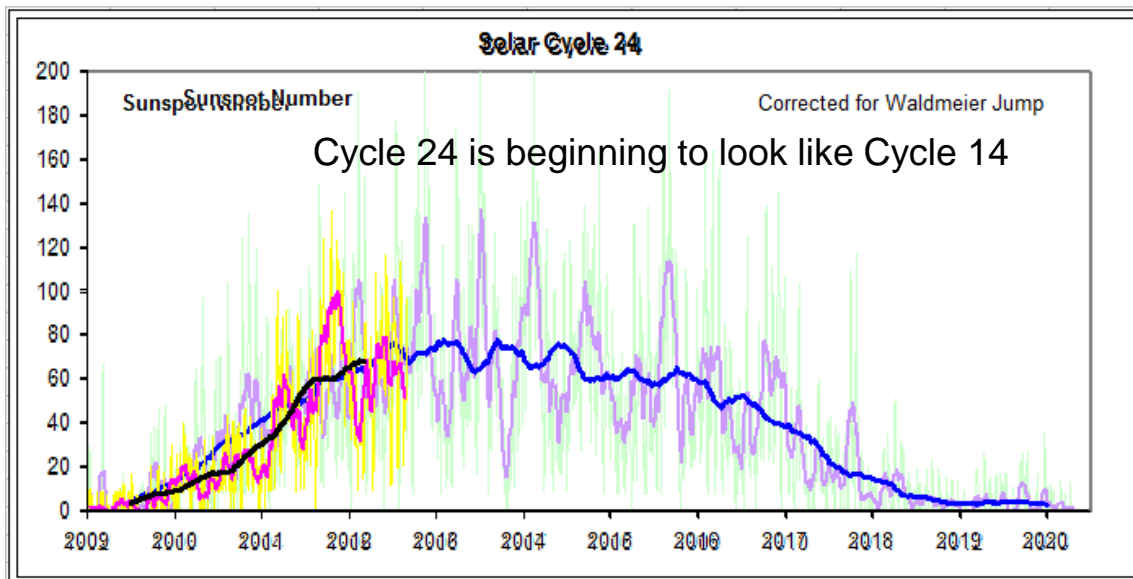
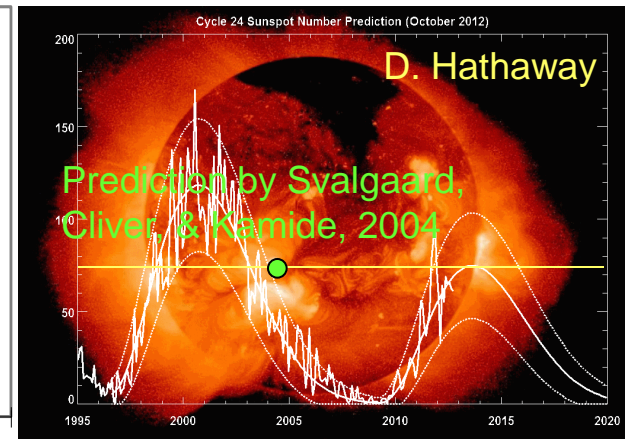
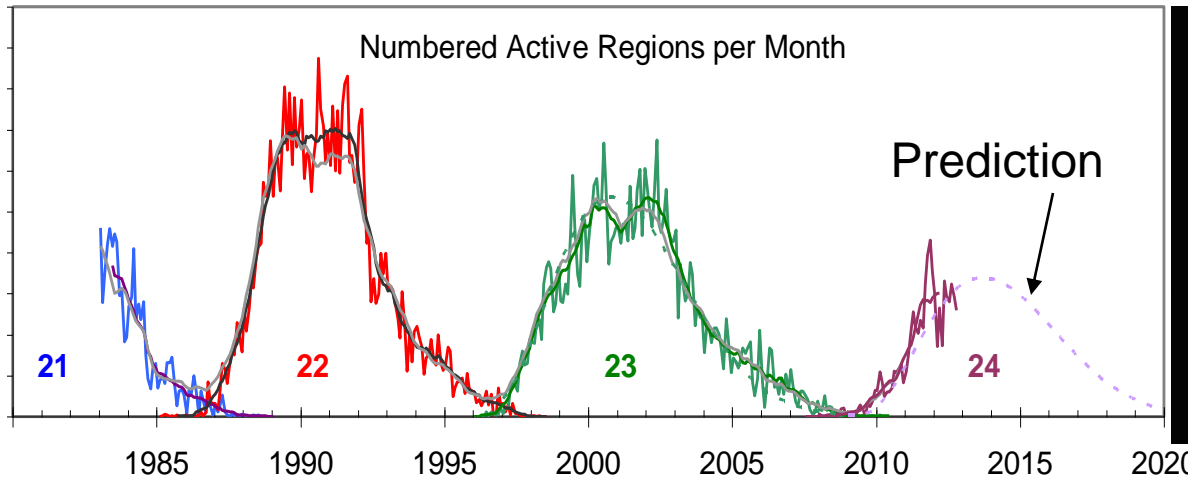


Observations and theory suggest that the magnetic field at the poles of the Sun at solar minimum is a good predictor of the next solar cycle.

The low polar fields at the recent minimum predicted a small cycle 24

How is Cycle 24 Evolving? As Predicted!

Active Region Count



What have we learned?

- Science and Scientists are International
- The Earth itself can be used as an 'instrument' to study the Sun and the Solar System
- Such Study crosses many scientific Disciplines
- Science is a Learning Process that lasts your whole Life
- Our technological civilization is becoming more vulnerable to Solar and Space Weather, so we need to study hard and learn more



The End