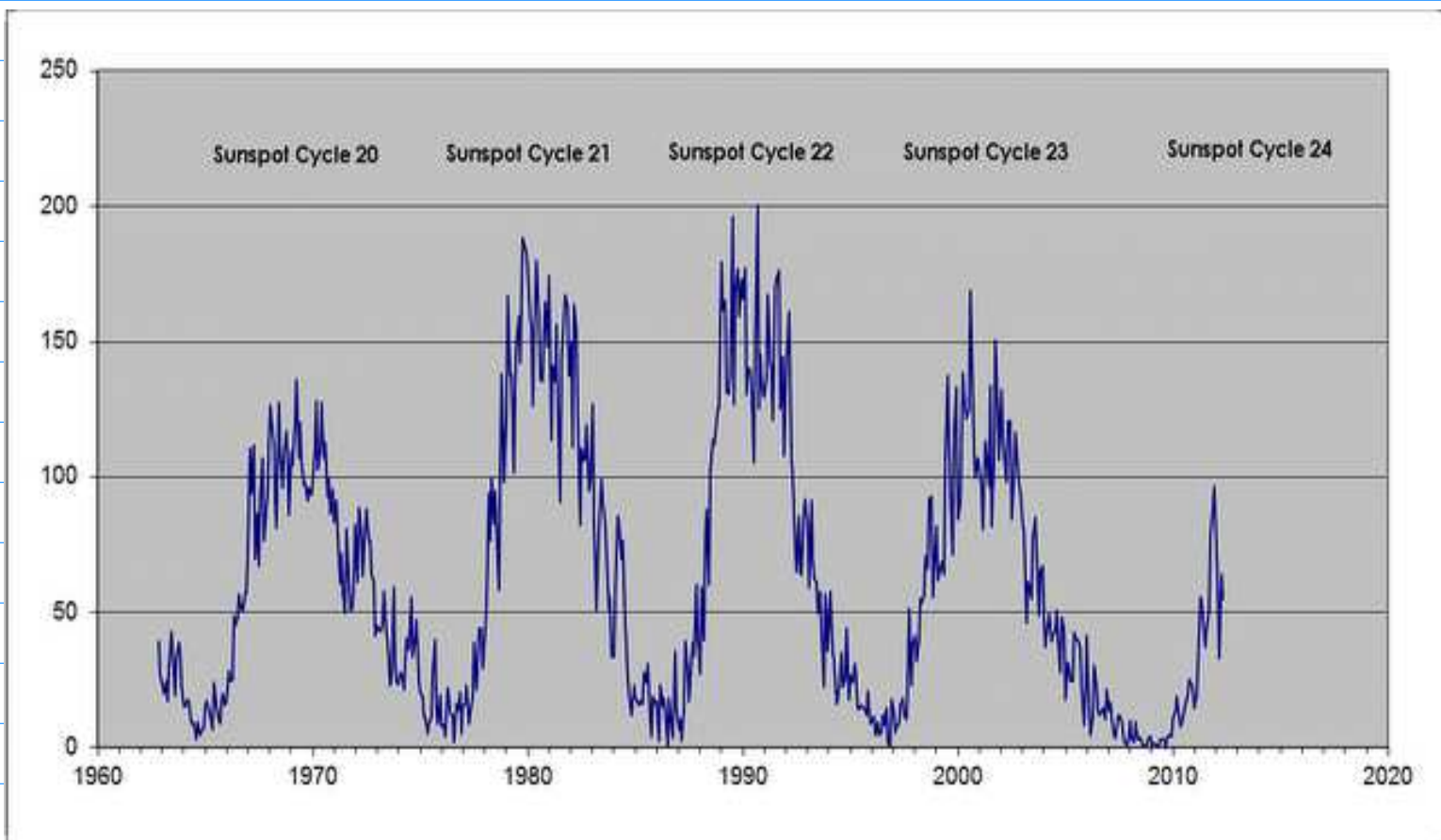
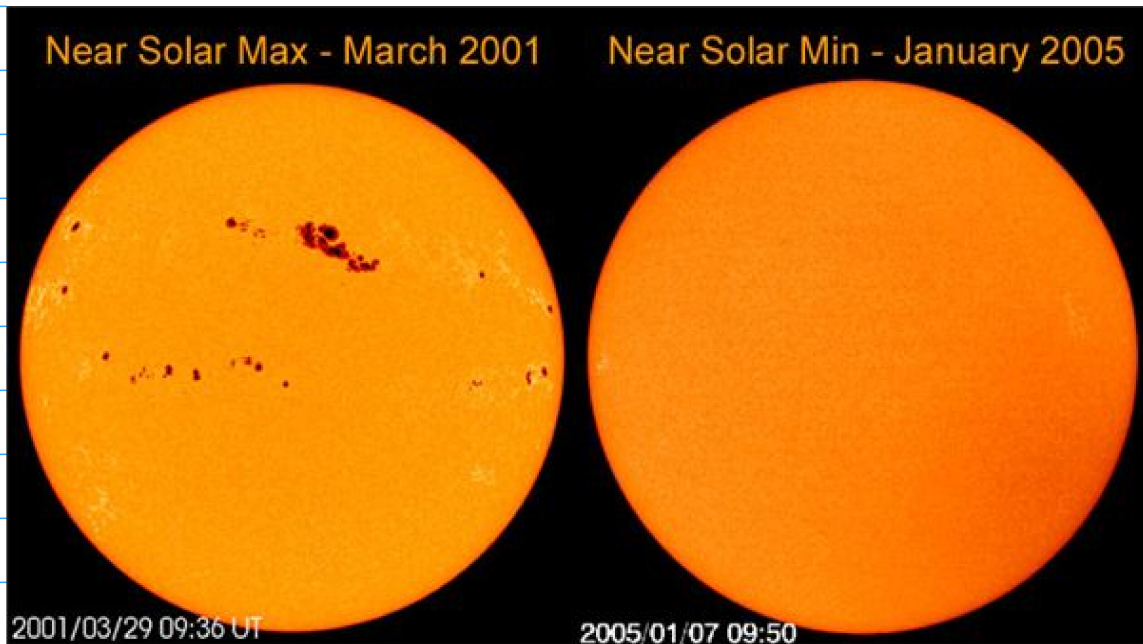


THE SOLAR ACTIVITY CYCLE

THE TOTAL NUMBER OF SUNSPOTS VISIBLE ON THE SUN IS NOT CONSTANT - IT VARIES IN A PERIODIC WAY WITH A PERIOD OF ABOUT 11 YEARS (H. SCHWABE 1843). THIS IS NOW KNOWN AS THE SUNSPOT CYCLE OR SOLAR ACTIVITY CYCLE:

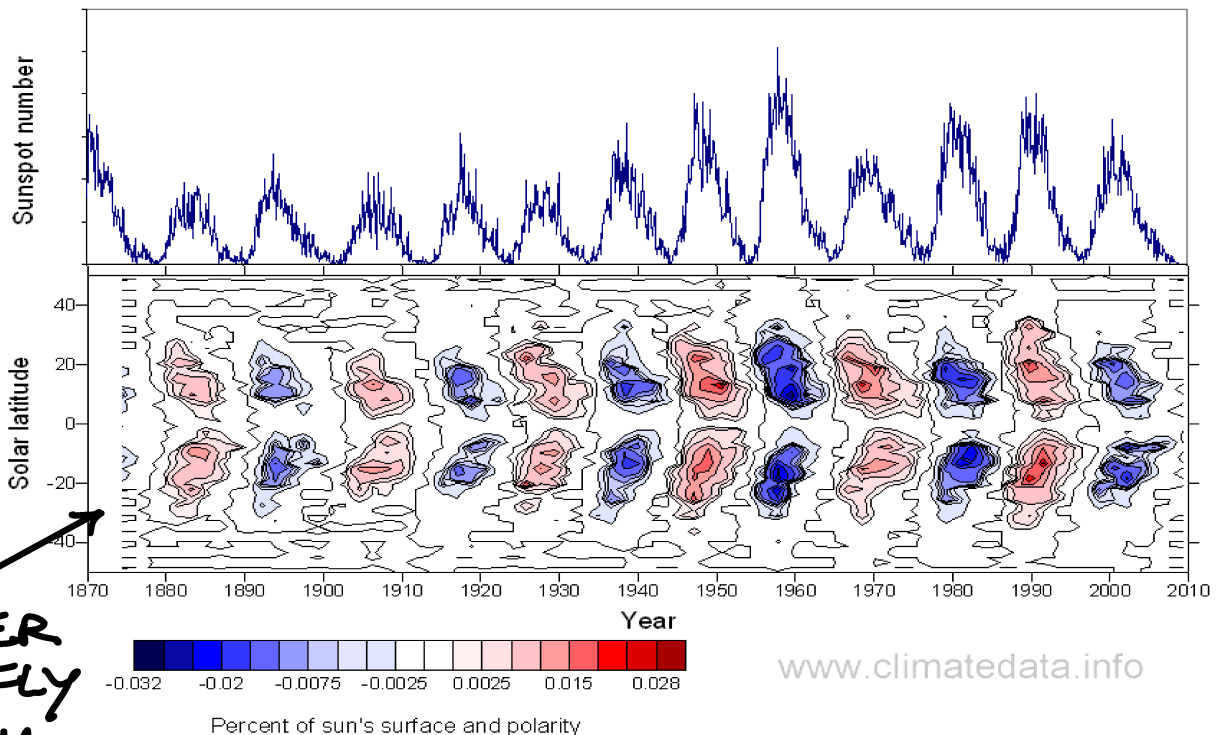


AT A SUNSPOT MAXIMUM THERE COULD BE 100-200 SPOTS VISIBLE AT ANY ONE TIME.



AT A SUNSPOT MINIMUM THERE ONLY FEW SMALL SPOTS (IF ANY).

Solar cycles - variation with solar latitude and time

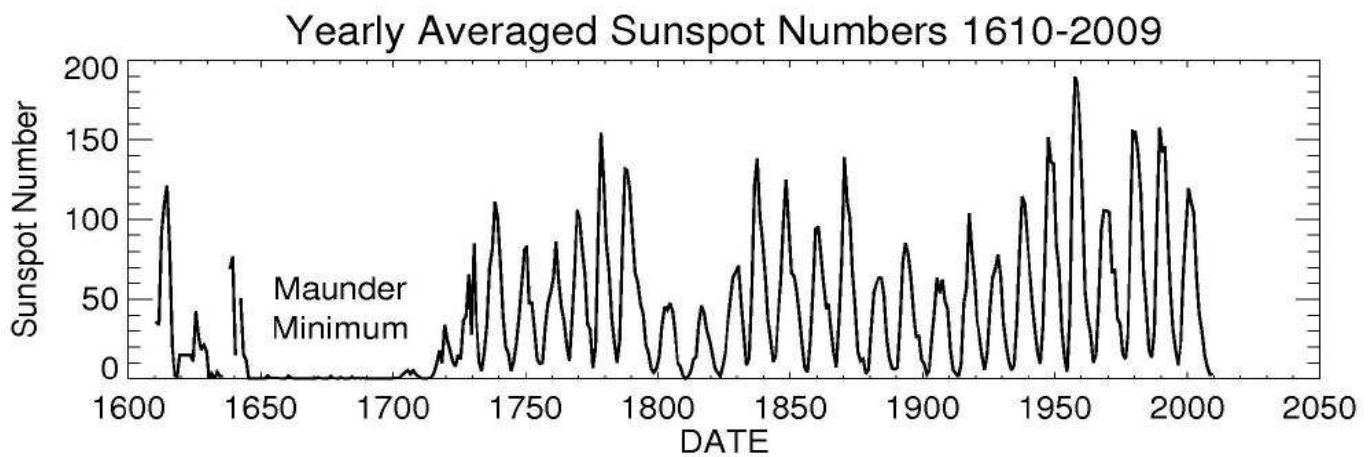


MAUNDER BUTTERFLY DIAGRAM

AT THE BEGINNING OF EACH CYCLE, THE SPOTS BEGIN TO APPEAR AT SUN'S LATITUDES OF ABOUT 35° ABOVE AND BELOW THE SUN'S EQUATOR.

AS THE CYCLE PROCEEDS, THE SPOTS MOVE TO THE LOWER LATITUDES, AND THE END OF THE CYCLE THEY ARE WITHIN 5° OFF THE SUN'S EQUATOR.

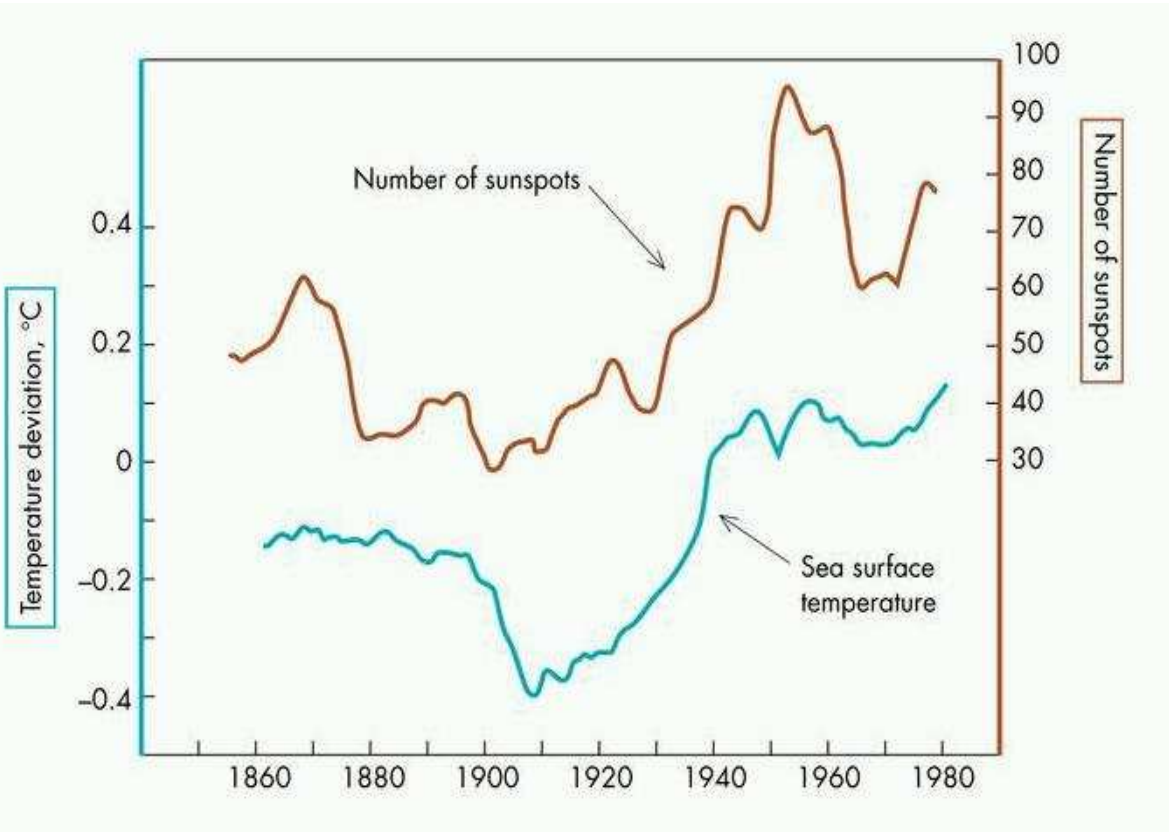
MAUNDER NOTICED THAT THE RECORDS SHOW VERY FEW SUNSPOTS FROM 1645 TO 1715 (MAUNDER MINIMUM):



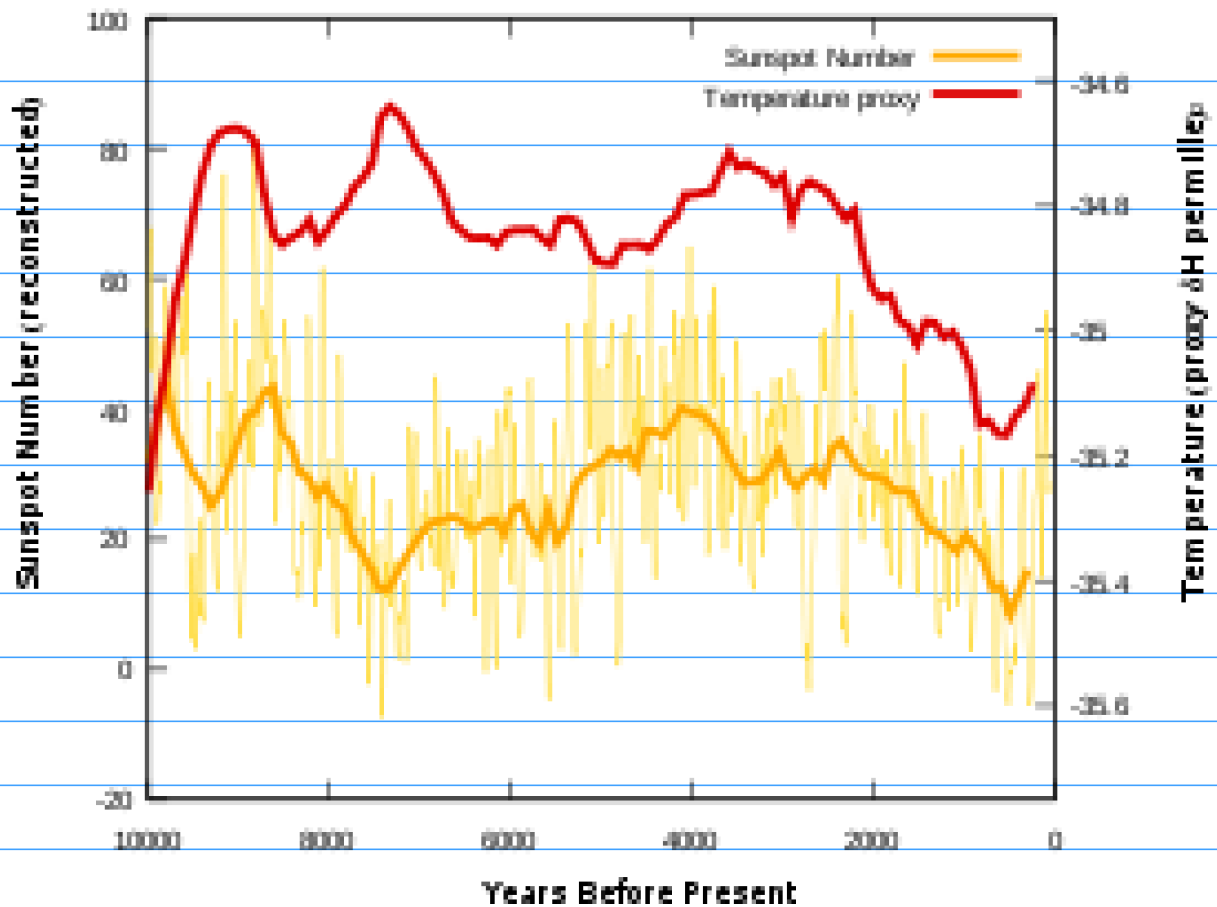
THE MAUNDER MINIMUM COINCIDED WITH THE LITTLE ICE AGE IN EUROPE AND NORTH AMERICA: GLACIERS IN THE ALPS ADVANCED, RIVERS FROZE EARLY AND REMAINED FROZEN LATE, THE NORTH SEA AND THE BALTIC SEA FROZE.



FROST FAIR ON THE THAMES, 1685 BY UNKNOWN ARTIST

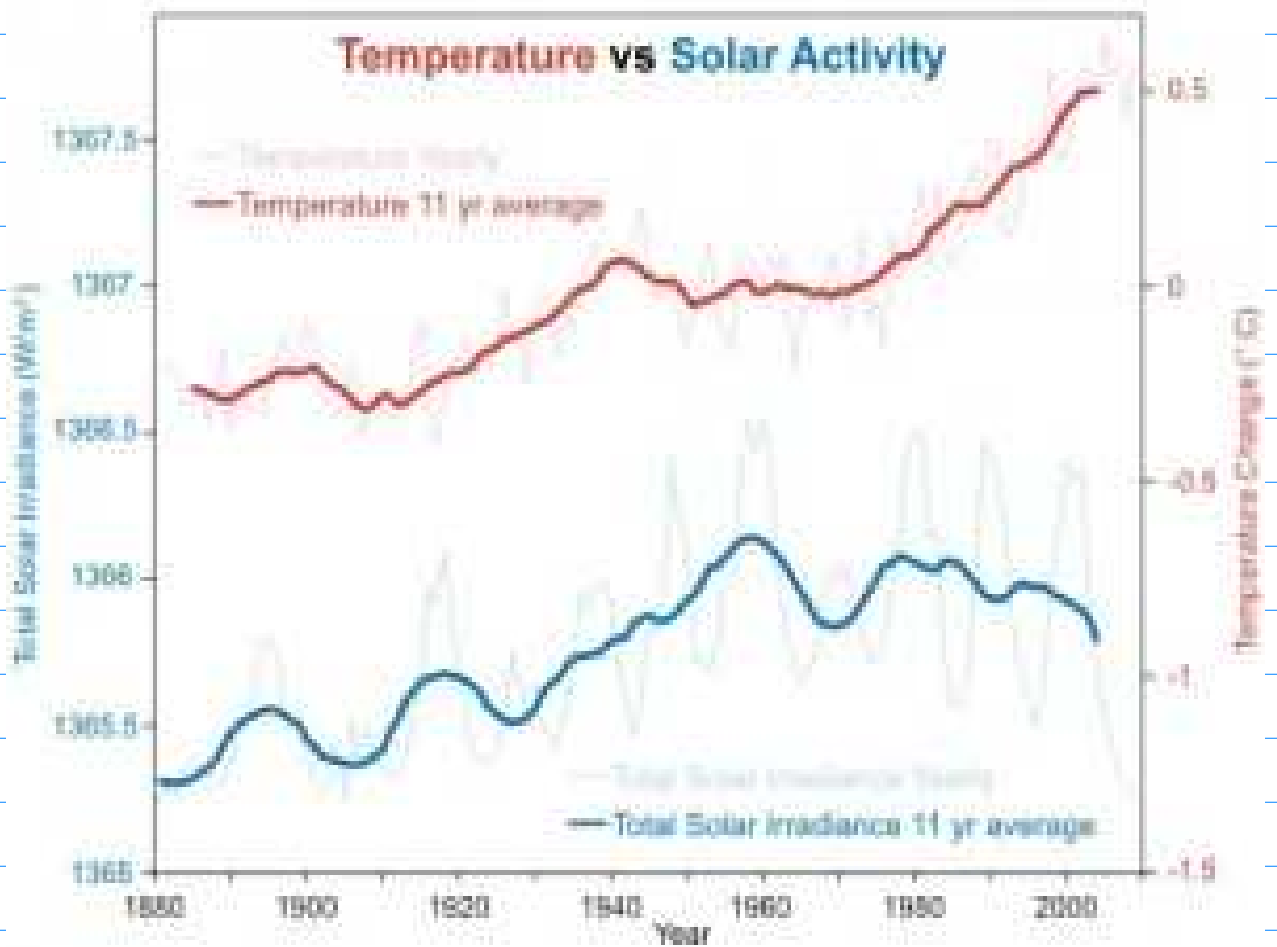


Sunspot Activity and Temperature

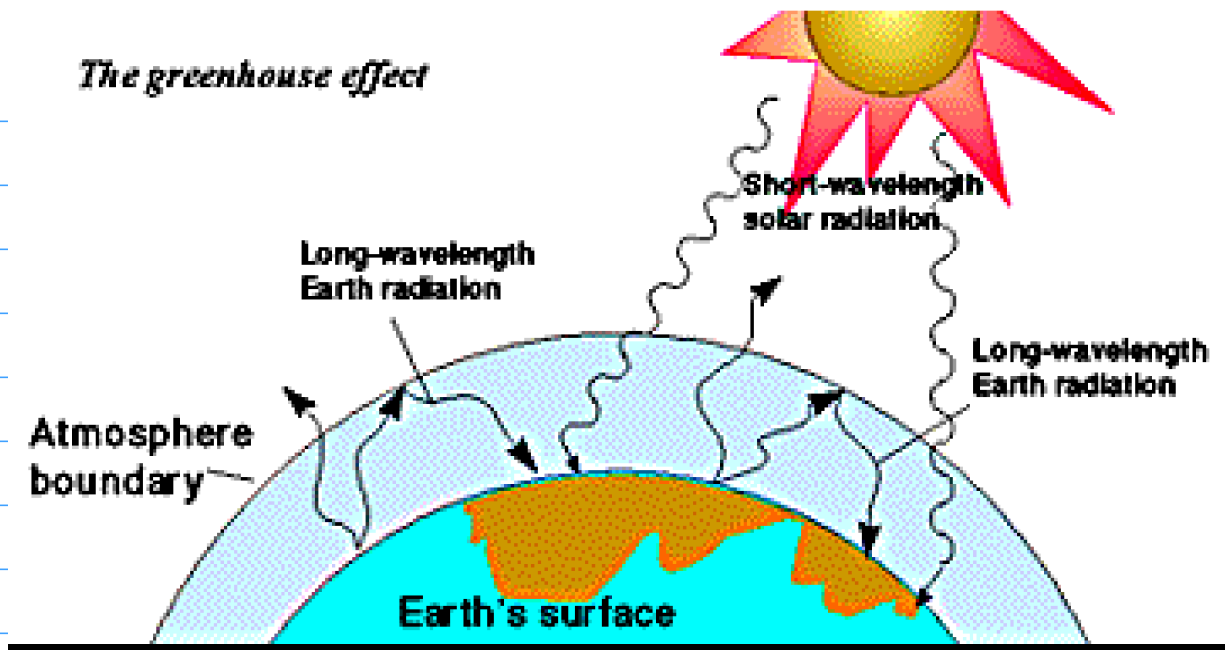


THE DATA FROM BEFORE 1980 SUGGEST THAT THE SOLAR ACTIVITY AS MEASURED BY THE AVERAGE NUMBER OF SUNSPOTS GOES HAND-IN-HAND WITH THE AVERAGE OCEAN TEMPERATURE.

HOWEVER, AFTER 1980 THAT DOES NOT SEEM TO BE THE CASE:



THE INCREASE IN TEMPERATURE WITH DECREASE IN SOLAR ACTIVITY AFTER 1980 IS ATTRIBUTED TO AN INCREASE IN CO₂ EMISSIONS. WATER VAPOR (H₂O), CO₂ AND METHANE ARE THE GREENHOUSE GASES THAT TRAP INFRARED RADIATION WHICH WARMS UP THE ATMOSPHERE:

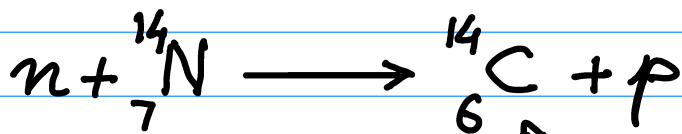
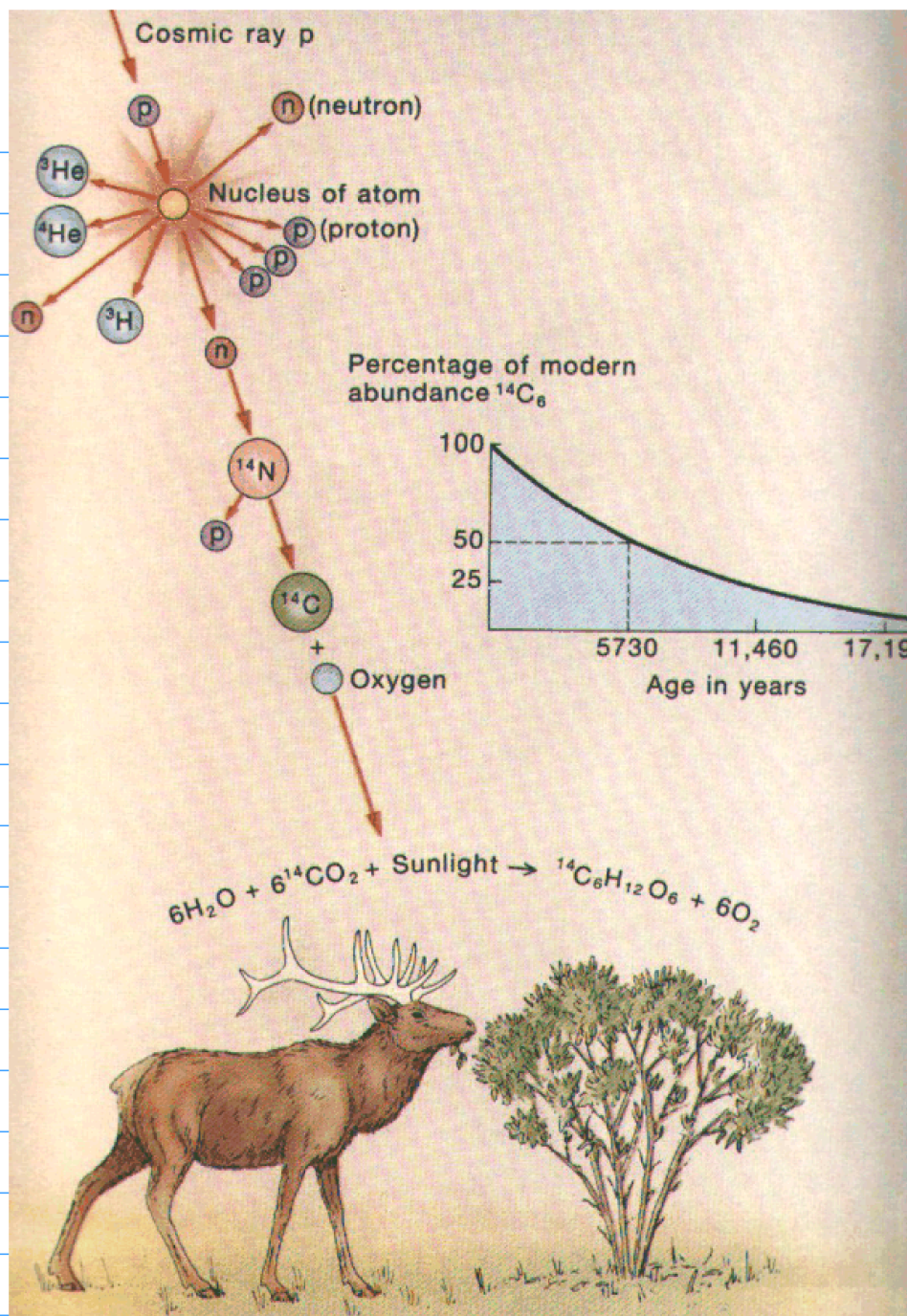


OTHER THAN THE SUNSPOT CYCLE, DO WE HAVE OTHER EVIDENCE ABOUT THE SUN'S ACTIVITY IN THE PAST?

THE EVIDENCE COMES FROM THE VARIATION IN THE CONCENTRATION OF ^{14}C IN THE PAST.

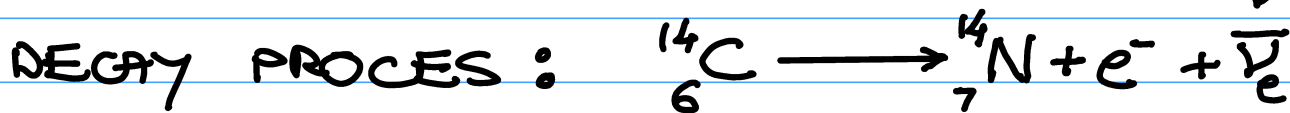
THERE ARE TWO STABLE ISOTOPES OF CARBON OCCURRING IN NATURE: $^{12}_6\text{C}$ AND $^{13}_6\text{C}$.

HOWEVER, THE COSMIC RAYS COULD TRIGGER TRANSFORMATION OF NITROGEN NUCLEI $^{14}_7\text{N}$ IN THE ATMOSPHERE (78% OF THE AIR IS N_2) TO THE NUCLEI OF UNSTABLE NUCLEUS $^{14}_6\text{C}$.



UNSTABLE

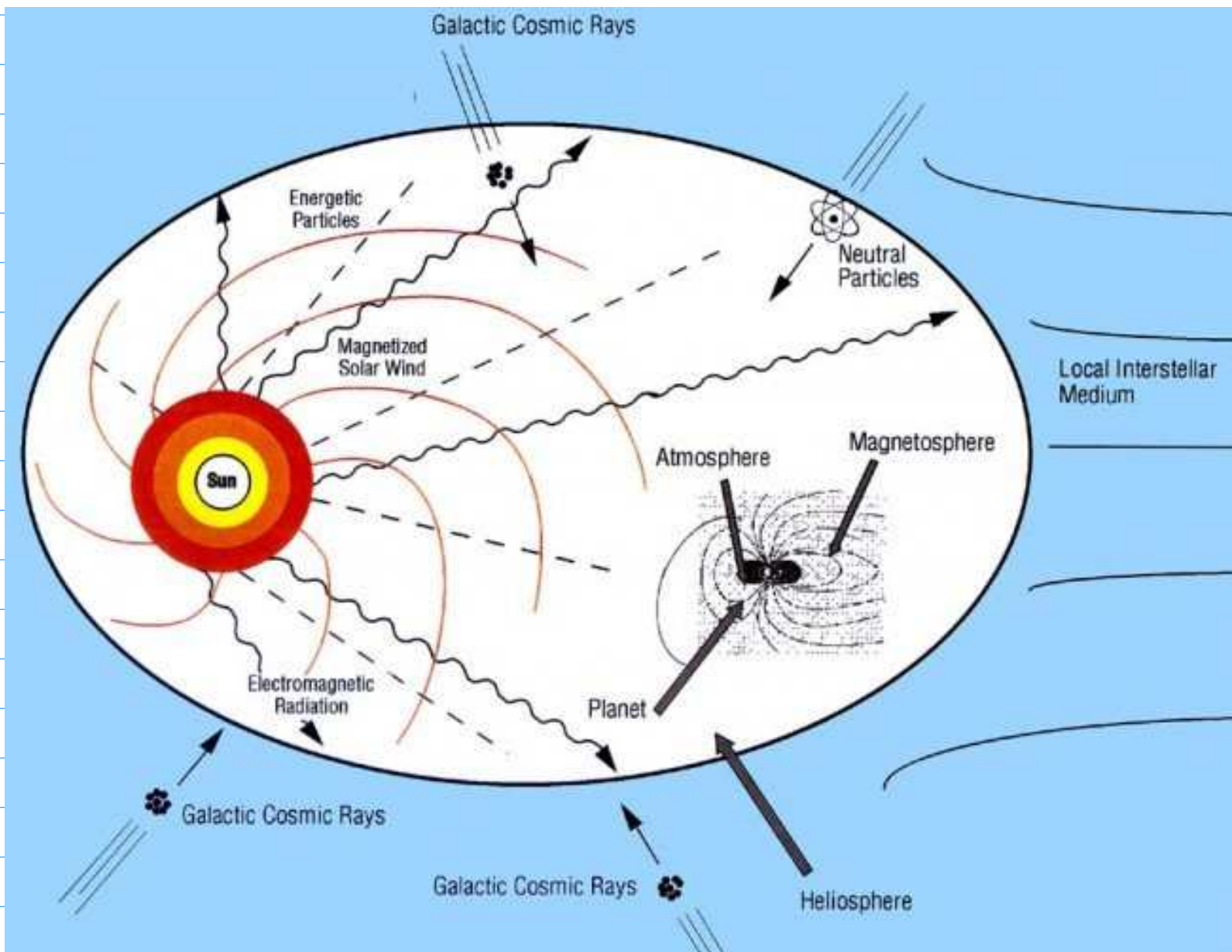
ELECTRON.
ANTINEUTRINO



THE DECAY PROCESS IS STOCHASTIC: WE CANNOT SAY WHEN EXACTLY A GIVEN NUCLEUS WILL DECAY BUT WE KNOW THE PROBABILITY THAT IT WILL DECAY IN

TIME t . THE HALF-LIFE OF $^{14}_6\text{C}$, I.E. THE TIME IN WHICH A HALF OF A LARGE NUMBER OF $^{14}_6\text{C}$ NUCLEI DECAY, IS 5730 YEARS.

WHEN THE SUN IS ACTIVE (NEAR SUNSPOT MAXIMA) THE SOLAR WIND IS STRONG AND IT CARRIES WITH IT THE SUN'S MAGNETIC FIELD WHICH SHIELDS THE EARTH FROM COSMIC RAYS:



THEREFORE:

DURING A HIGH SOLAR ACTIVITY THERE IS A LOWER CONCENTRATION OF $^{14}_6\text{C}$.

DURING A LOW SOLAR ACTIVITY THERE IS A HIGHER CONCENTRATION OF $^{14}_6\text{C}$.

$^{14}_6\text{C}$ IS INCORPORATED INTO PLANTS VIA $^{14}_6\text{CO}_2$ THROUGH PHOTOSYNTHESIS. BY MEASURING THE CONCENTRATION OF $^{14}_6\text{C}$ ONE CAN DEDUCE THE LEVEL OF SOLAR ACTIVITY IN THE PAST.

RESULTS:

LOW SOLAR ACTIVITY: 1280-1340, 1410-1530, 1645-1715 (MAUNDER MINIMUM)

HIGH SOLAR ACTIVITY: 800-1300 (TIME OF MEDIEVAL WARM PERIOD.)

AROUND 1000 AD IT WAS SUFFICIENTLY WARM THAT VIKINGS COULD FORM A LARGE SETTLEMENT AT THE NORTH OF NEWFOUNDLAND:



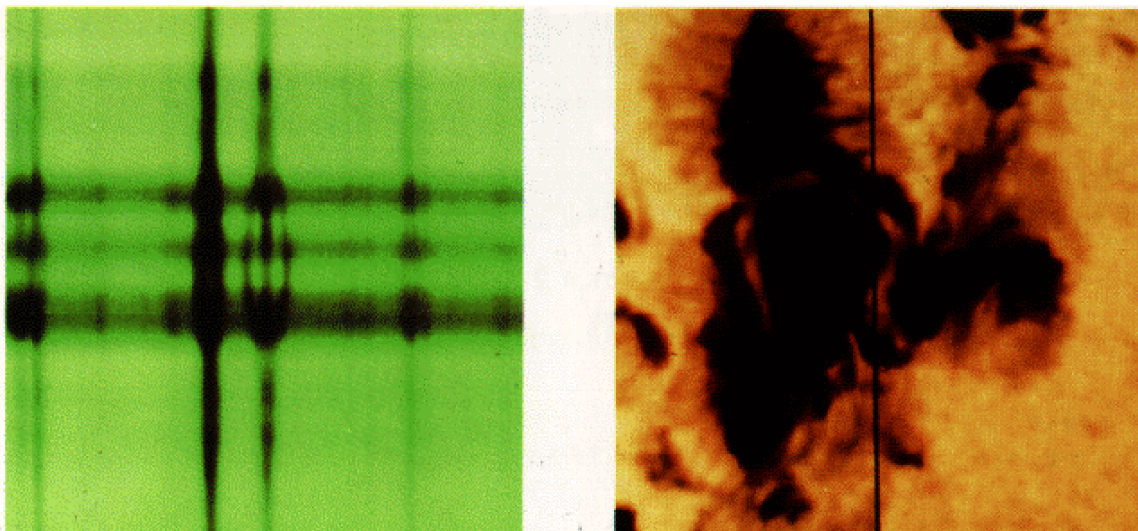
L'ANSE AUX MEADOWS, NEWFOUNDLAND

WHAT ARE THE SUNSPOTS? THE CLUE CAME IN 1908 WHEN G.E. HALE ESTABLISHED THAT THE MAGNETIC FIELD IN A SUNSPOT IS ABOUT 1000 TIMES STRONGER THAN THE SUN'S AVERAGE MAGNETIC FIELD:

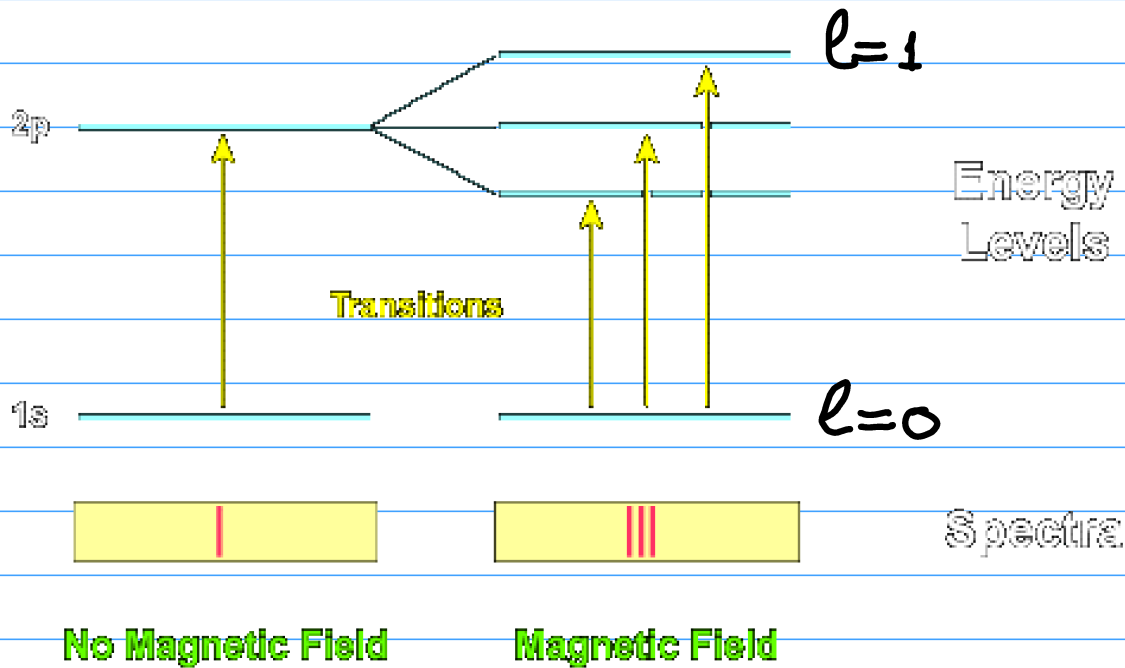
REGION
OUTSIDE OF
SUNSPOT

REGION IN
SUNSPOT

REGION
OUTSIDE
OF SUNSPOT



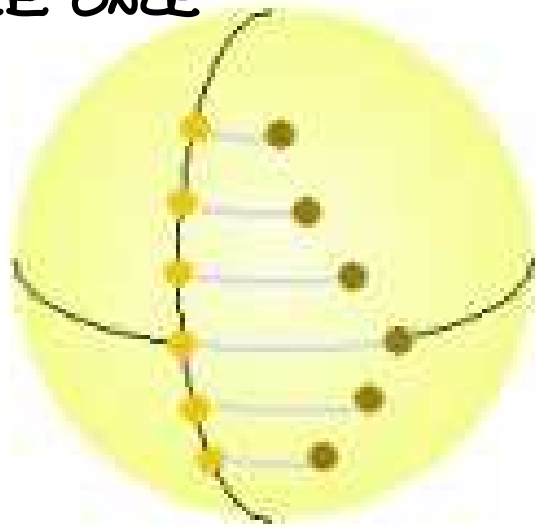
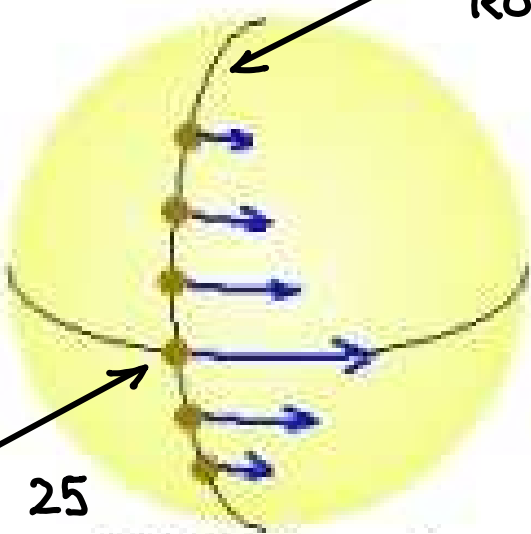
ZEEHAN EFFECT:



THE SUN'S MAGNETIC FIELD IS PRODUCED THROUGH A COMPLICATED PROCESS CALLED THE SOLAR DYNAMO WHICH IS STILL POORLY UNDERSTOOD.

THE ESSENTIAL PART OF THE SOLAR DYNAMO IS THE FACT THAT THE SUN UNDERGOES A DIFFERENTIAL ROTATION: THE POINTS NEAR SOLAR EQUATOR MOVE FASTER THAN THE POINTS NEAR THE POLES:

APPROXIMATELY 30 DAYS TO ROTATE ONCE

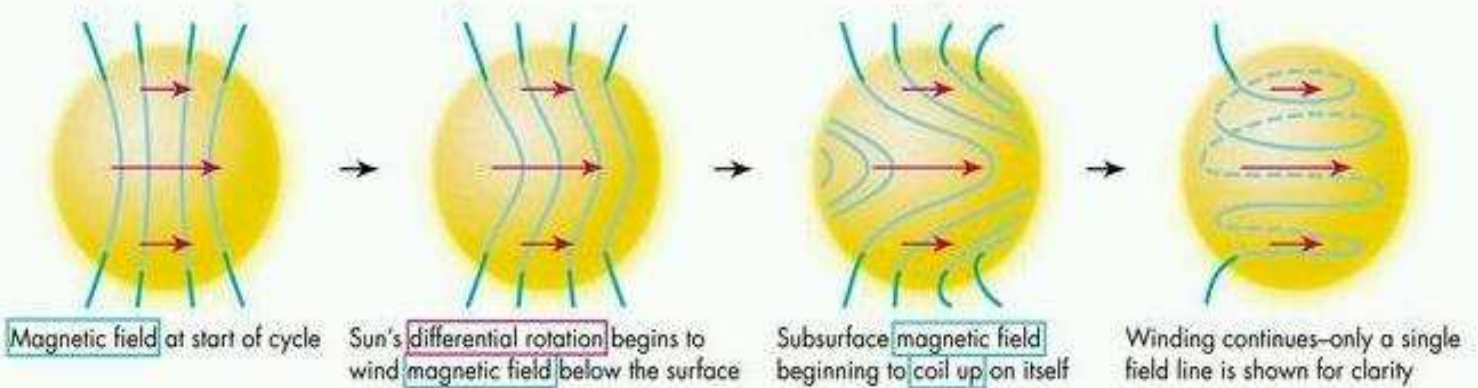


APPROX. 25 DAYS TO ROTATE ONCE

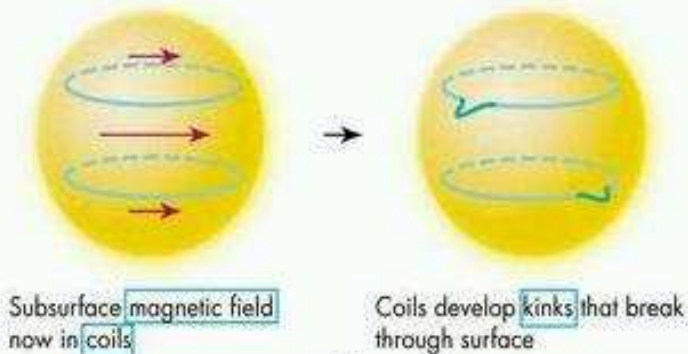
Initially, all lined up

Five days later

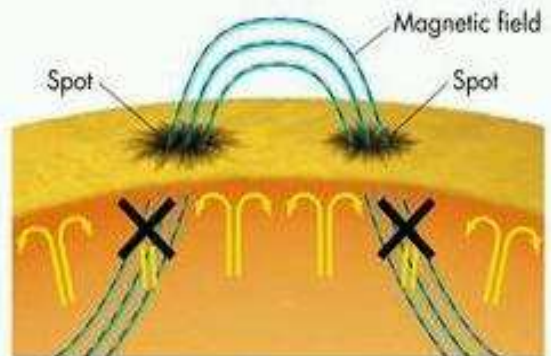
THIS DIFFERENTIAL ROTATION CAUSES THE WINDING AND STRETCHING OF THE MAGNETIC FIELD LINES:



A



B

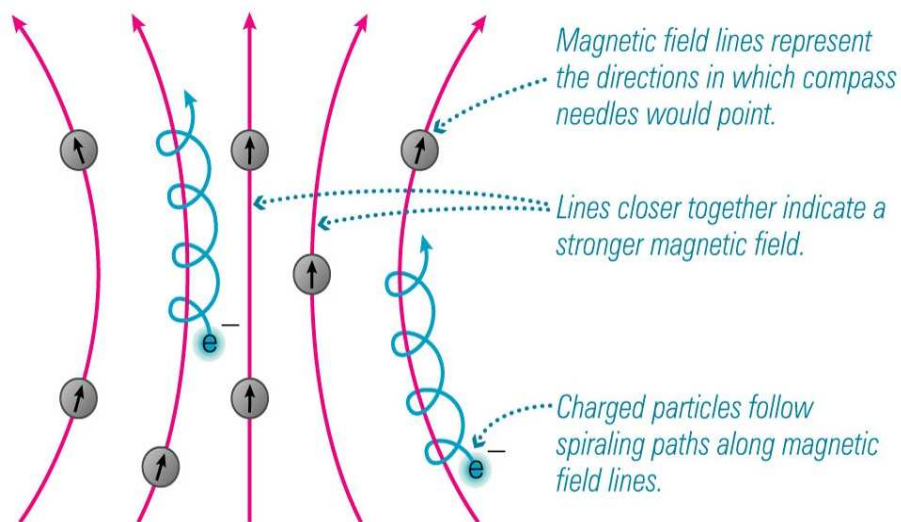


C

THE MAGNETIC FIELD LINES GET SO WOUND UP THAT THEY DEVELOP KINKS, LIKE A WOUND UP RUBBER BAND:

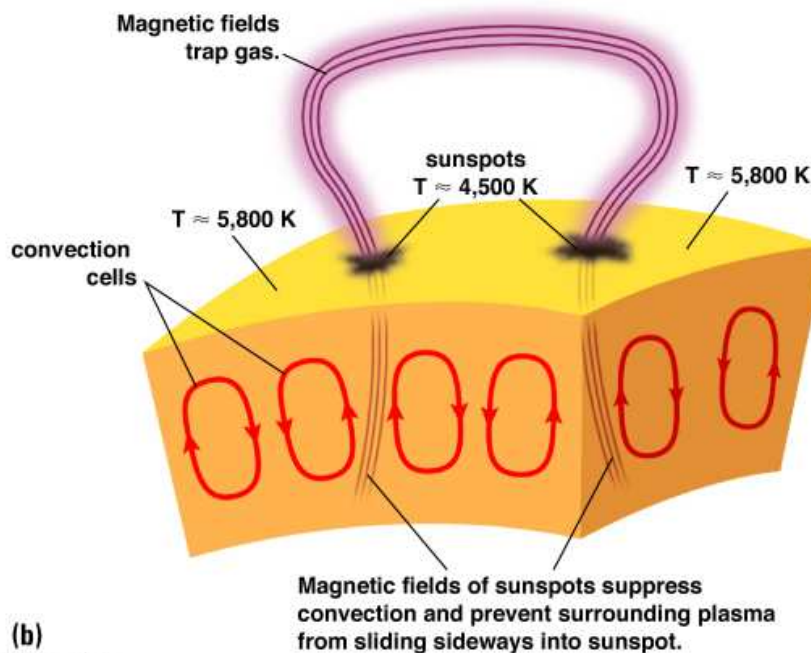


THE SUNSPOTS OCCUR AT THE FOOTINGS OF THE KINKS. THE CHARGED PARTICLES FORMING THE PLASMA IN THE CONVECTION ZONE ARE CONFINED BY THE MAGNETIC FIELD LINES:

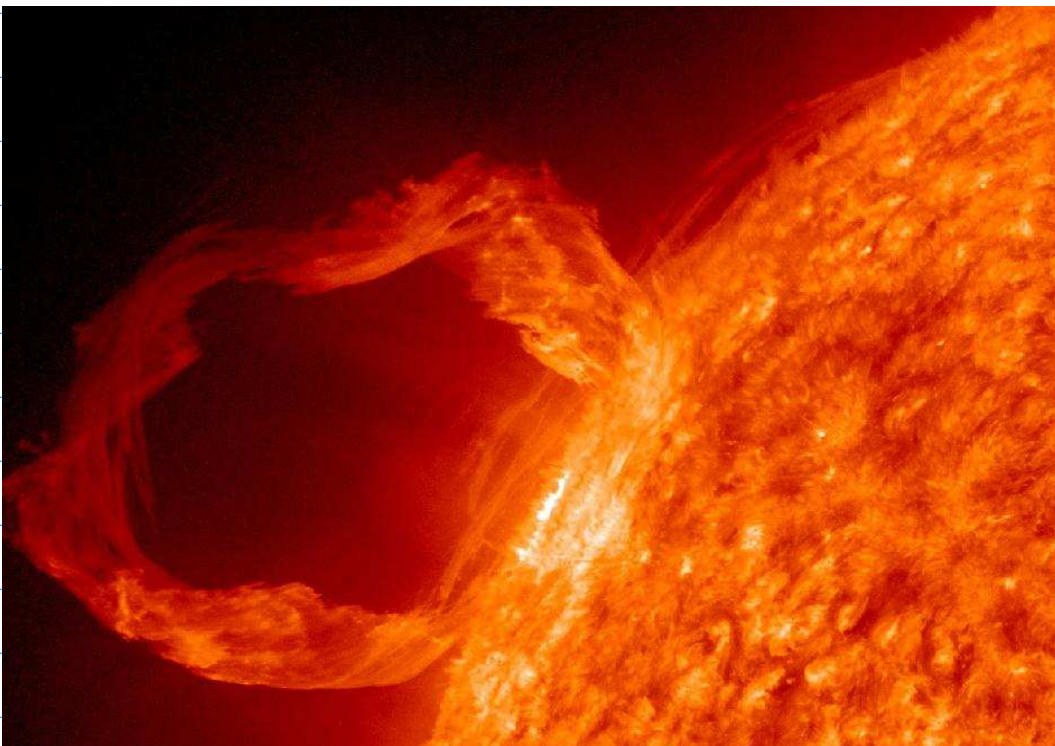


THE CONVECTION CURRENTS CANNOT BRING THE HOT GAS TO THESE REGIONS AND THERE

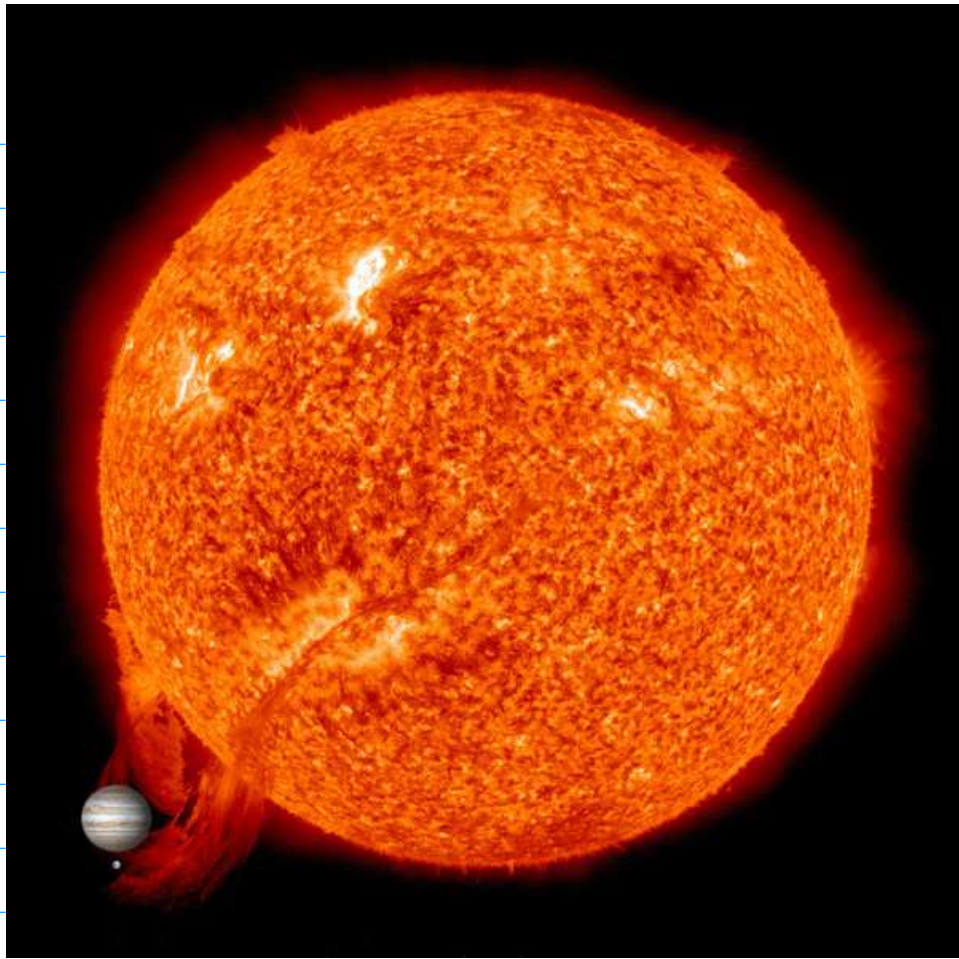
TEMPERATURE IS LOWER :



THE LOWER TEMPERATURE T RESULTS IN A LOWER BRIGHTNESS (STEFAN-BOLTZMANN LAW: $L \propto T^4$).

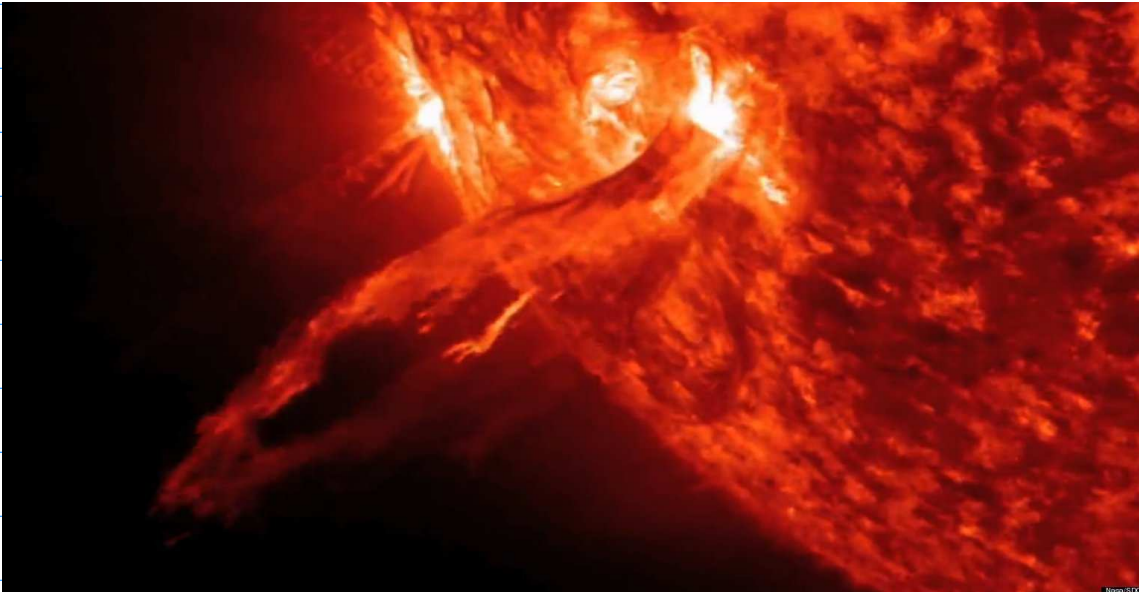


SOLAR
PROMINENCE
(MARCH 30, 2010)



A LARGE PROMINENCE COMPARED TO THE SIZE OF JUPITER AND EARTH.

SOLAR FLARES:



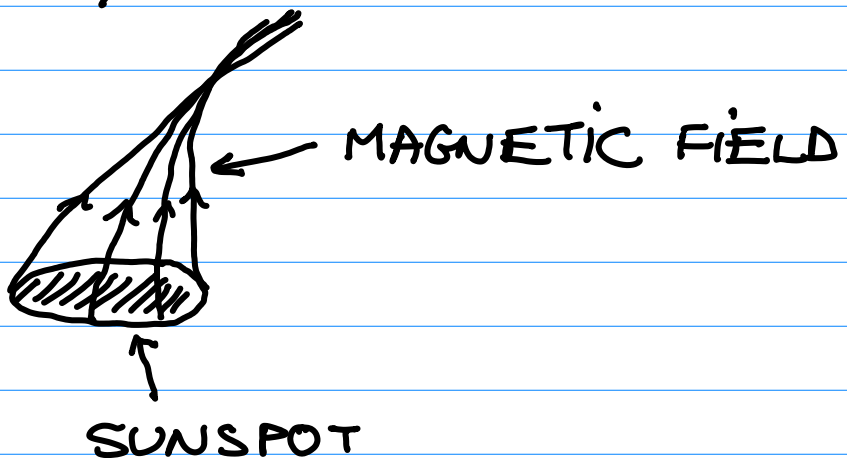
FEBRUARY 25
2014

A TYPICAL FLARE LASTS FOR 5-10 MINUTES; LARGE FLARES LAST FOR SEVERAL HOURS.

THE FLARES RELEASE ENERGY EQUIVALENT TO TENS OF MILLIONS OF H-BOMBS.

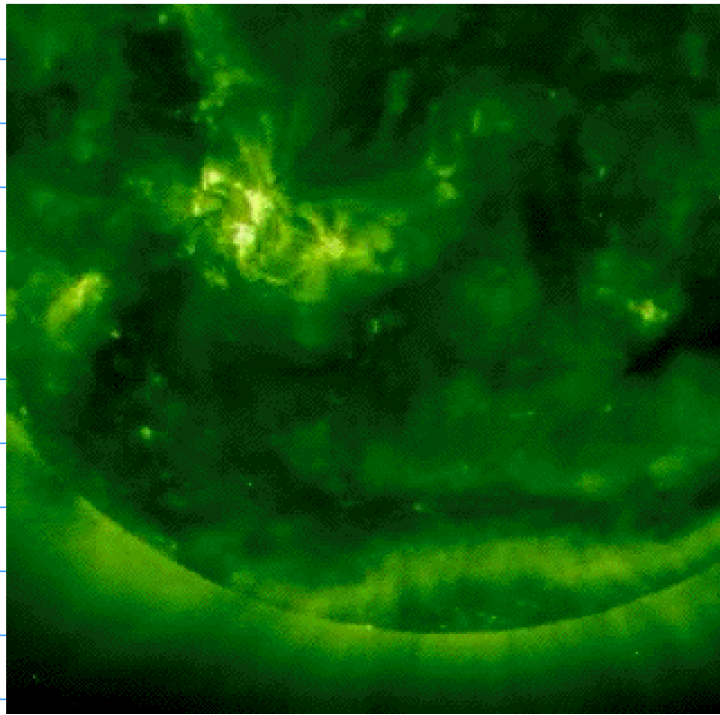
NEAR A SUNSPOT MAXIMUM SMALL FLARES OCCUR SEVERAL TIMES A DAY, AND THE BIG ONES MAY OCCUR EVERY FEW WEEKS.

FLARES HAPPEN WHEN MAGNETIC FIELD ABOVE THE SUNSPOT BECOMES TWISTED AND STRETCHED. IT RECOILS WITH TREMENDOUS RELEASE OF ENERGY:

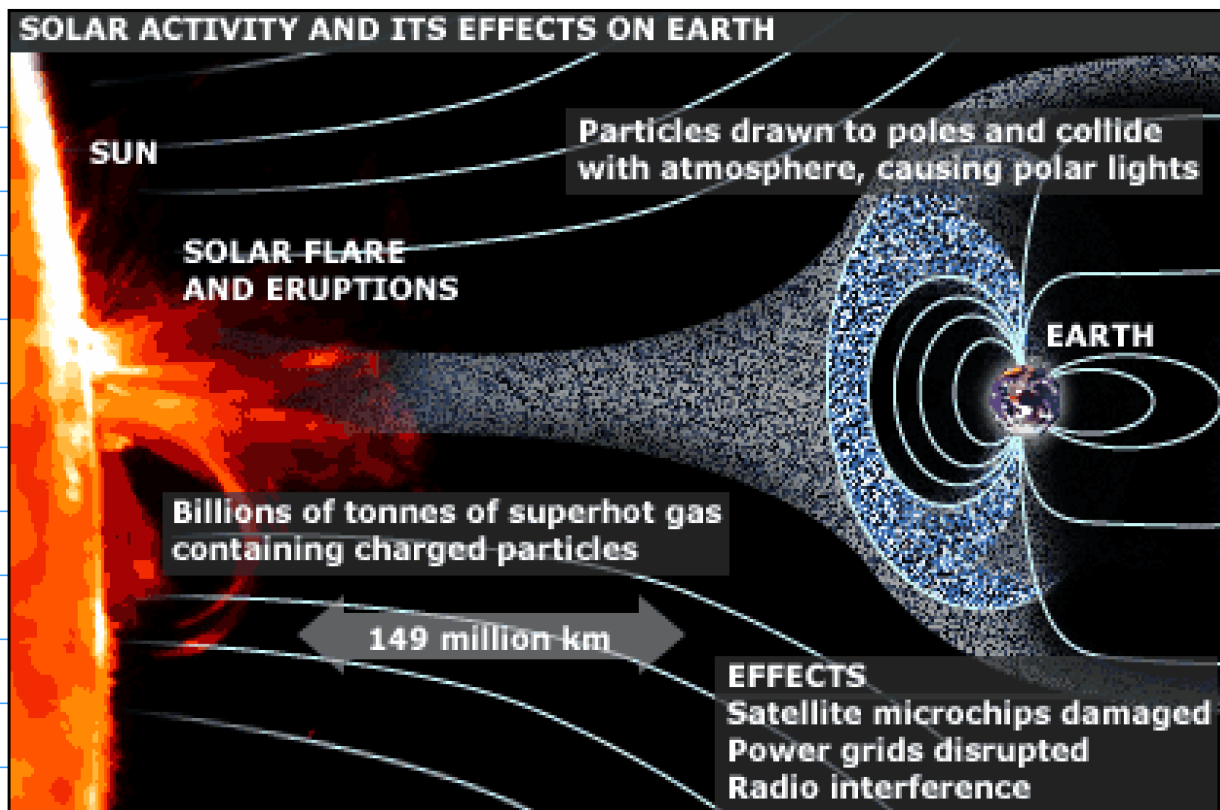


AT VISIBLE WAVELENGTHS WE OBSERVE THEM AS RED FROM HYDROGEN-ALPHA EMISSION.

HOWEVER AT THE MOMENT OF EXPLOSION
THE MATTER ASSOCIATED WITH THE FLARE
IS HEATED UP TO 10 MILLION DEGREES
AND IT EMITS THE X-RAY AND UV RADIATION:



IN ADDITION TO RADIATION THE FLARE
EJECTS HIGH SPEED PROTONS AND ELECTRONS -
- THE SOLAR WIND IS INTENSIFIED. AS A RESULT
THE AURORAE ARE MORE FREQUENT.

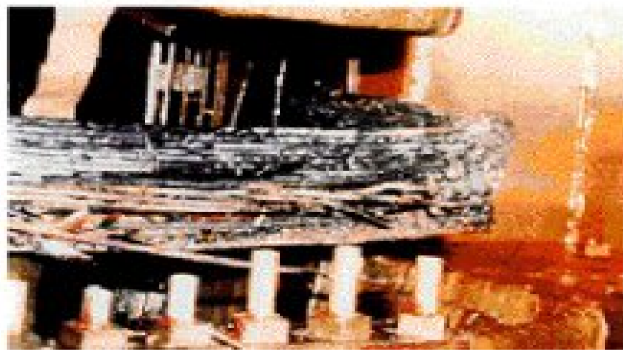


High energy solar wind particles tap on the Earth's magnetic field protective shield causing it to oscillate like a drum skin. Changing magnetic field induces the electric field (the Faraday's Law) which causes the current surges in power lines and in electric circuits that could disrupt them (Quebec, March 1989).



PJM Public Service
Step Up Transformer

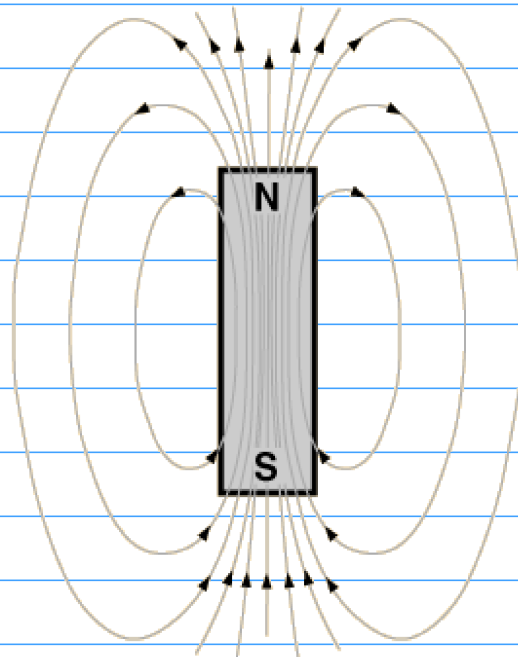
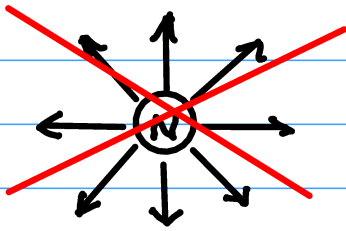
Severe internal damage caused by
the space storm of 13 March, 1989

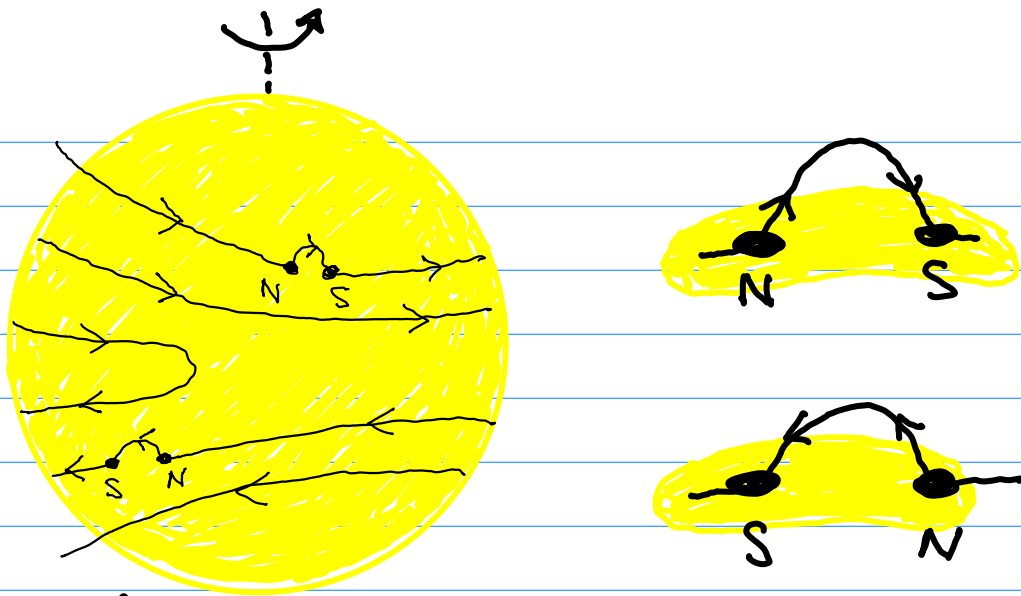


MAGNETIC POLARITY OF SUNSPOTS

MAGNETIC FIELD OF
A BAR MAGNET:

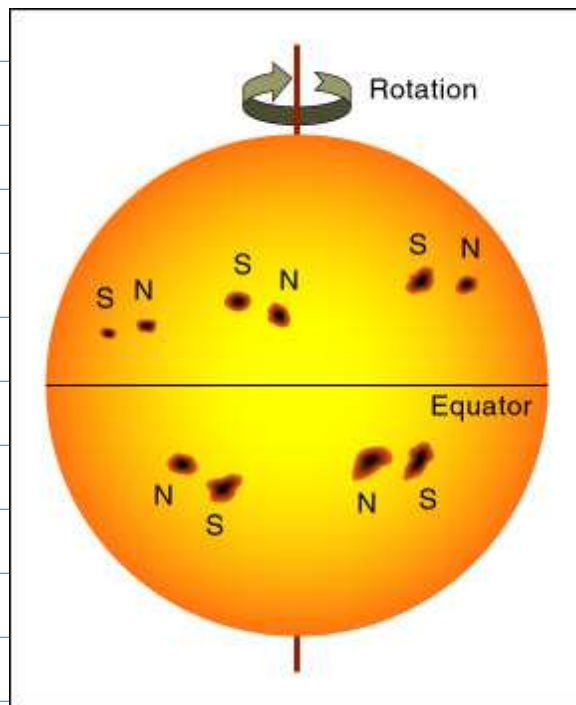
THERE ARE NO
MAGNETIC MONOPOLES!



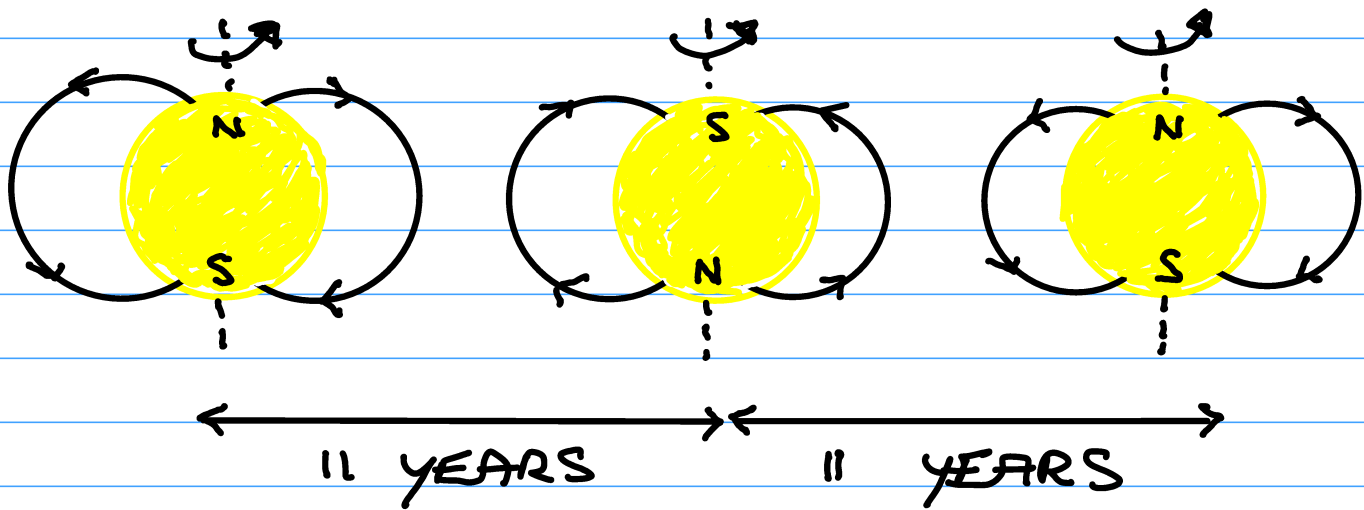


SUN'S ROTATIONAL
 AXIS →

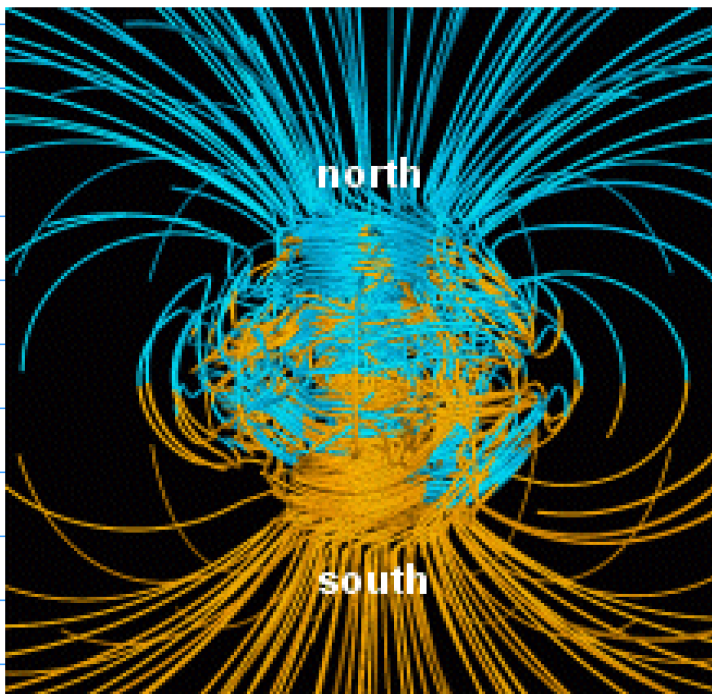
MAGNETIC POLARITY OF SUNSPOTS BELOW
 THE EQUATOR IS OPPOSITE TO THEIR POLARITY
 ABOVE THE EQUATOR :



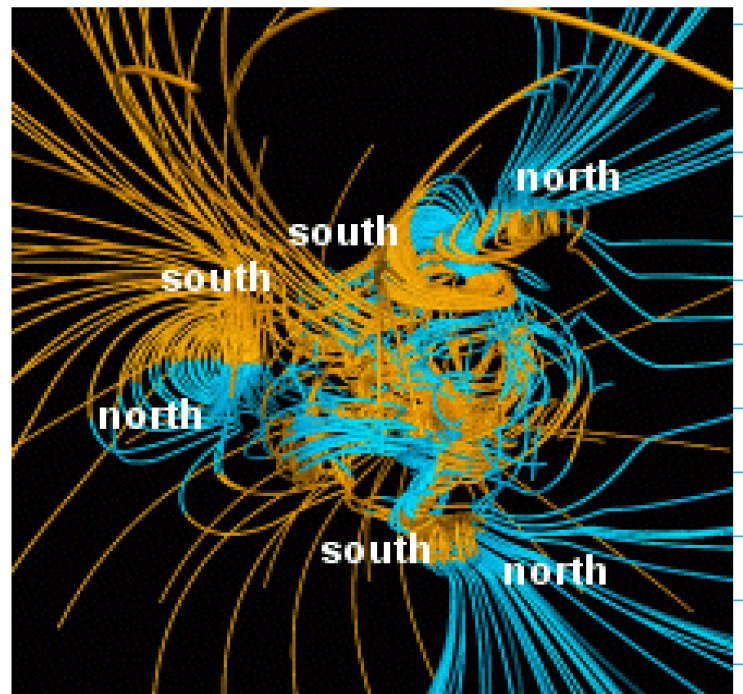
AFTER ONE 11-YEAR SOLAR CYCLE
THE POLARITY OF THE SOLAR MAGNETIC
FIELD IS REVERSED:



THUS THE SOLAR MAGNETIC CYCLE IS
ABOUT 22 YEARS LONG.

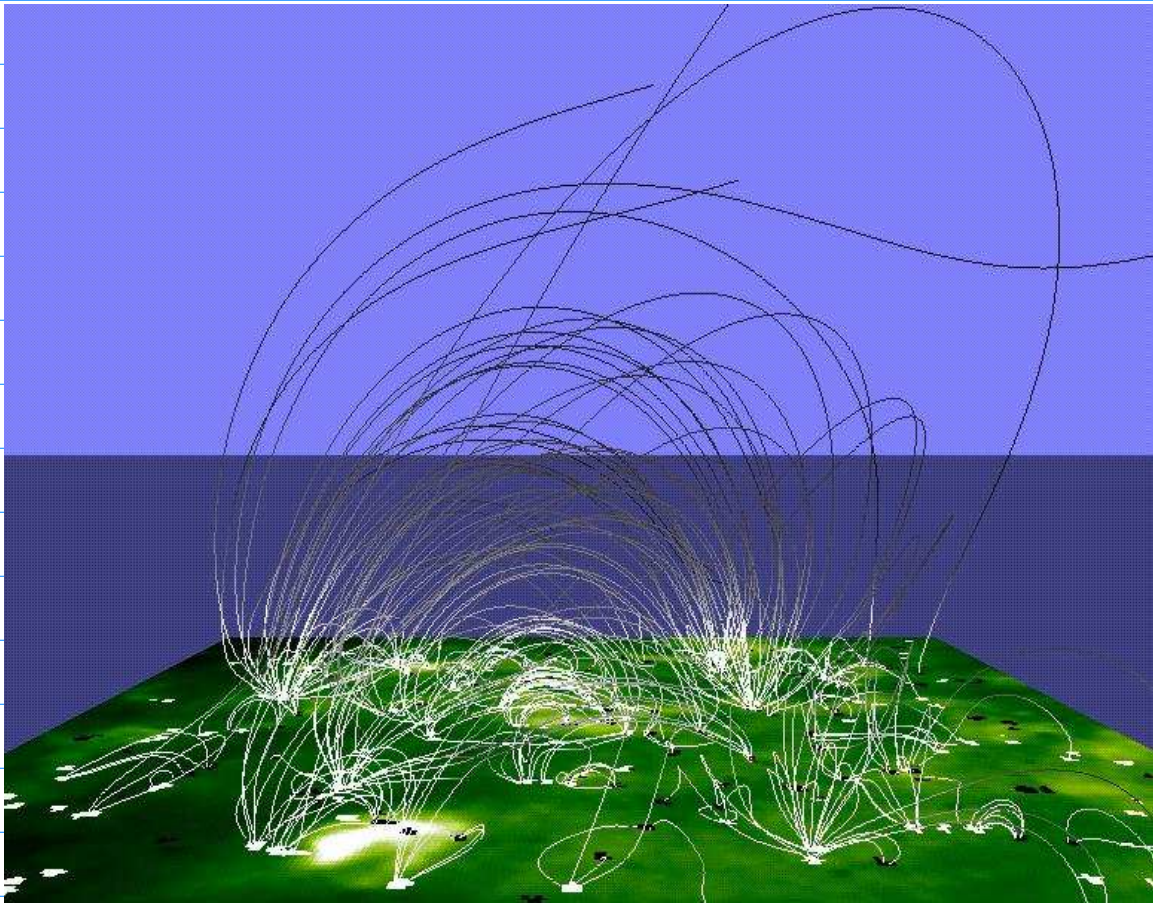


between reversals



during a reversal

SOLAR MAGNETIC CARPET AND HEATING OF CORONA:



THERE ARE TENS OF THOUSANDS OF MAGNETIC NORTH AND SOUTH POLES ON THE PHOTOSPHERE WITH THE MAGNETIC FIELD LINES EXTENDING TO THE SOLAR CORONA. EACH MAGNETIC LOOP CARRIES A LARGE AMOUNT OF ENERGY. THE ENERGY FLOWS FROM THE LOOPS WHEN THEY INTERACT VIA SHORT CIRCUITS. A VERY LARGE ELECTRIC CURRENT IN THE SHORT CIRCUITS HEATS CORONA TO SEVERAL MILION DEGREES.