The active sun

Activity areas; the dynamo; Grand Episodes and the transitions between them

C. de Jager and S. Duhau

NIOZ

A sphere with a 1.4 million km diameter; 200,000 times the mass of the Earth

A very stable source of light

But brightness increases slowly;
0.15 % per million years

Solar radiation increases steadily

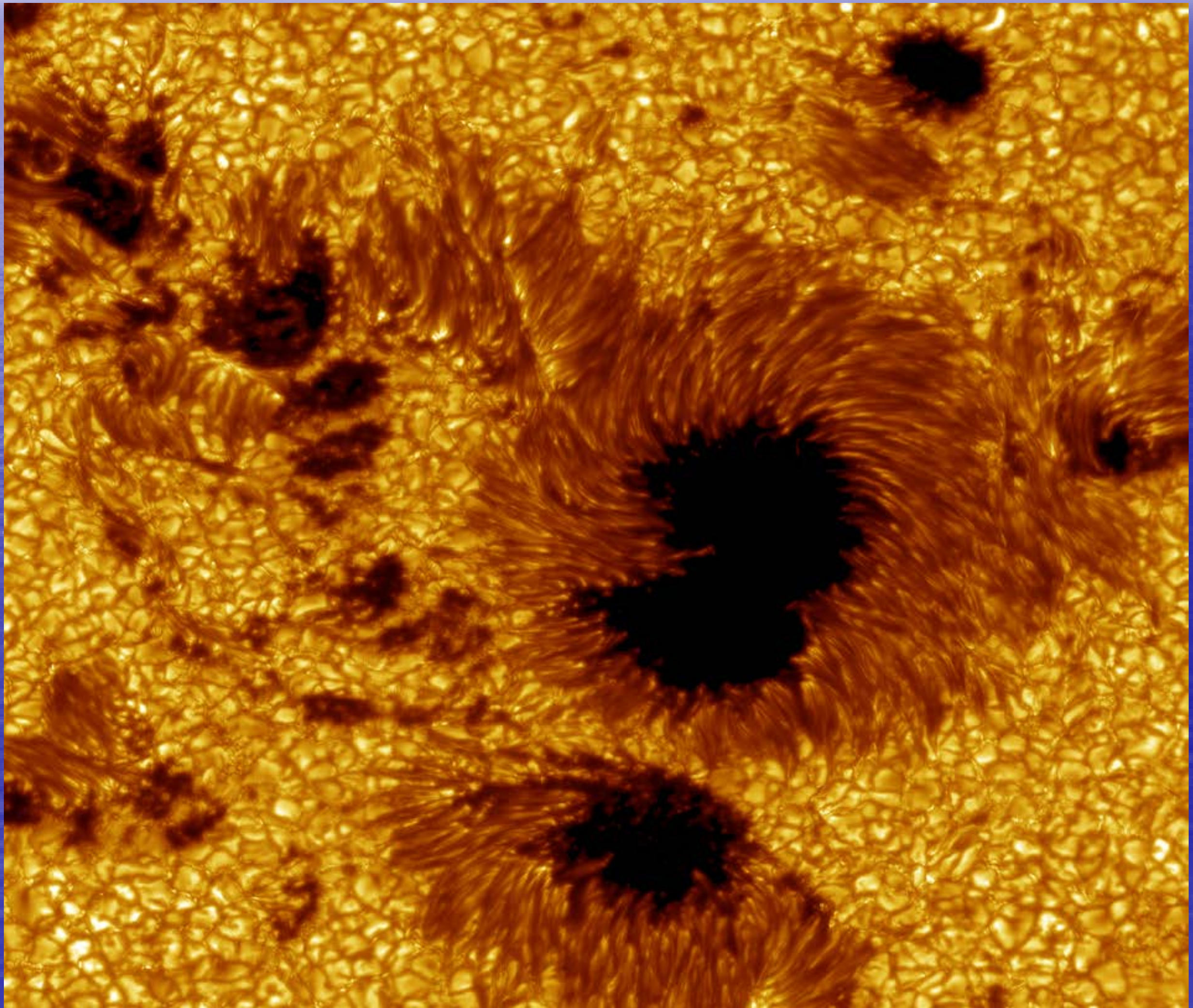
- Only 0.15% per million years
- Nevertheless, the earth will receive ever more radiation energy and will steadily become warmer
- After 300 million years the average earth temperature would be 50 degrees Celcius
- And that will be 100 degrees in 600 million years
- 5 billion years from now, the sun will be 1000 times brighter than present

And in 6 billion years the sun will be a white dwarf in a planetary nebula

But there are major variations in the shorter term

Activity areas with sunspots, flares, Coronal Mass Ejections and more ...

Very short term variations. The sunspots. Tightly concentrated magnetic fields



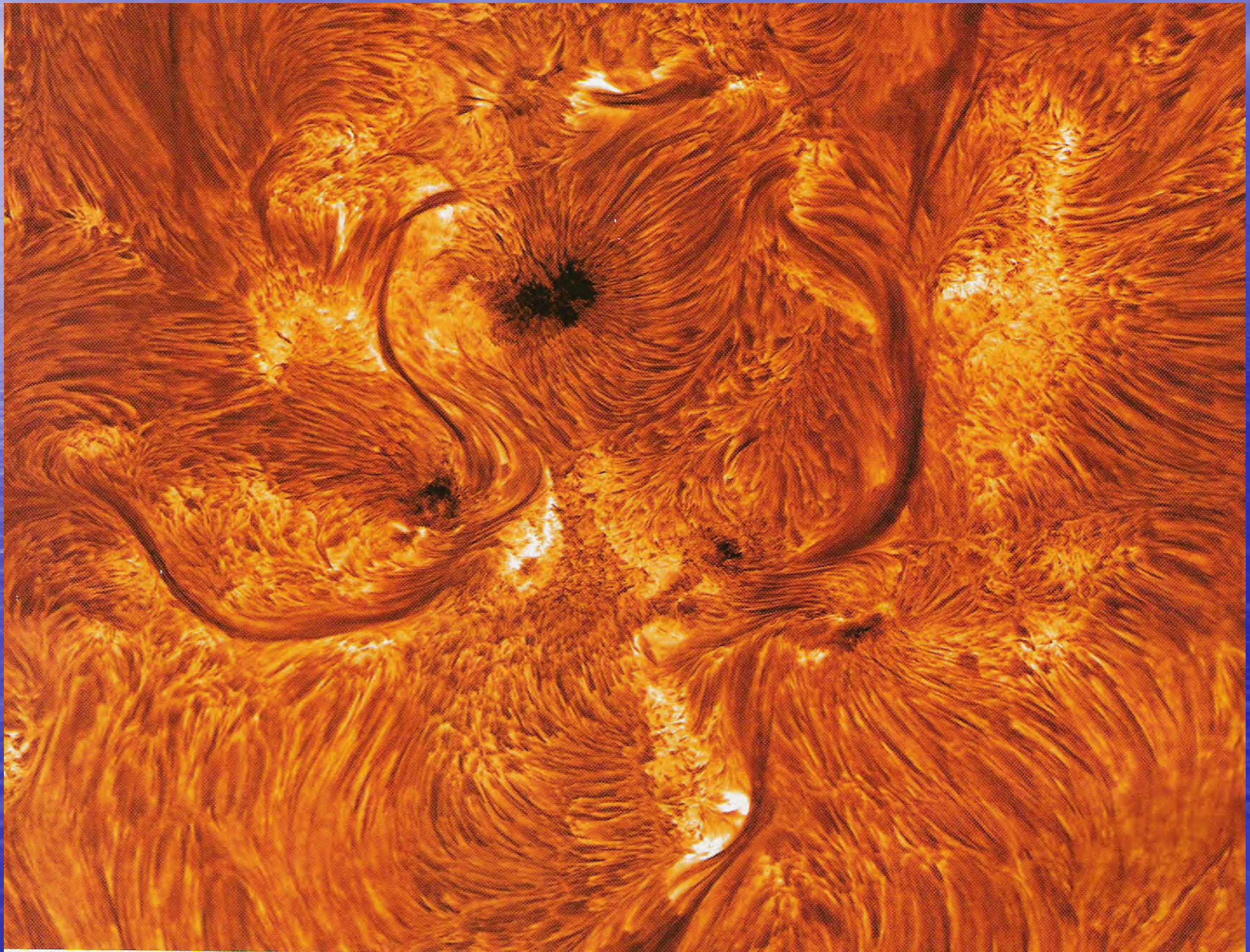
Mostly in pairs or in larger groupings

- Magnetic fields with strengths in the order of 10,000 times those at the earth's poles
- Opposing magnetic polarity among the members of a group
- A lifespan from hours to weeks and sporadically longer
- Occur in the equatorial area below latitudes of about 40º

Horseshoe magnets

- The sunspots rise up from the depths – That’s where they originate. How?
- Their structure compares with a horseshoe magnet
- Their magnetic fields are closed, as all magnetic fields are. It continues above the sun’s surface (usually invisible – rarified gas)

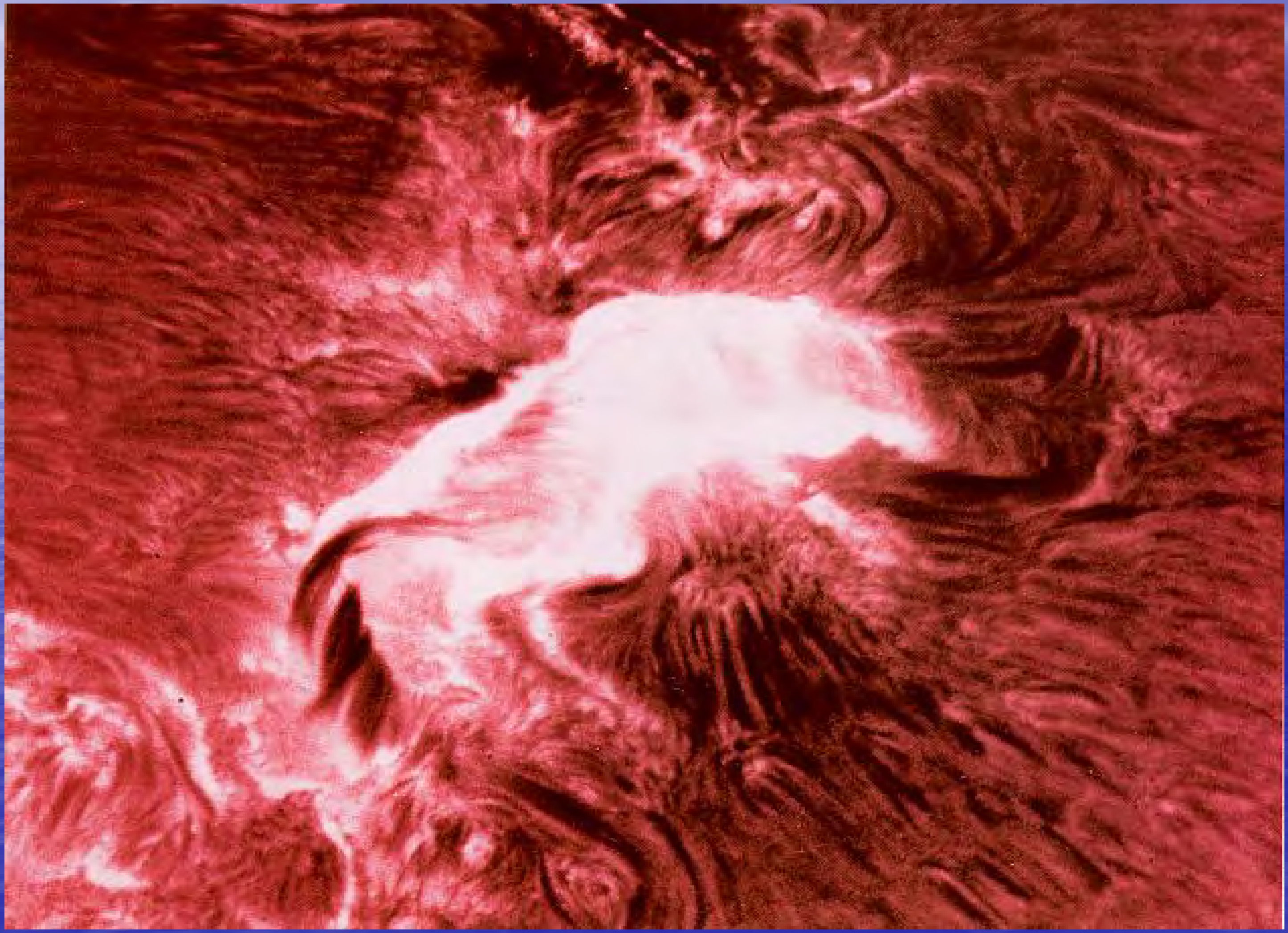
Sunspots are the centres of the *Activity Areas*



Facular fields (faculae) in Activity Areas

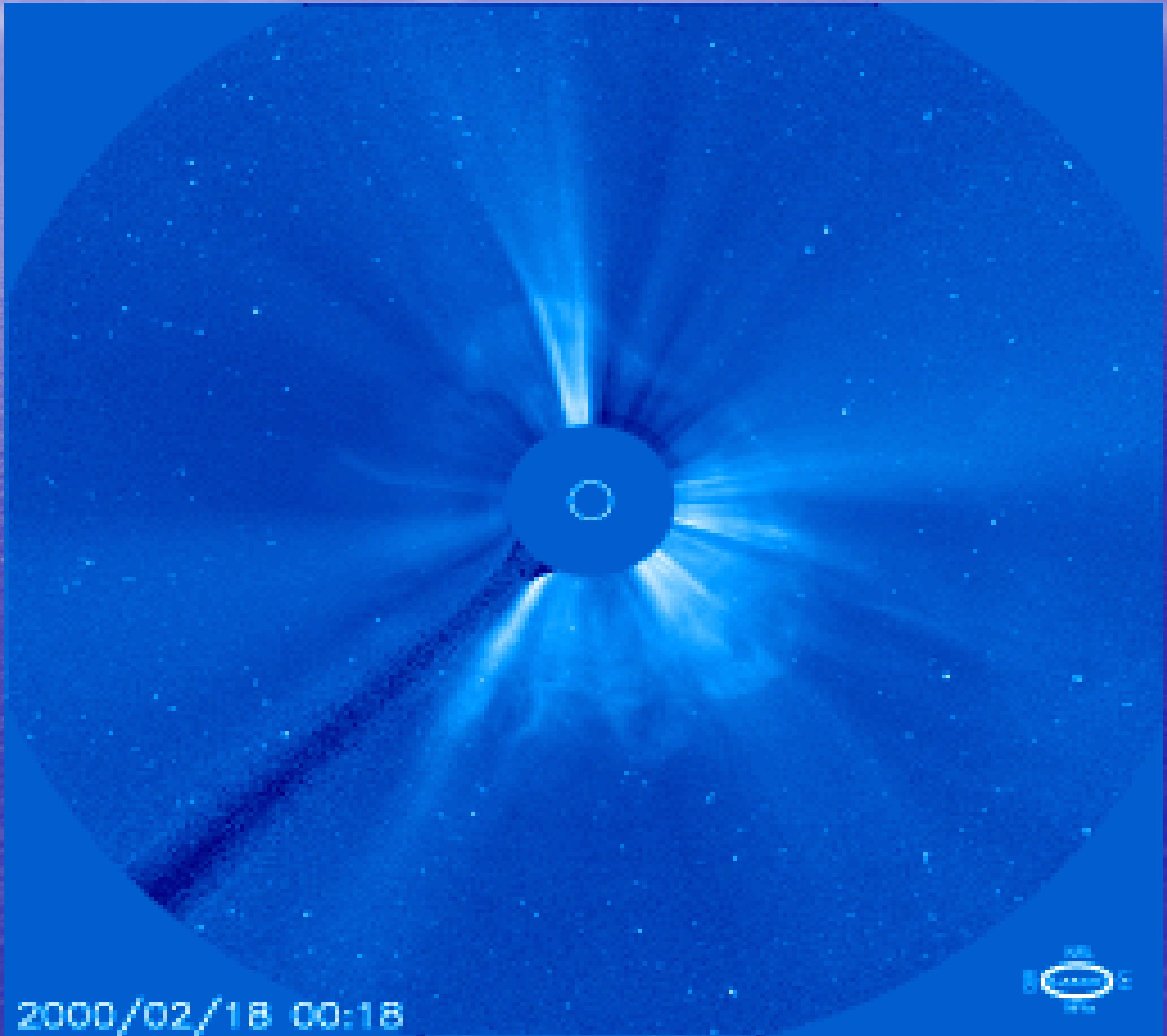
- Faculae are the bright areas around the sunspots, dragged up with the rising magnetic fields
- Weaker magnetic field strengths; a few hundred gauss
- Higher temperatures than surrounding area. About 10,000 K
- Thus, variable sources of UV radiation

In activity areas: *solar flares*. On average 1 – 10 per day. Energy output about a billion Hiroshima bombs



Near and within Active Areas the *Coronal Mass Ejections.* Radiated over broad area

About 1 – 6 per day. Each CME carries as much energy as 10^{10} Hiroshima bombs



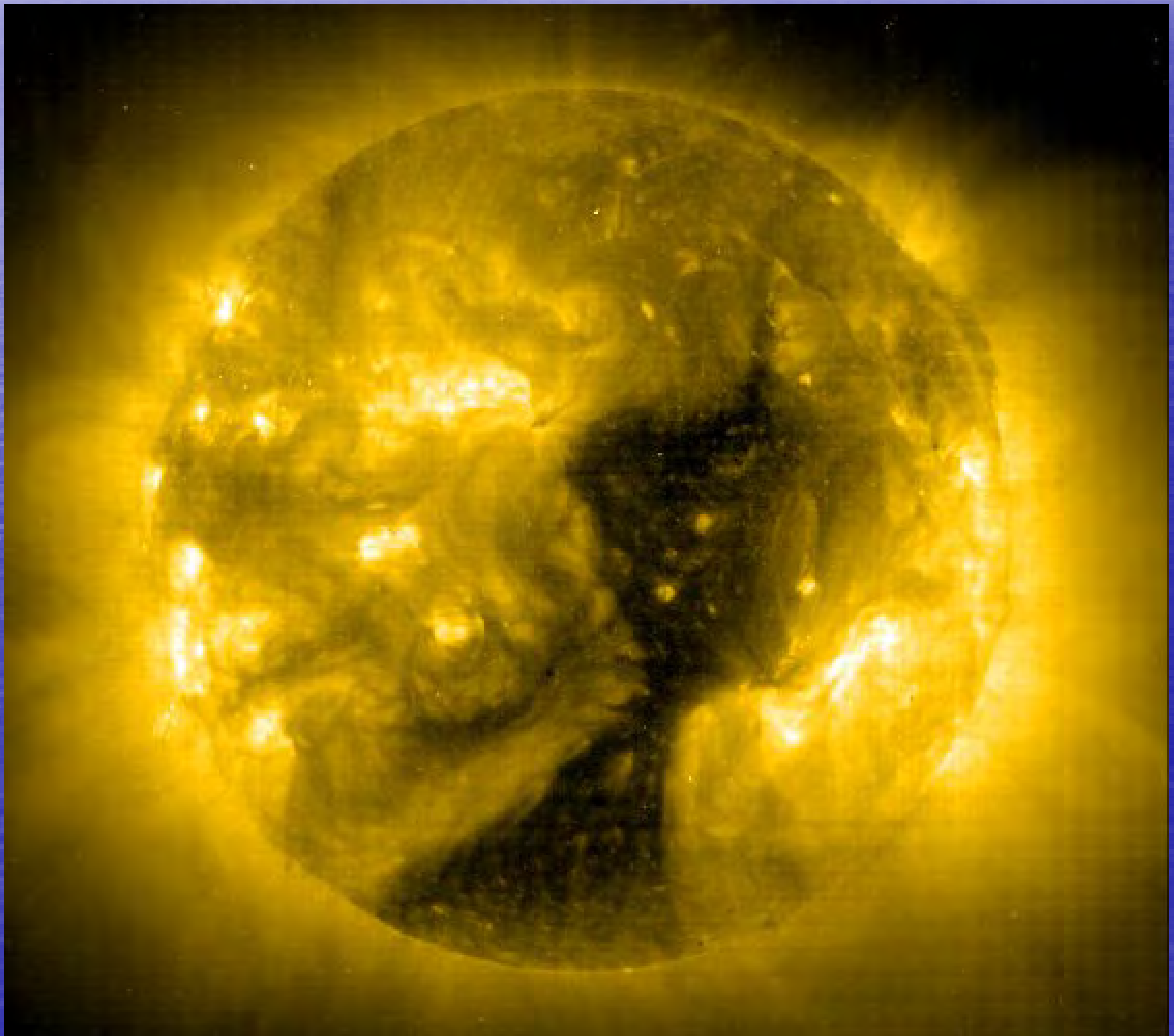
An Activity Area near the solar limb. Loops, carrying electric currents up to 10^{12} Amperes, are confined by magnetic fields

A solar flare is an electric short-circuit

- Electric arcs with currents up to 10^{12} Amperes in Activity Areas
- Sometimes two such loops are coming close
- That results in rapidly increasing attraction
- Eventually a gigantic short-circuit

A second large magnetic area occurs around the poles. Bright spots, polar faculae, coronal holes.

This view is from above the pole



Polar and equatorial magnetic fields

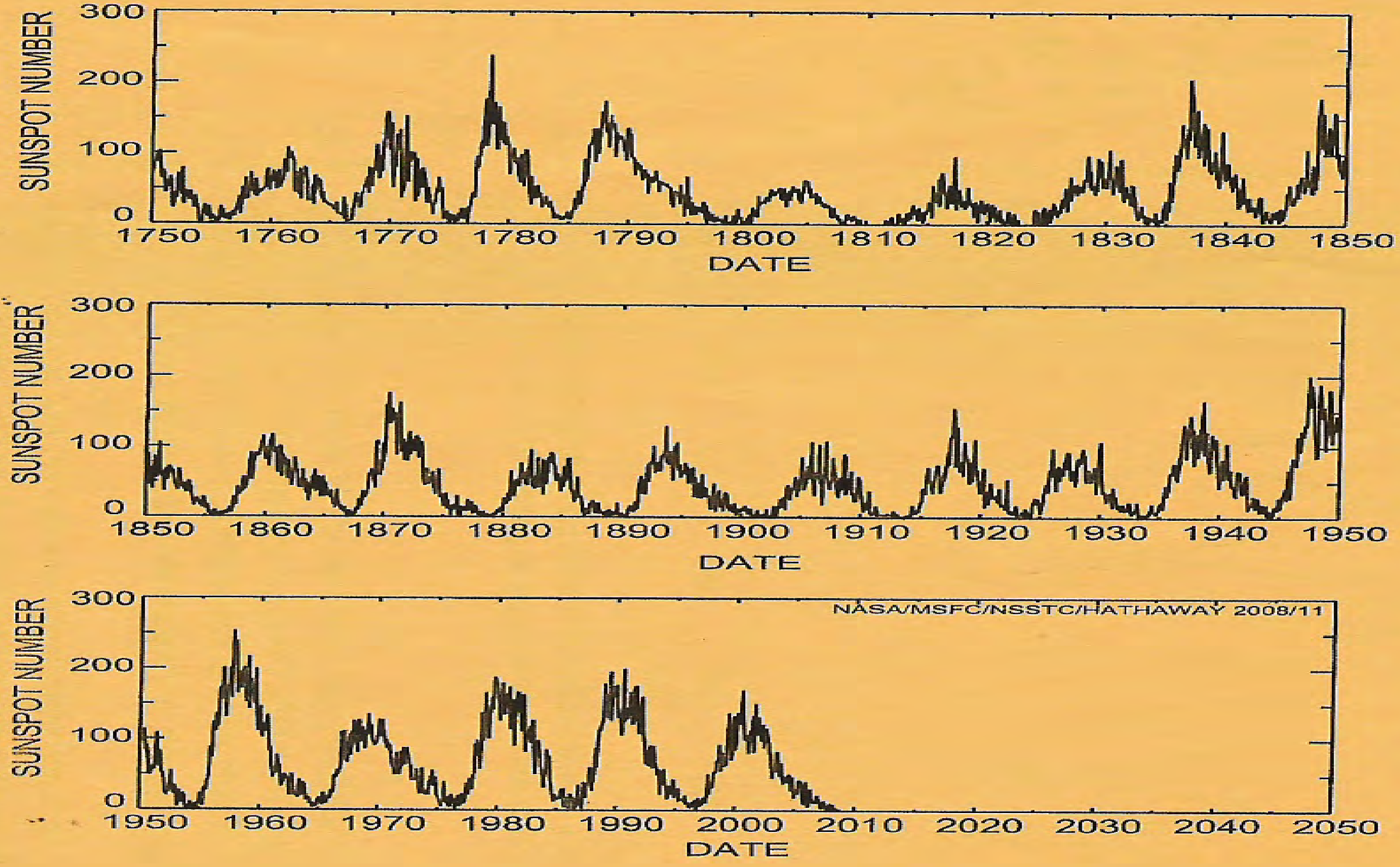
- Total magnetic flux from the polar and equatorial areas is comparable
- Polar fields are at maximum strength when the equatorial fields are at minimum
- Conversely: maximum equatorial fields during minimum polar magnetic flux
- *The exotic dance of the two fields*

Changes with time

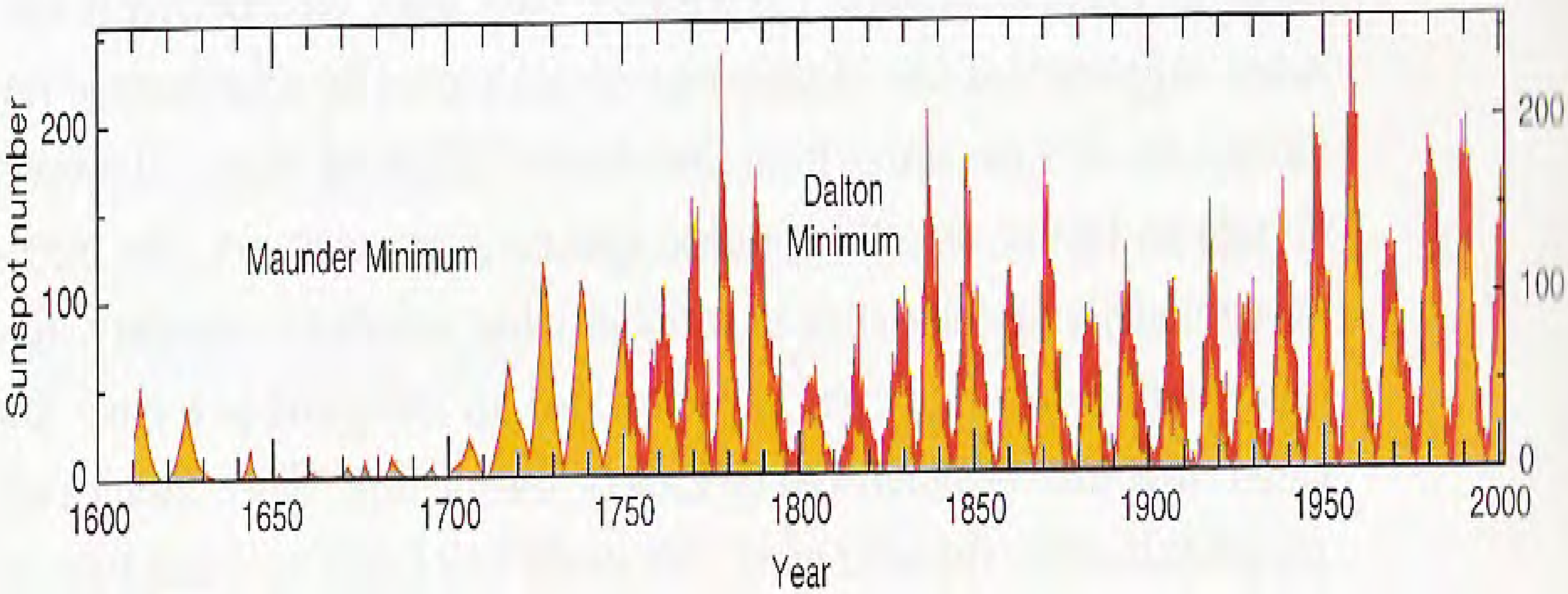
The 11 years period

Other periodicities

The ‘eleven’ years sunspot cycle



The eleven years *Schwabe cycle* is variable. See the *Grand Minimum* (1630 - 1710), the *Dalton Minimum* (1800 - 1830) and the *Grand Maximum* (1924 - 2009)



There are more cycles

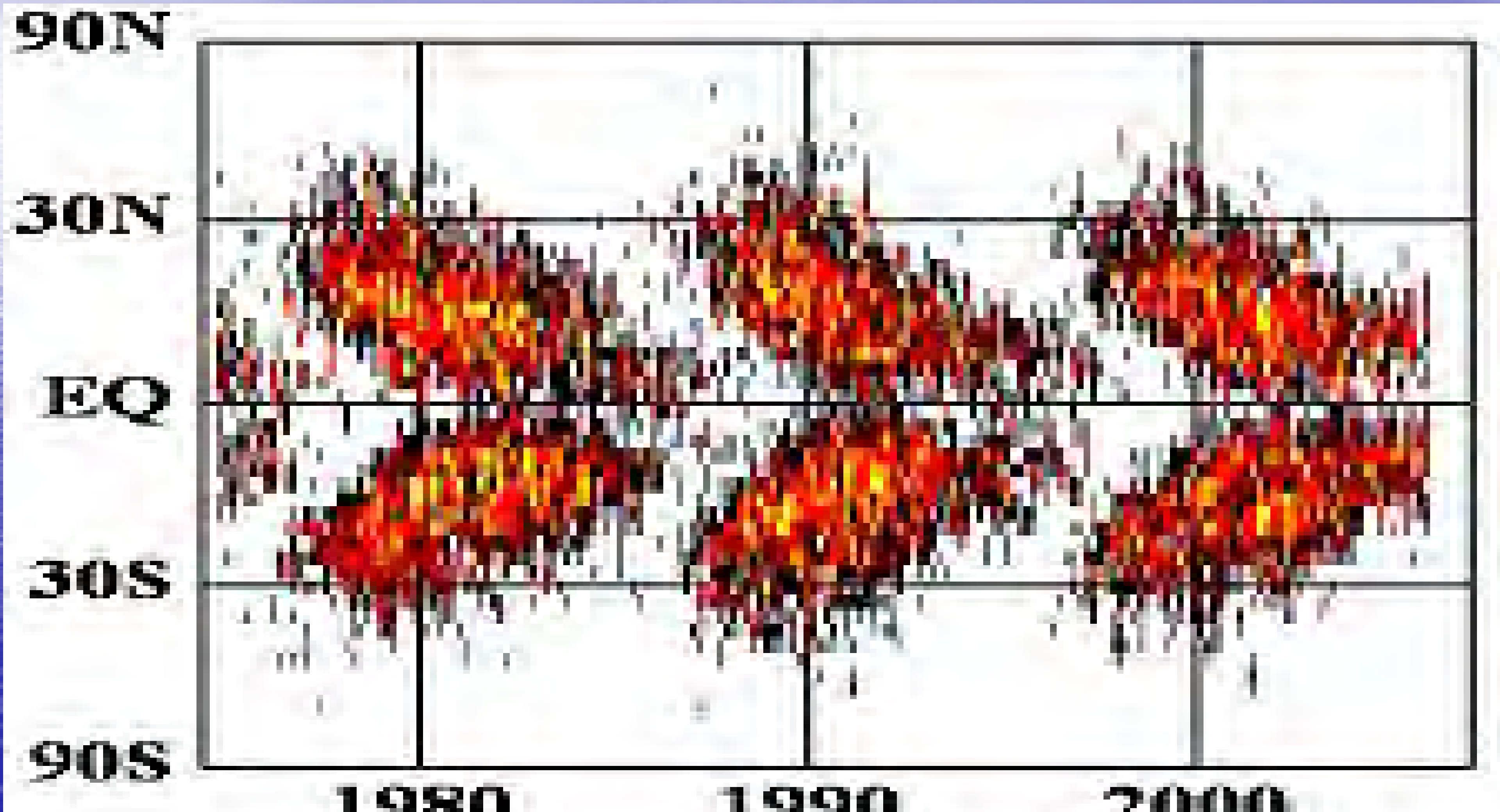
- After two *Schwabe* cycles the magnetic configuration is again the same as before. The *Hale cycle* consists of two successive Schwabe cycles
- The *Gleissberg* cycle takes about 88 years but the period changes with time. During several centuries it was 50 to 80 years; at other times it was 90 -140 years
- The *De Vries (Suess)* cycle of 205 years
- The *Hallstatt* cycle of appoximately 2300 years

The solar dynamo

The exotic dance of the polar and equatorial magnetic fields

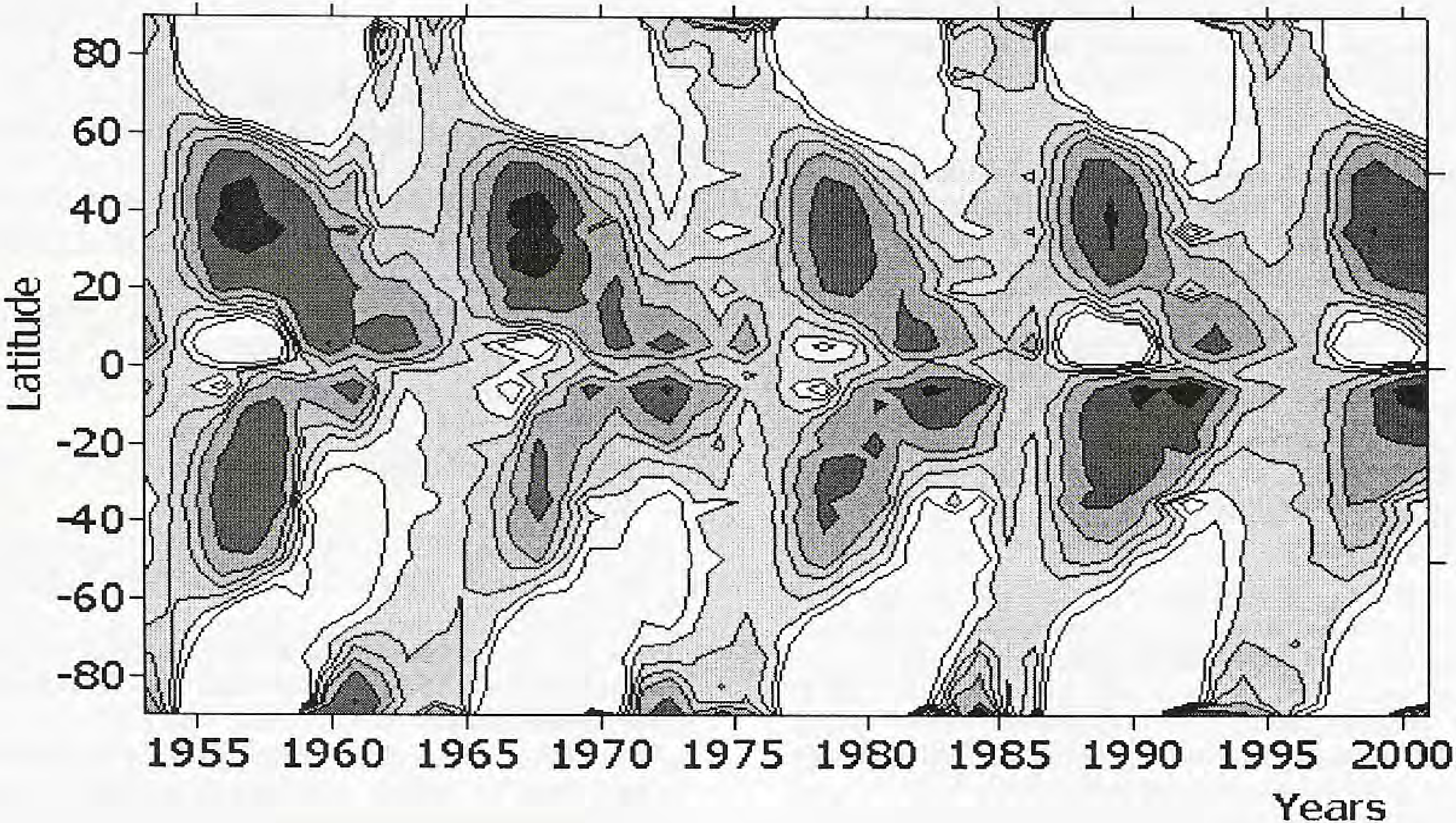
Butterfly diagram

The first sunspots of a new cycle appear at high latitudes

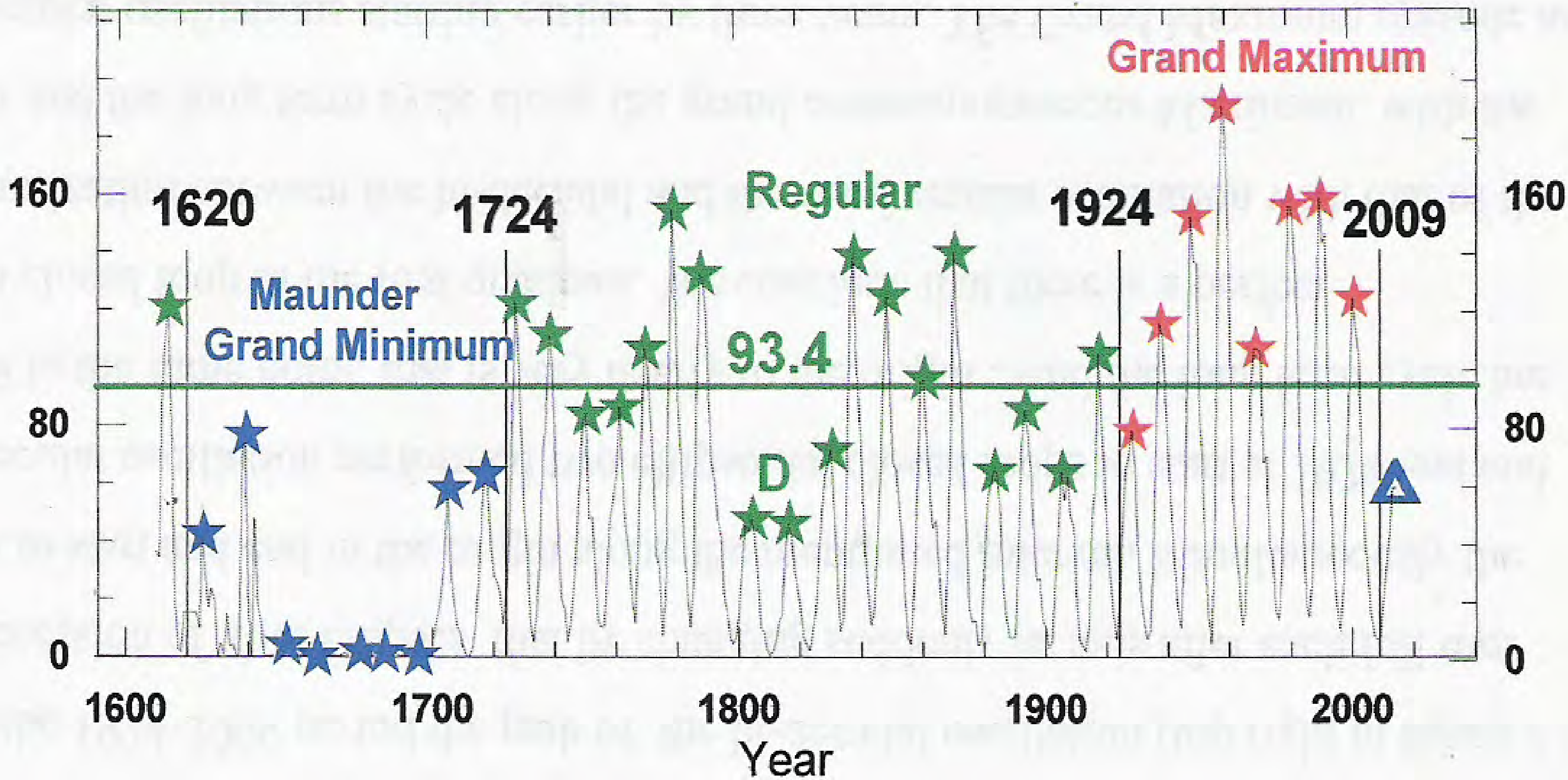


Polar activity precedes the equatorial one.

Knowledge of the polar field enables predictions



Thus we (Duhau and De Jager, 2009, 20011) predict for the current cycle a maximum sunspot number of 62; it will occur mid-2013



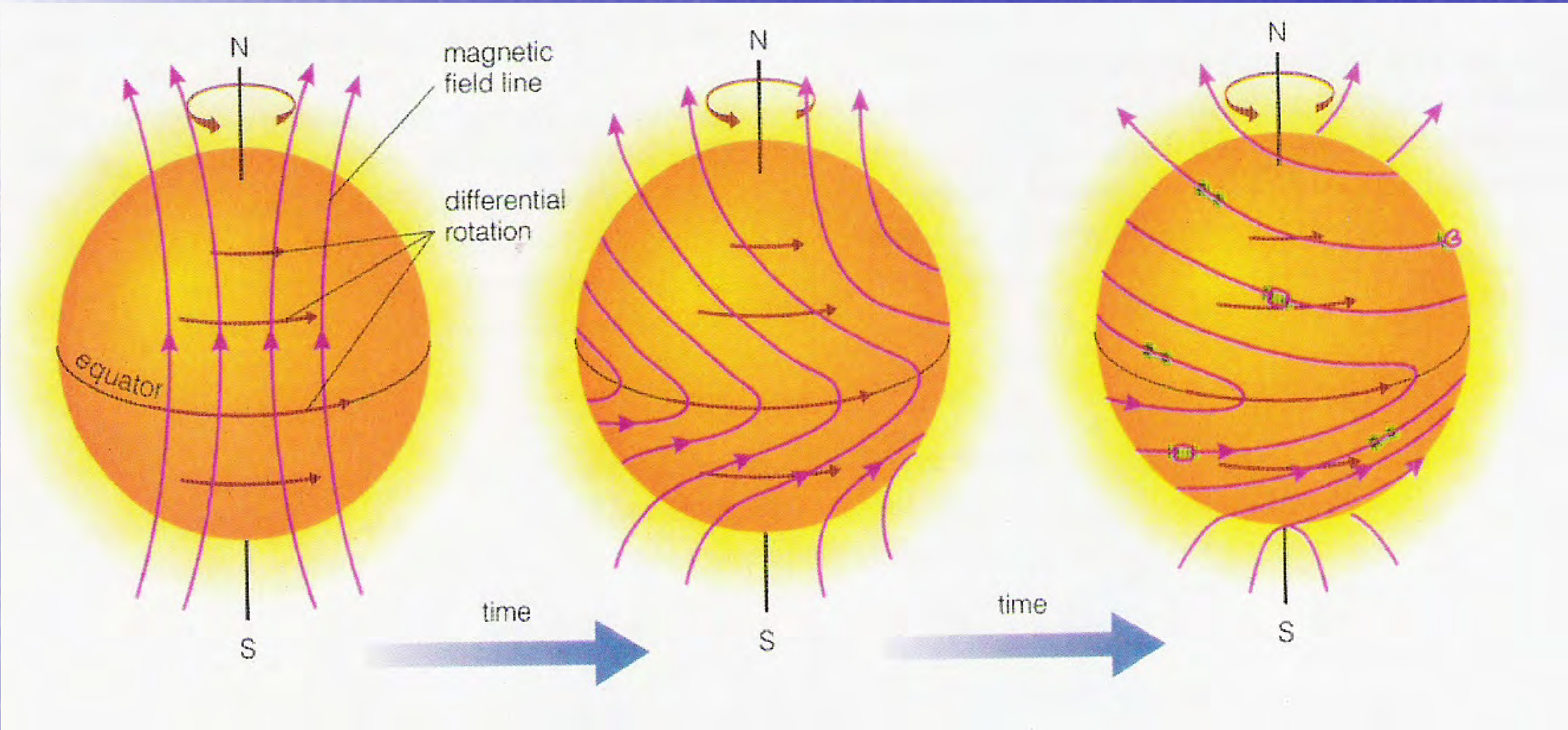
The mechamism

Solar activity has its basis in the tachocline

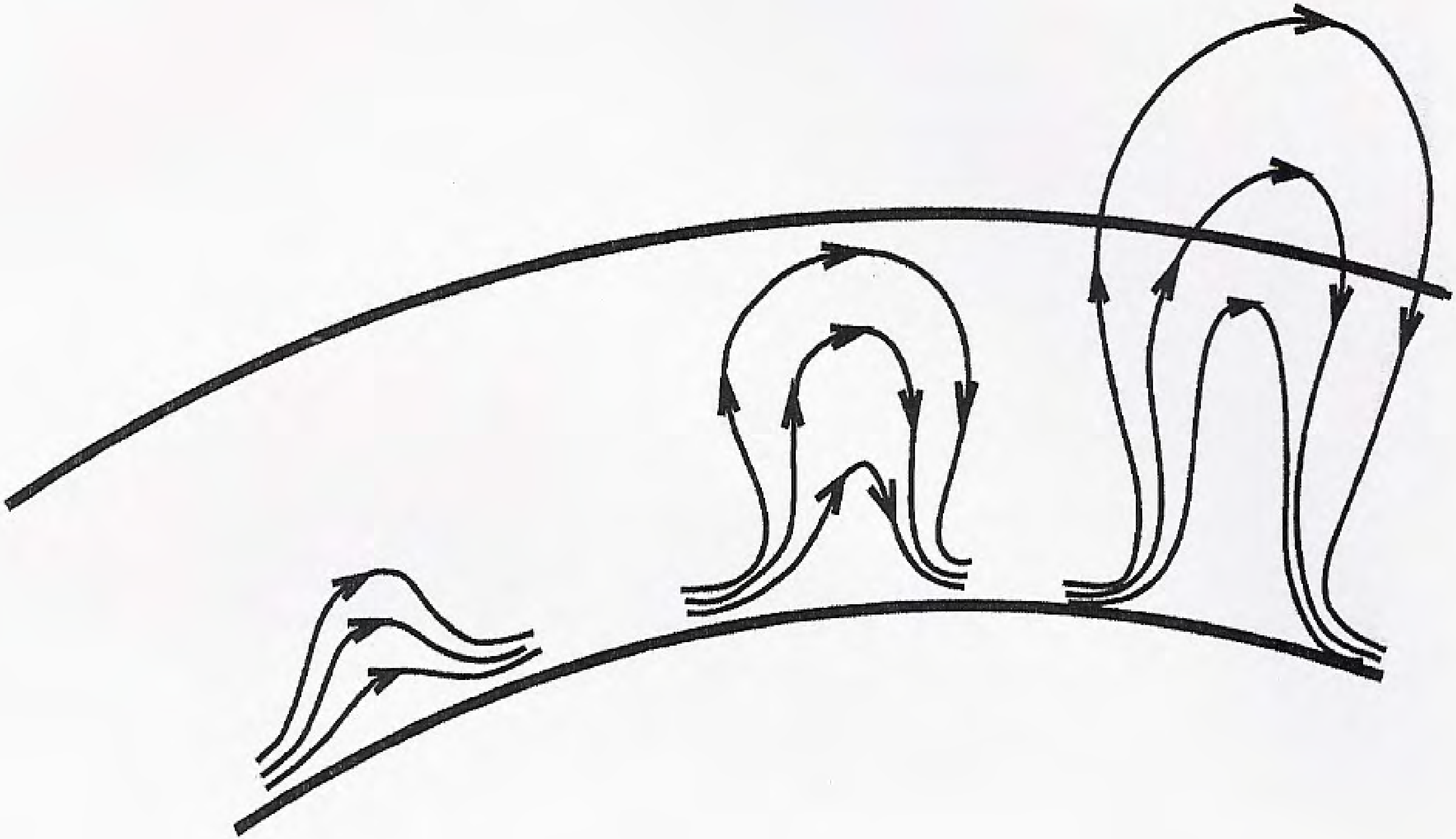
The tachocline

- A circa 30,000 km thick layer at about 200,000 km depth; this is the basis of the area where convection (= rising and falling currents) occurs
- Solar rotation is latitude-dependent: the differential rotation also plays a part
- The combined effect of convection and differential rotation creates enormous whirls
- The solar gas at that depth is a plasma (= it consists of electrically charged particles). Hence the tachocline contains strong swirling electric currents. These produce magnetic fields
- The resulting magnetic fields are then slowly amplified through differential rotation

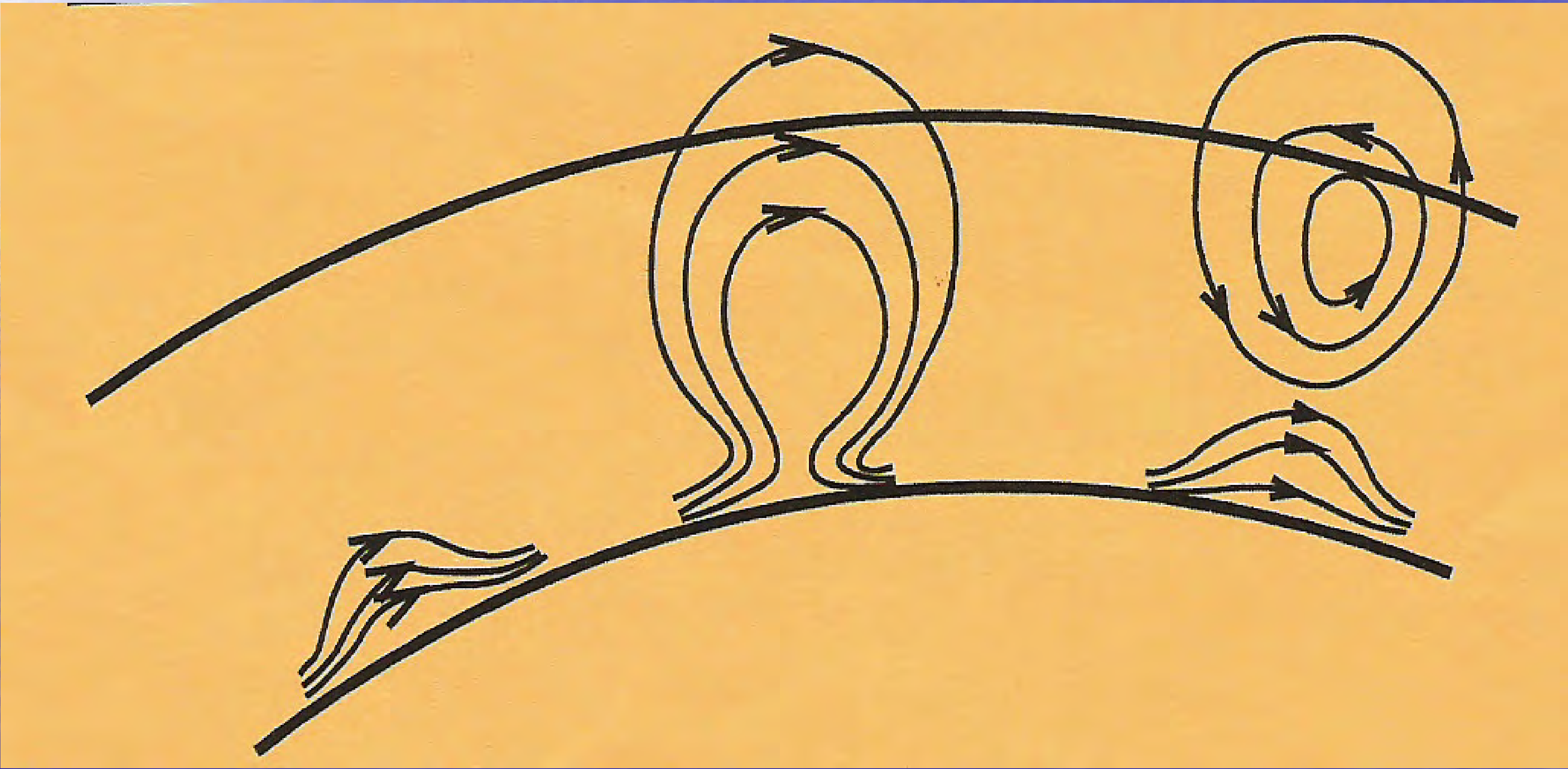
Differential rotation strengthens the magnetic fields. This continues in many solar rotations, and ultimately very strong magnetic fields are built up



Strong fields have smaller specific gravity than their suroundings. Portions of them may rise



Parts will detach when the field strengths exceed ~ 80,000 Gauss. After a few months such a detached loop appears at the surface – a pair of sunspots



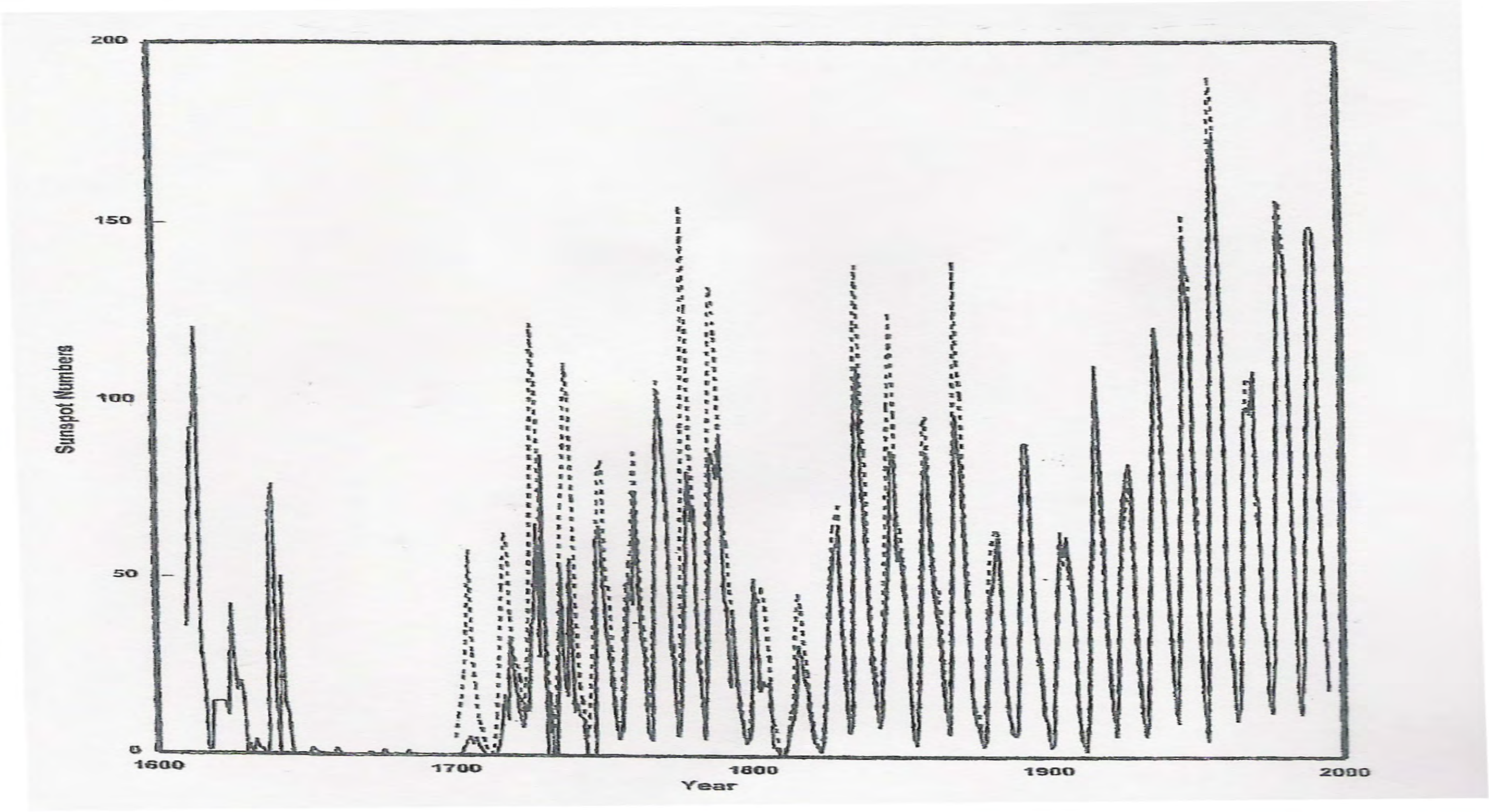
What happens at the end of a Schwabe cycle:

- The equatorial (toroïdal) field disintegrates into many small loops with lower magnetic strenghts
- These rise fairly slowly and it takes a long time for them to reach the surface
- The Coriolis force rotates them by about 90º
- This way the polar (poloïdal) field develops, while the equatorial field shrinks to its minimum strength – a Schwabe cycle is completed

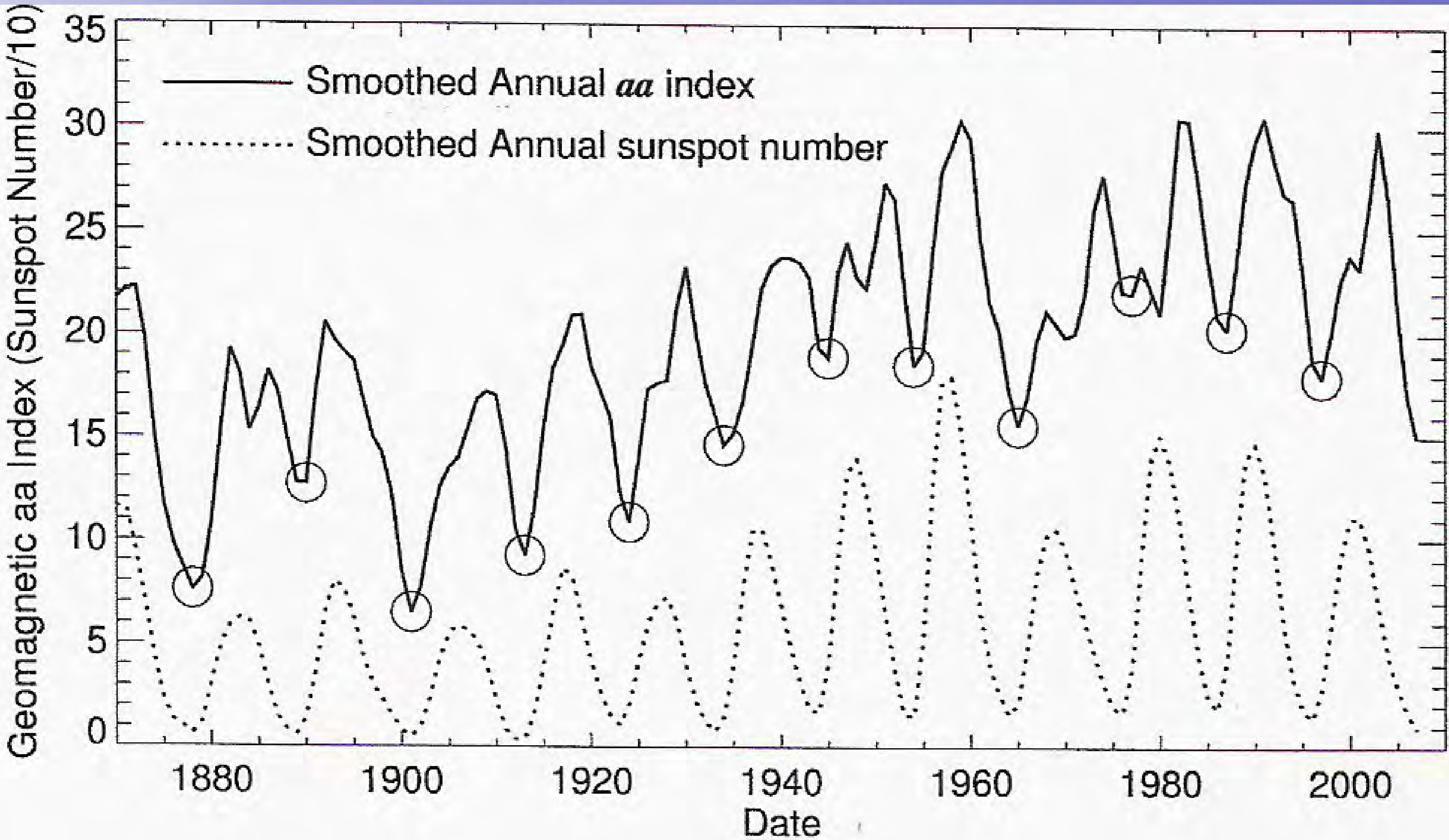
‘Proxies’ for the two fields

The solar magnetism has actually been measured for less than a century. ‘Proxies’ serve as substitutes for the two fields

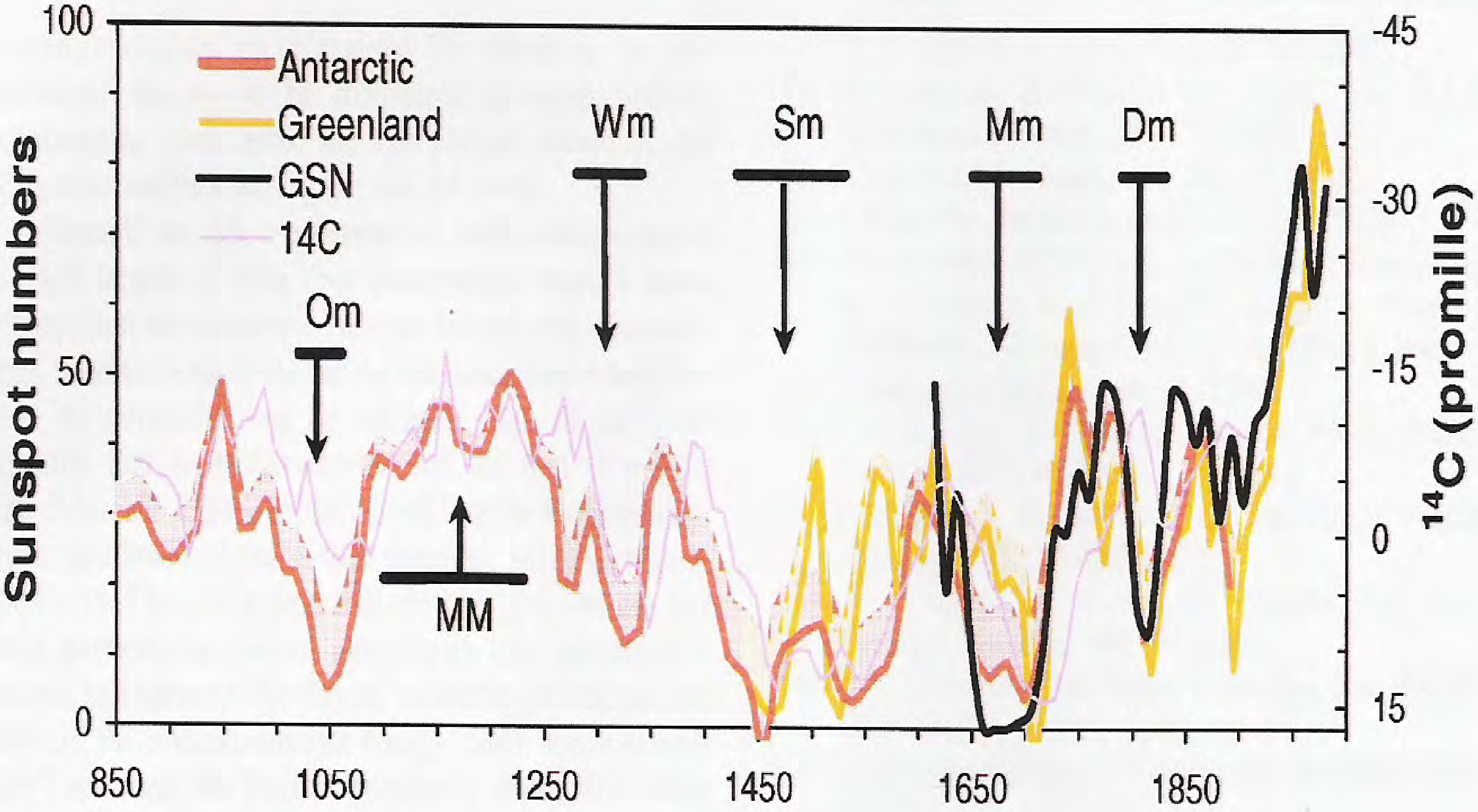
1. The sunspot number is a proxy for the equatorial (toroidal) fieldstrength. Note the enormous variations over time



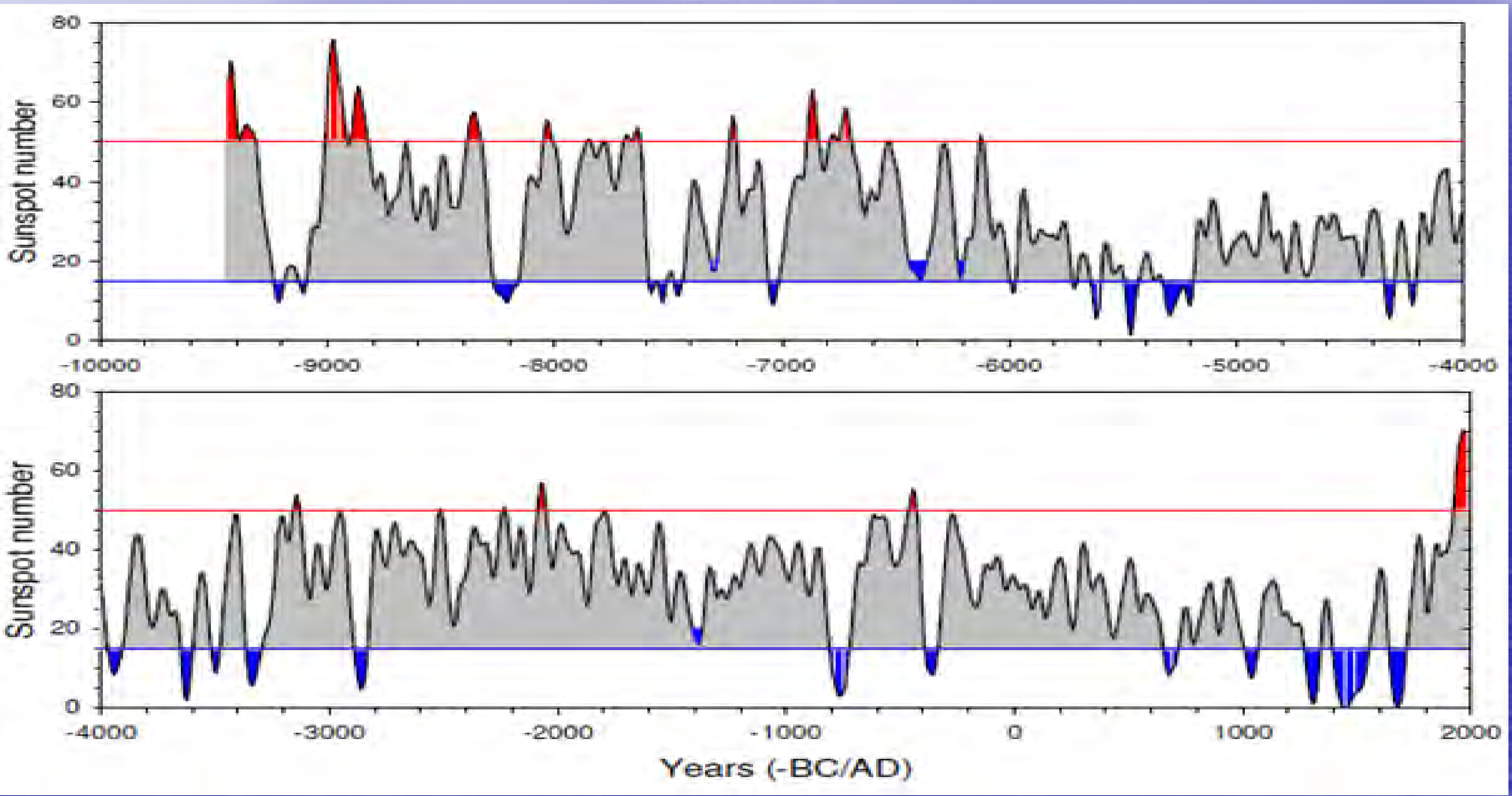
2. The minimal value of the geomagnetic *aa* index is a measure for the polar (poloidal) field



3. *Cosmogenic radio-nucleides* are a measure for the amount of radiated solar magnetism. Note the Grand Minima of the past millennium



Extreme cases: Grand Maxima (of the 20th century and of 11,000 years ago). Complexes of Grand Minima are approximately Hallstatt periods apart



Recent transitions between Episodes occurred in:

- 1730 – ‘40: transition from Grand Minimum (Maunder) to episode of Regular Oscillations
- 1923: from Regular Oscillations to a Grand Maximum
- 2009: transition from Grand Maximum to another Grand Episode
- We know this through the study of the *Phase Diagram* and its *Transition Point*

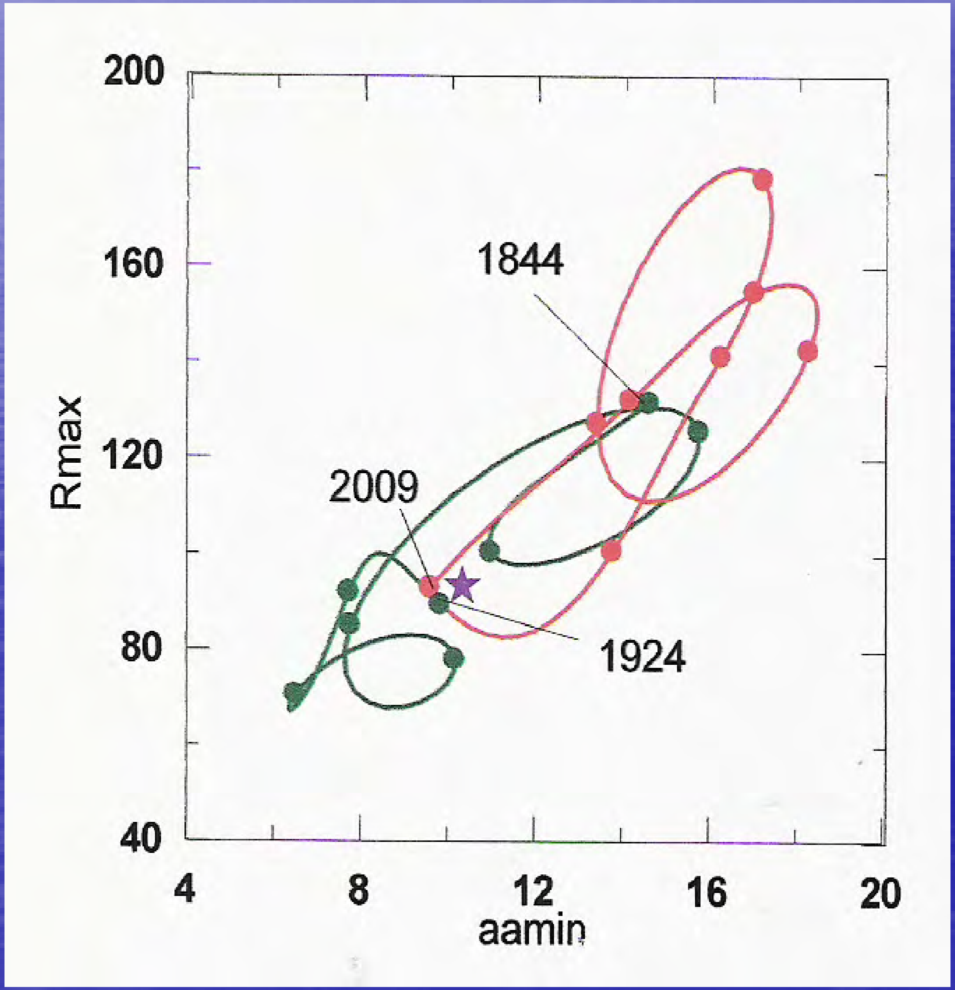
Transitions between Grand Episodes

Can they be predicted?

The phase diagram

A graph in which we plot the strength of the equatorial field against the polar field. It is an assist to view the transitions between Grand Episodes. The *Transition Point* is an essential element

The star in the phase diagram is the *Transition Point*. When the *Rmax-aamin* curve is at or near the Transition Point another Grand Episode will start



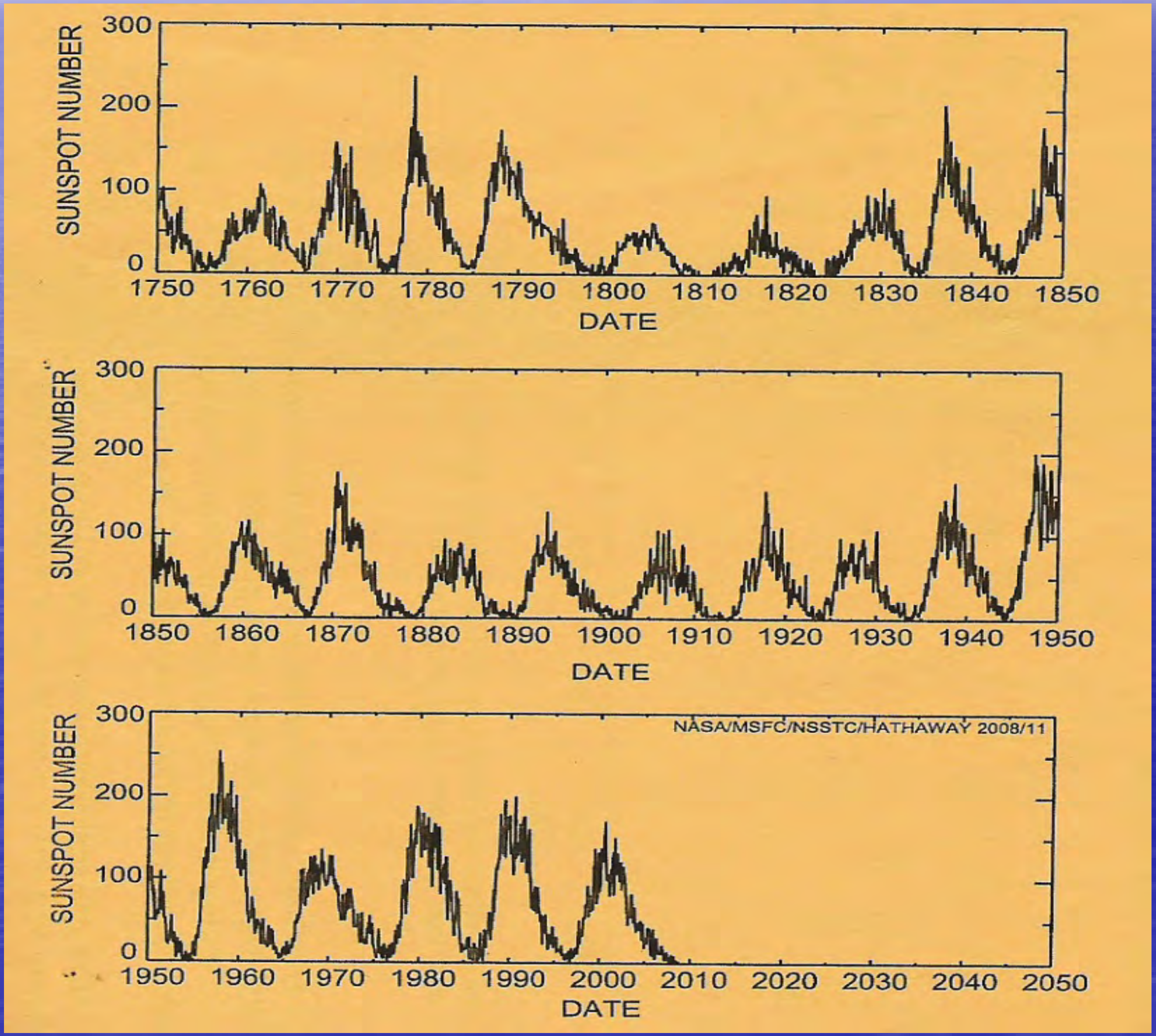
The phase diagram shows

- Another Grand Episode is imminent
- It will be either Regular Oscillations or a Grand Minimum
- It was reecently found that Grand Minima occur only during negative phases of the Hallstatt oscillation
- But Dalton type minima do occur during positive Hallstatt phases
- The Hallstatt periodicity was minimal between 910 and 1930 and is now in its positive phase
- So we may only expect Dalton type minima, no Grand Minima

Two predictions

- Based on the phase diagram we (S. Duhau en CdeJ, 2011) expect:
- The start of Regular Oscillations, like those between 1740 and 1924
- And based on the polar field strength during the transition period, we (SD+CdJ, 2009) expect for the current Schwabe cycle a low maximum sunspot number 62 ± 12
- That maximum will be in 2013.5

Compare this forecast with previous cycles. It resembles the Dalton Minimum (around 1810)



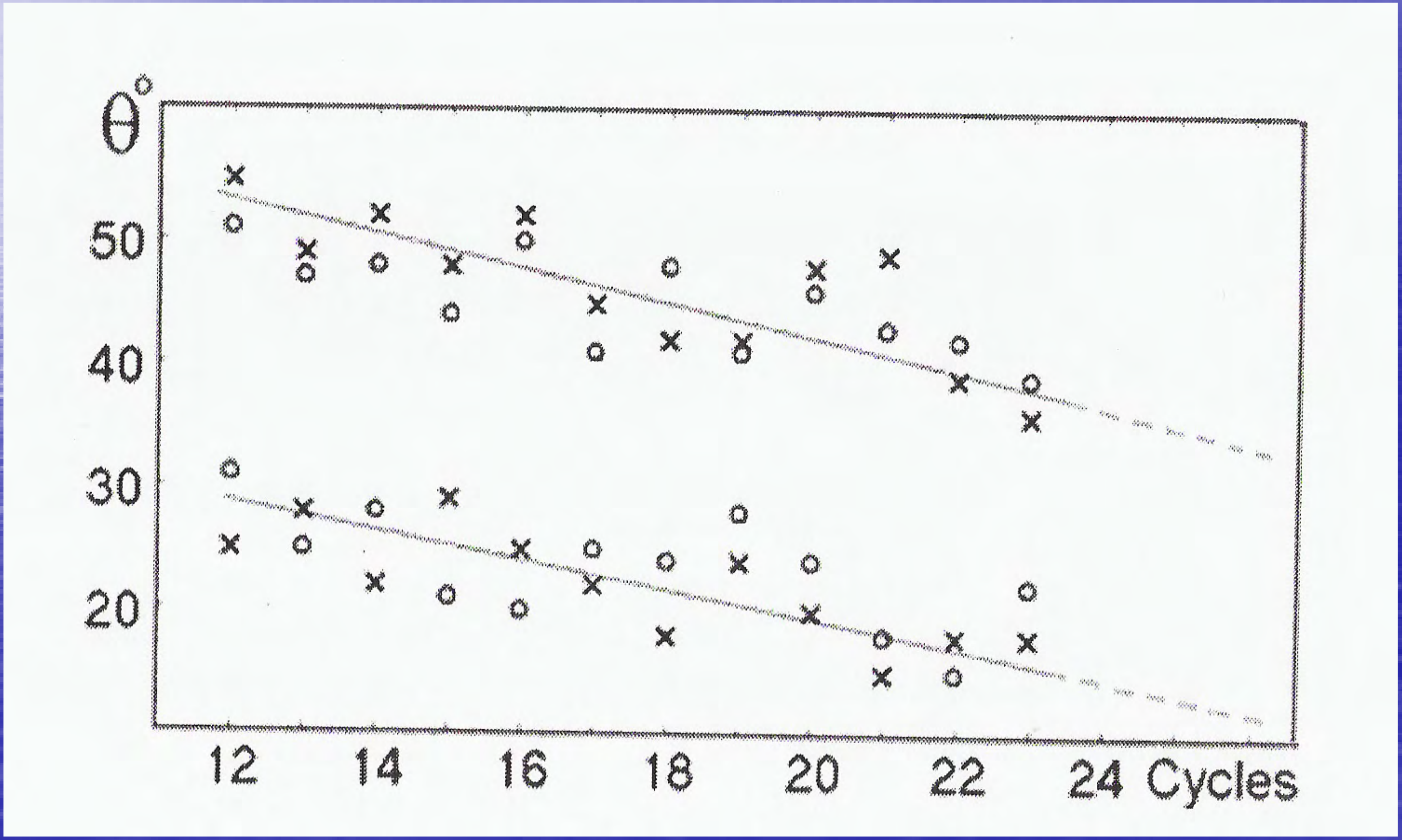
So : does the new Grand Episode start with a Dalton-type minimum?

We´ll have to wait because we will know this only at the end of the current Schwabe cycle (ca. 2018)

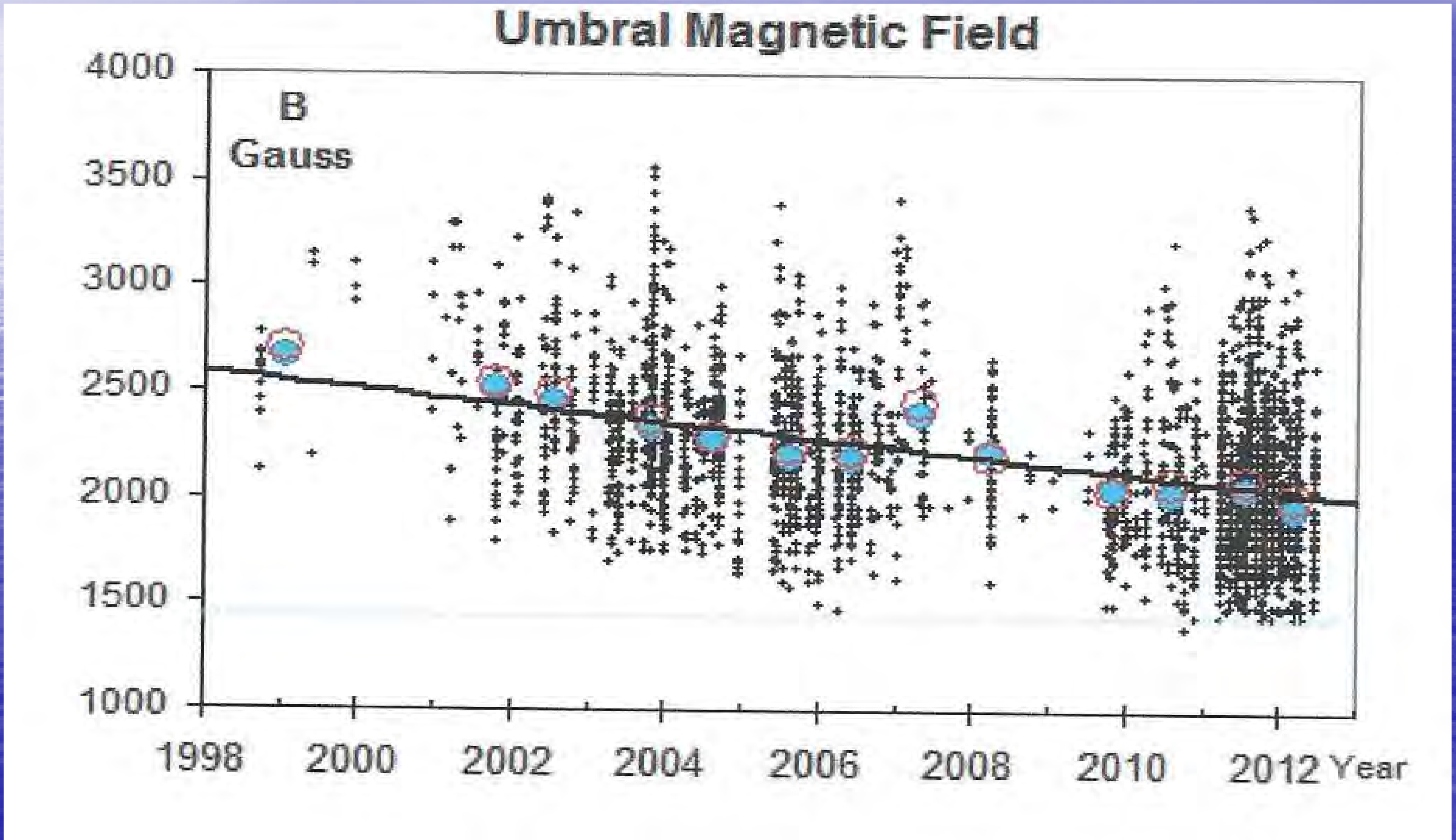
Finally:

Curious behaviour of the solar dynamo during and before the recent phase Transition

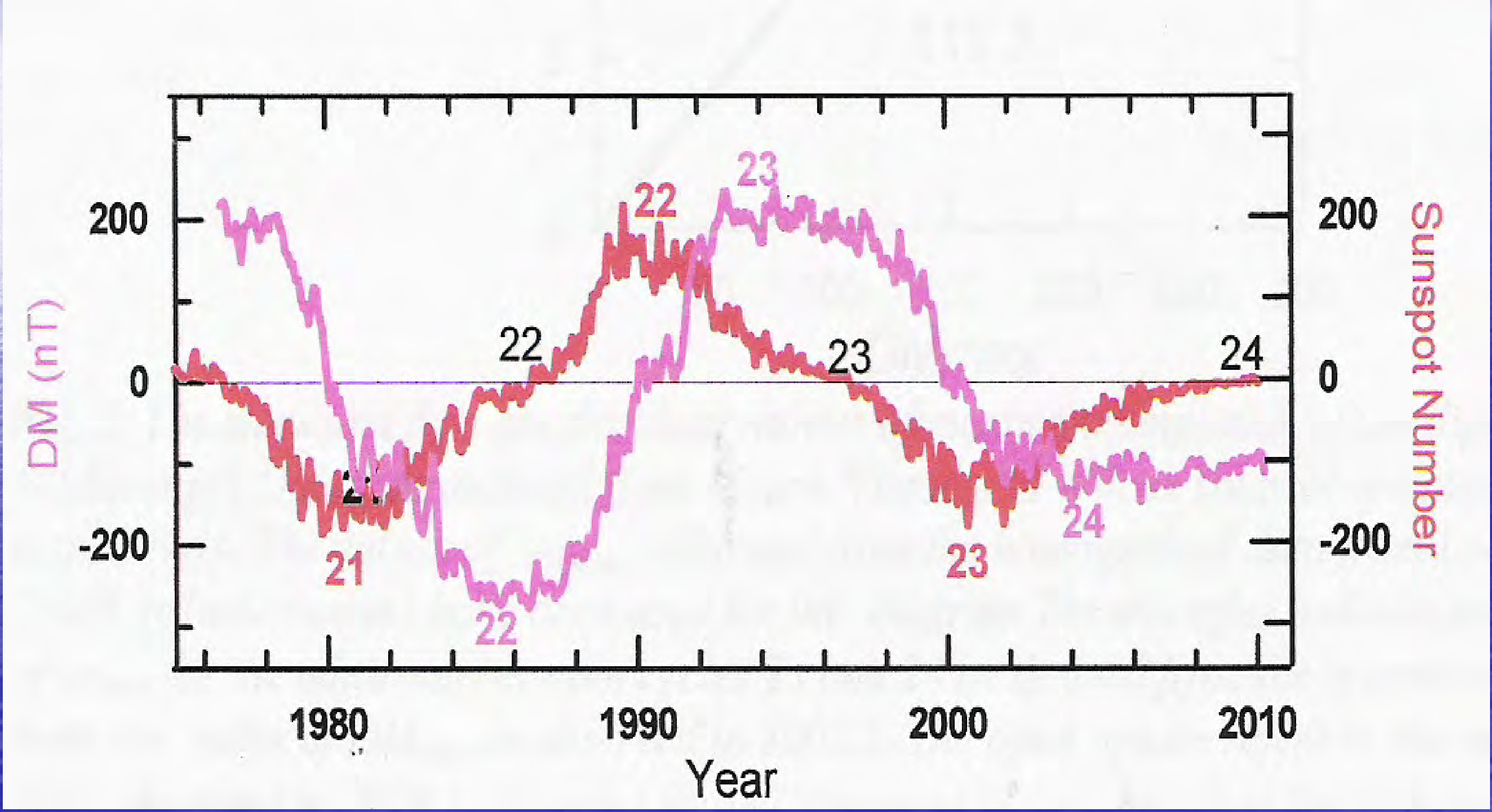
The sunspot belt shifted down to the solar equator (Makarov)



Magnetic field of sunspots became weaker (Livingston)



A much extended minimum has developed since about 2005 in the Hale cycle (compare 1982 with 2002). *Red*: sunspots; *pink*: polar field. DM is polar field strength



A fascinating period we live in

It is sometimes said that the tachocline´s behaviour is chaotic and unpredictable, but is that really so ?

The future will tell

Part of the foregoing is published in papers by S. Duhau and C. de Jager. The full text of these papers can be consulted at www.cdejager.com . Go there to the page *´ sun earth publications´*