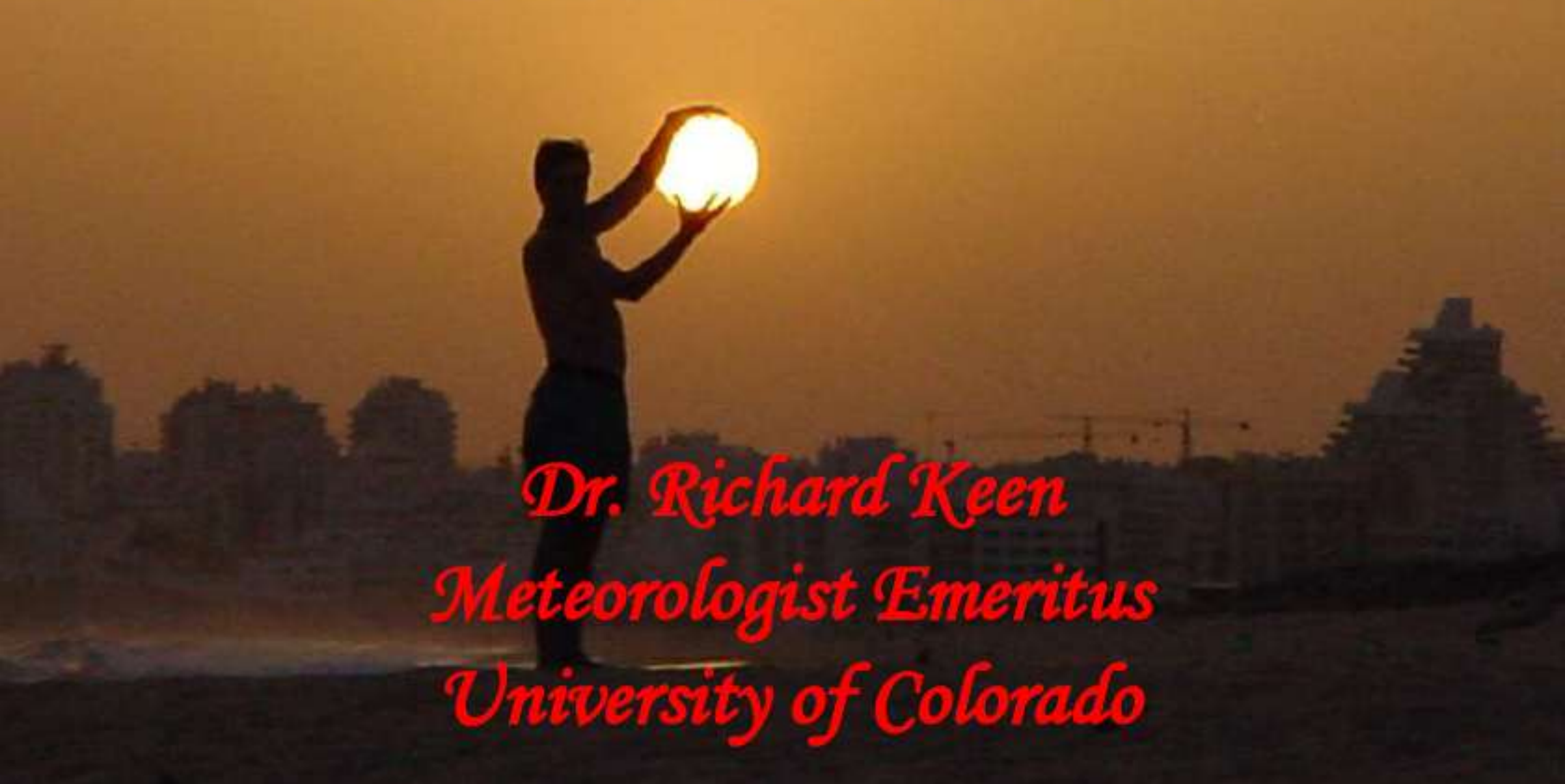
Changes: The Sun and Earth's Climate



Dr. Richard Keen
Meteorologist Emeritus
University of Colorado

Who am I
And why do I care about this?

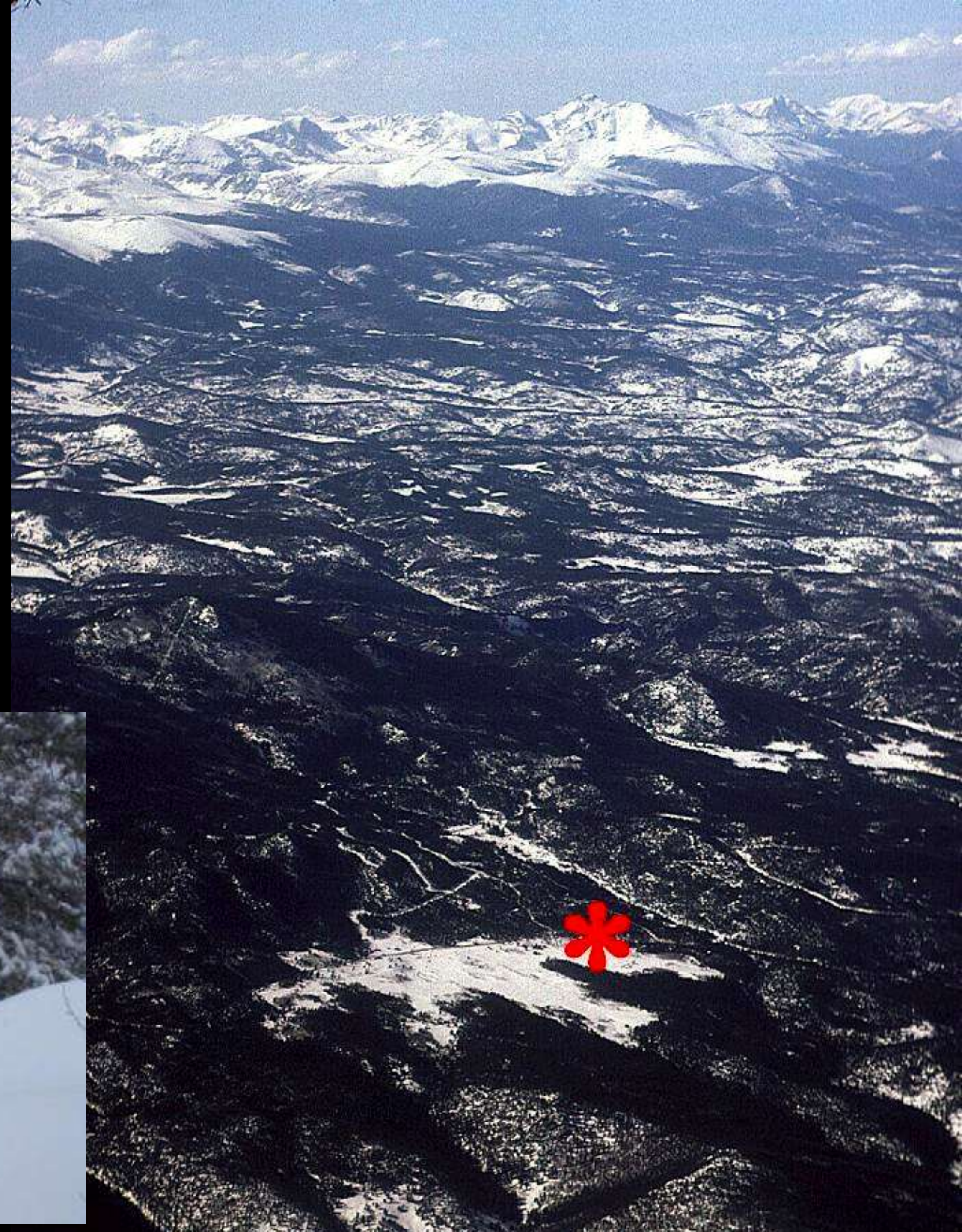
My thoughts on climate are tainted by my background as a…

Climate researcher
(el Niño, Volcanoes, Alaska…)
Astronomer
Eclipse watcher – solar & lunar
Reporter
Author
Teacher
Photographer
Mountaineer & Glaciologist
Storm chaser
Army Met guy
Weather observer
Weather "historian"
Talking Head
IPCC WG1 AR5 Expert Reviewer

Home,
Weather Station,
& Observatory

Coal Creek Canyon
Colorado

Above 28% of the
Earth's atmosphere



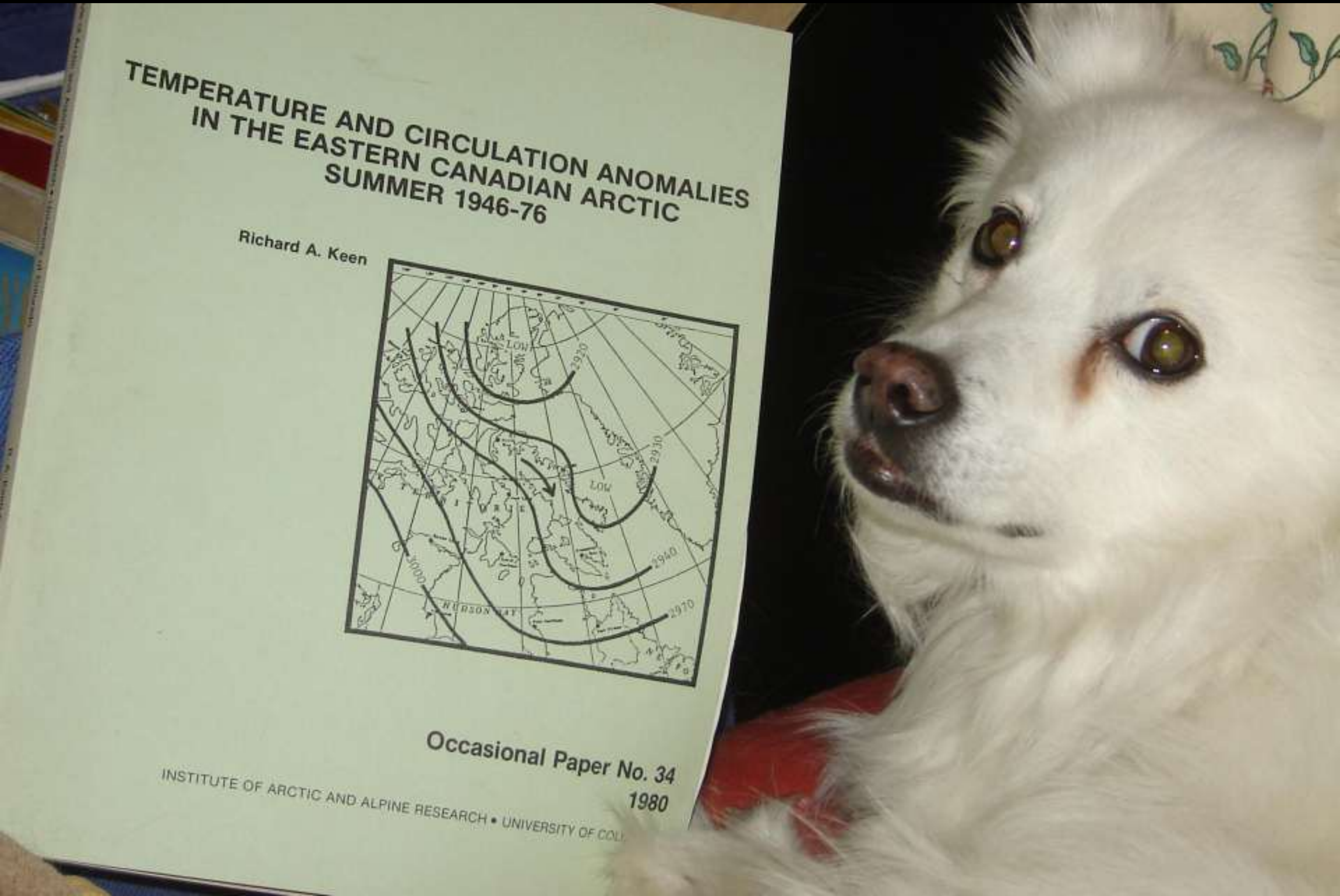
You can observe a lot by just watching.

Words to live by

I've written books, about the sky, of course.

And a PhD thesis about climate change in the Arctic.

Conclusion: jet stream winds and storm tracks are the major factors.



18 June 1976, Volume 192, Number 4245 **SCIENCE**

Jack Eddy, 1931-2009

The Maunder Minimum

The reign of Louis XIV appears to have been a time of real anomaly in the behavior of the sun.

John A. Eddy

It has long been thought that the sun is a constant star of regular and repeatable behavior. Measurements of the radiative output, or solar constant, seem to justify the first assumption, and the record of periodicity in sunspot numbers is taken as evidence for the second. Both records, however, sample only the most recent history of the sun.

When we look at the longer record—of the last 1000 years or so—we find indications that the sun may have undergone significant changes in behavior, with possible terrestrial effects. Evi-

The Sunspot Cycle

Surely the best-known features of the sun are sunspots and the regular cycle of solar activity, which waxes and wanes with a period of about 11 years. This cycle is most often shown as a plot of sunspot number (Fig. 1)—a measure of the number of spots seen at one time on the visible half of the sun (*1*). Sunspot numbers are recorded daily, but to illustrate long-term effects astronomers more often use the annual means, which smooth out the short-term variations and

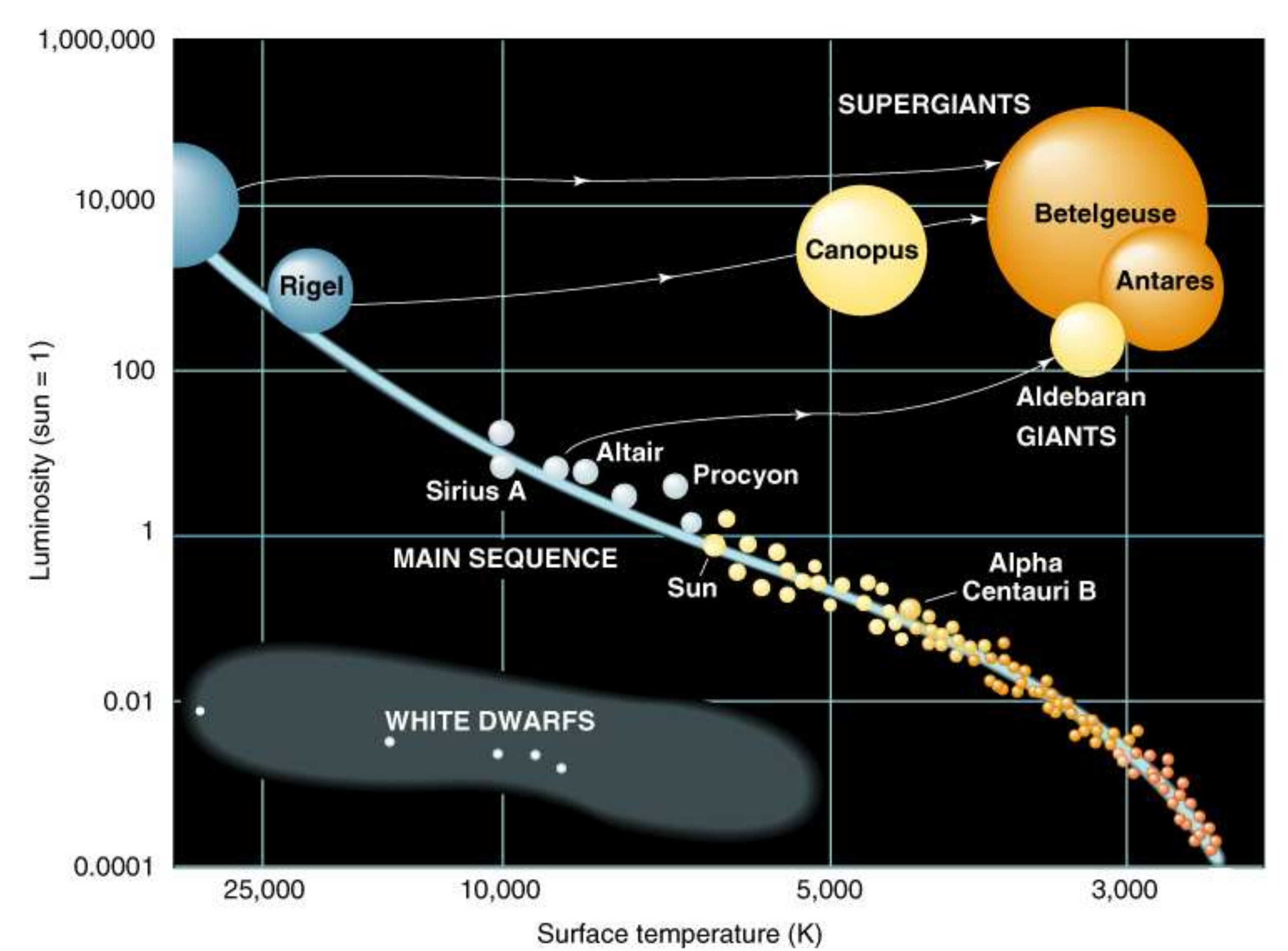
zero. In contrast, in the years around a sunspot maximum there is seldom a day when a number of spots cannot be seen, and often hundreds are present.

Past counts of sunspot number are readily available from the year 1700 (*3*), and workers in solar and terrestrial studies often use the record as though it were of uniform quality. In fact, it is not. Thus it is advisable, from time to time, to review the origin and pedigree of past sunspot numbers, and to recognize the uncertainty in much of the early record.

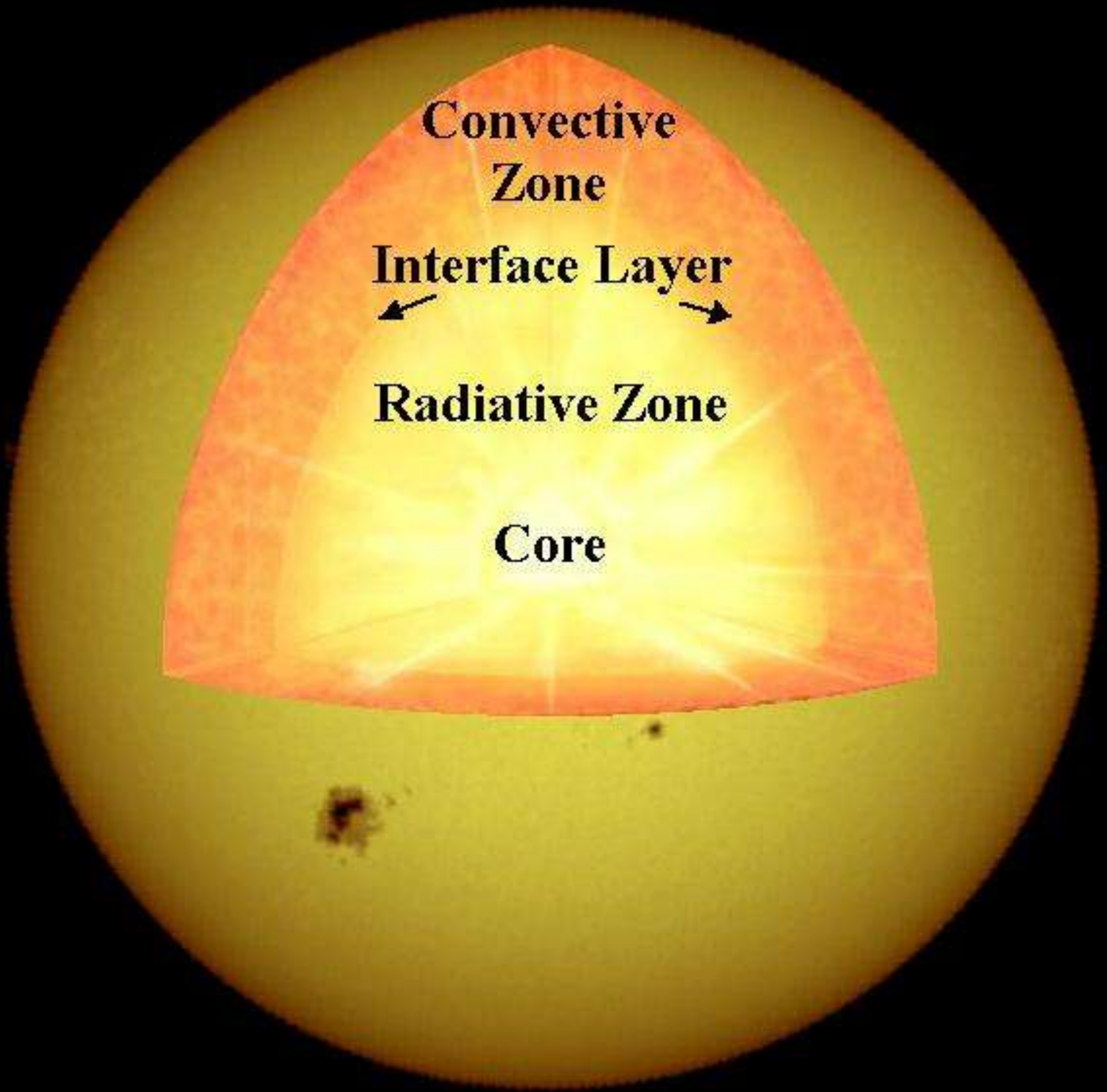
A Brief History

Dark spots were seen on the face of the sun at least as early as the 4th century B.C. (*4*), but it was not until after the invention of the telescope, about 1610, that they were seen well enough to be associated with the sun itself. It would seem no credit to early astronomers that over 230 years elapsed between the telescopic "discovery" of sunspots and the revelation of their now obvious cyclic behavior. In 1843, Heinrich Schwabe, an amateur, published a brief paper reporting his own observations of spots on the sun for the period

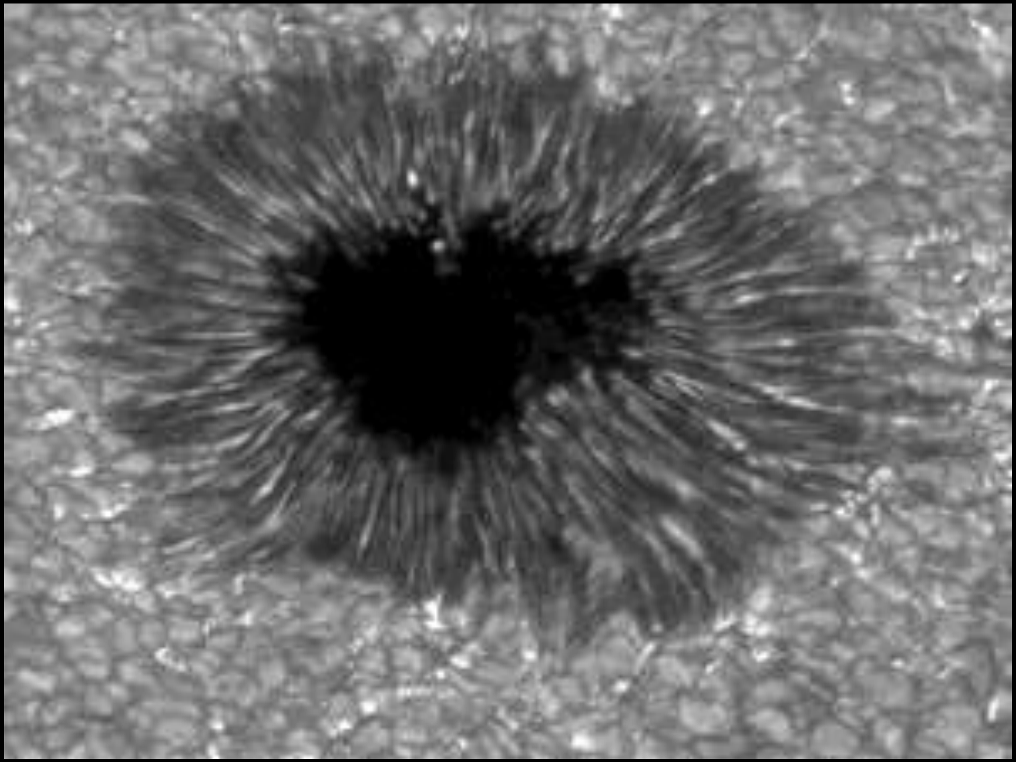
The Sun is an ordinary star, Smack-dab in the center of the Hertzsprung-Russell diagram



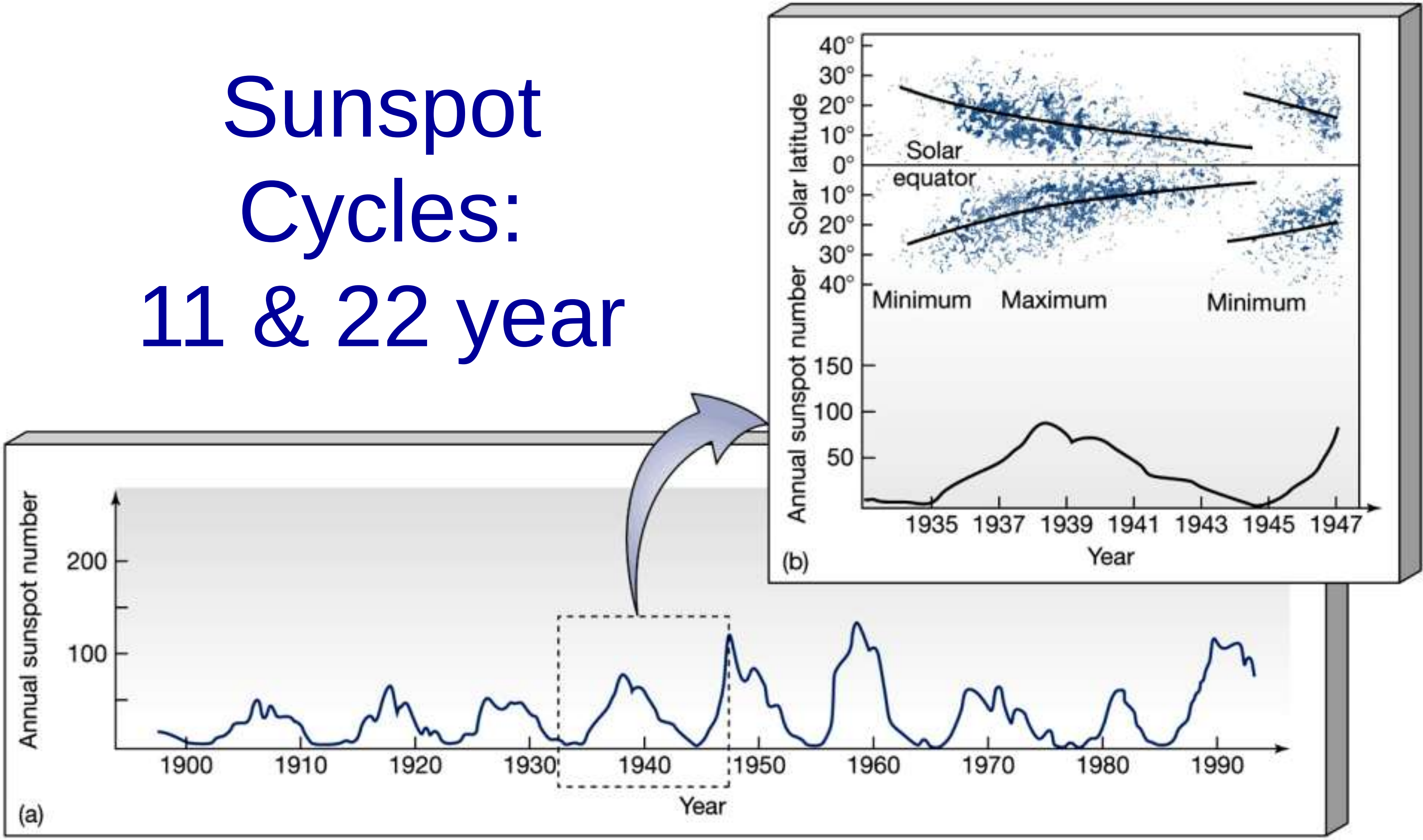
But the sun is still an exciting place



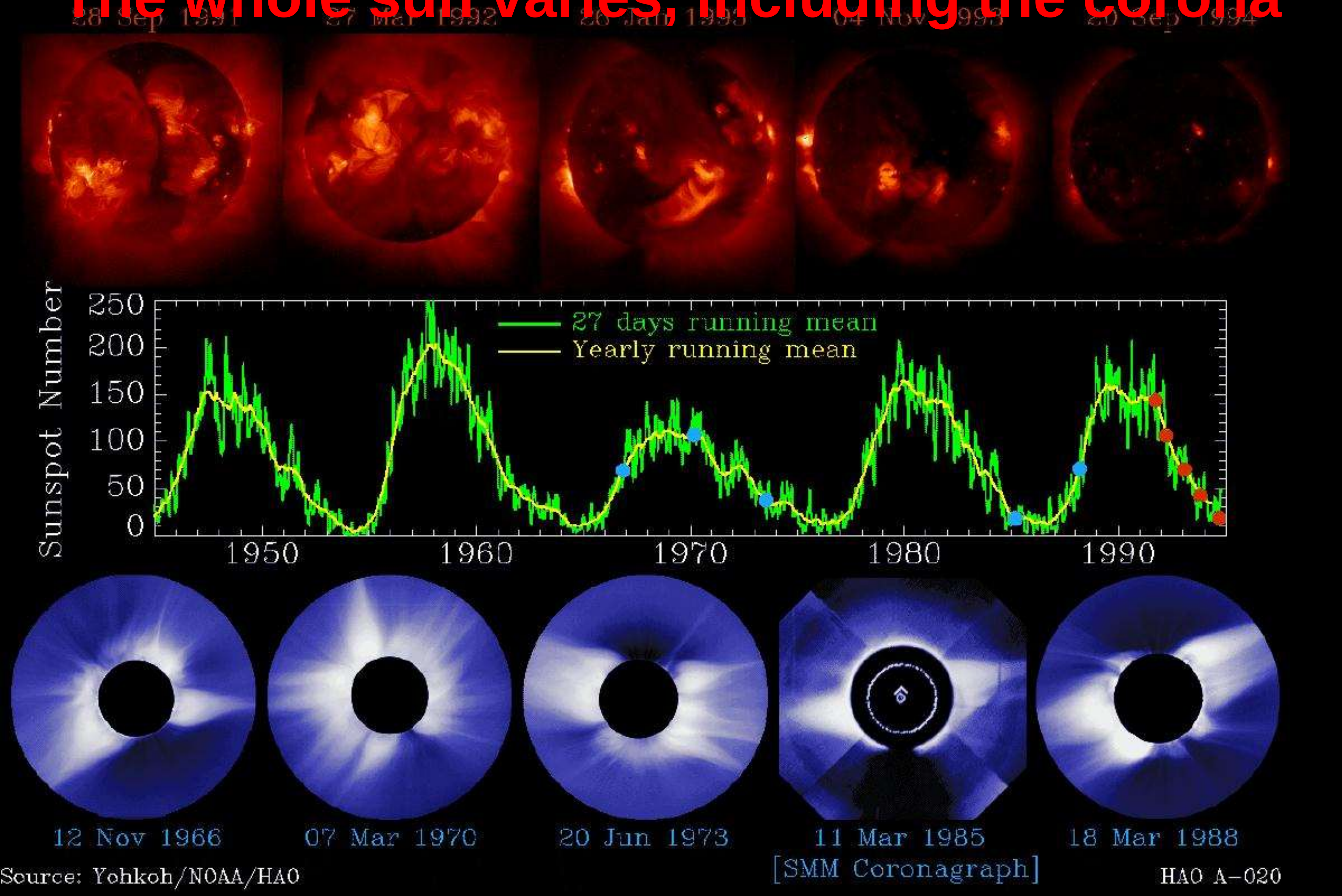
Sunspots



Sunspot Cycles: 11 & 22 year



The whole sun varies, including the corona



Another curious 22-year solar cycle

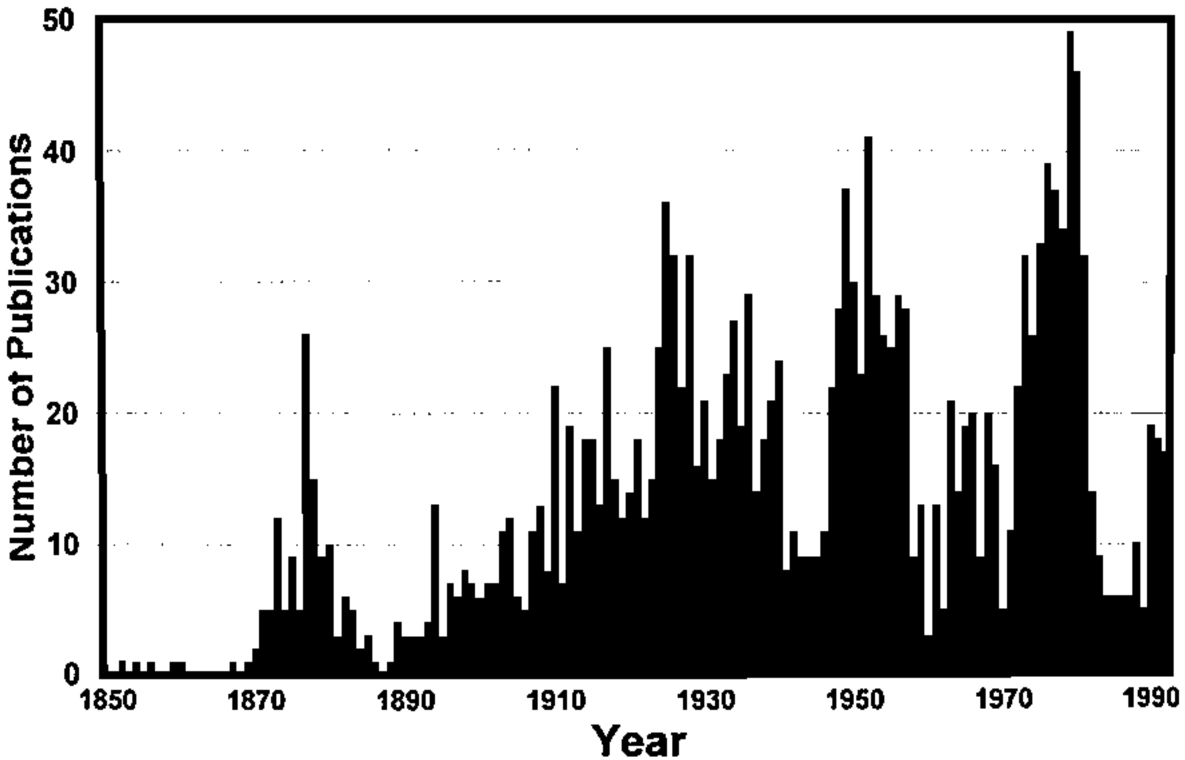
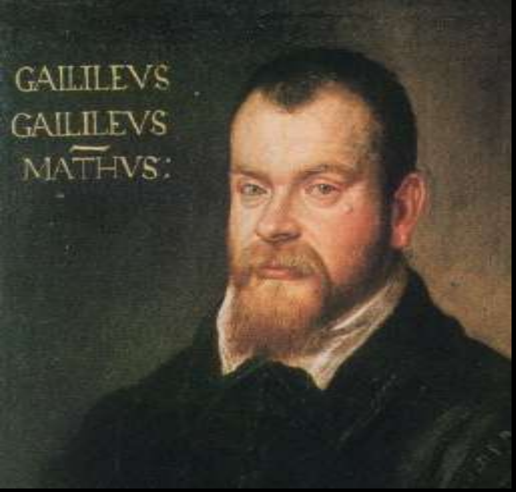
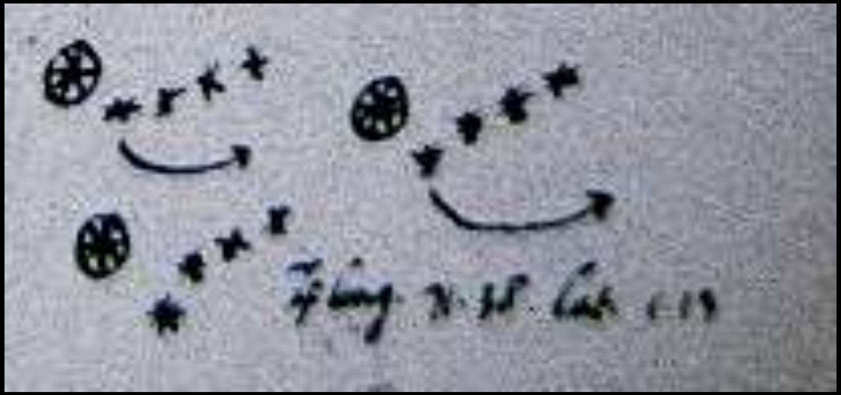
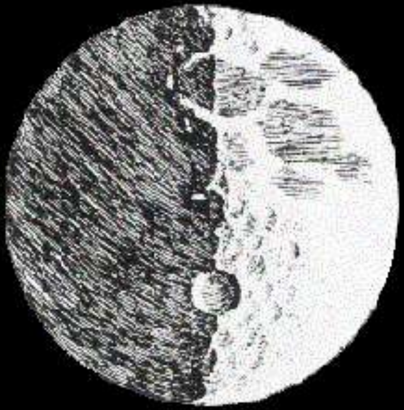


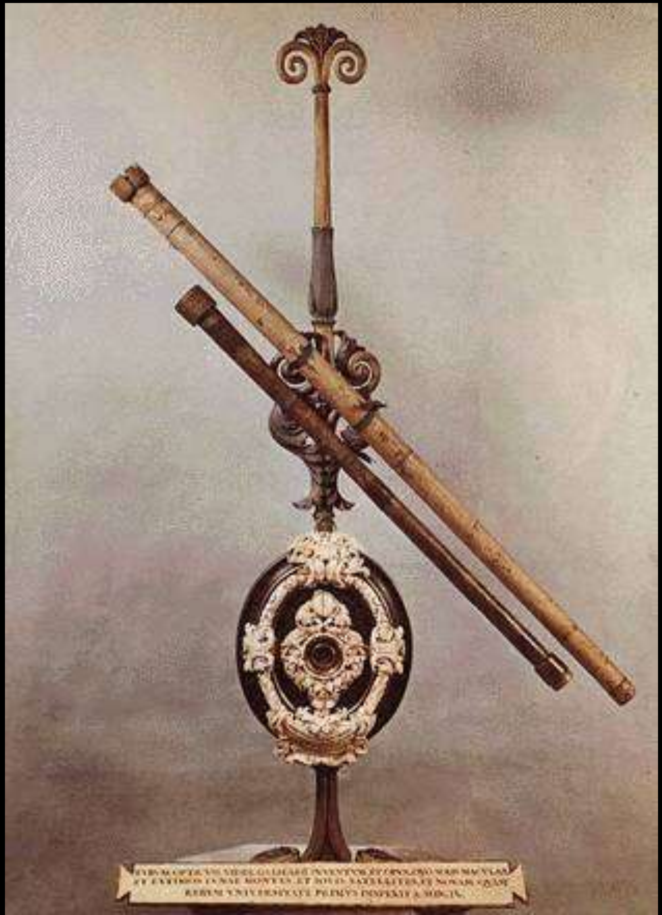
FIGURE 1.2 The approximate number of sun/weather/climate publications each year from 1850 to 1992 are shown (1,908 total). Note the initial surge of publications after 1870 followed by a decline around 1900. Since then, the increase in publications has remained almost steady. Two thousand papers represent less than 0.25% of the scientific literature published *each year*, so the sun/climate field remains relatively small.

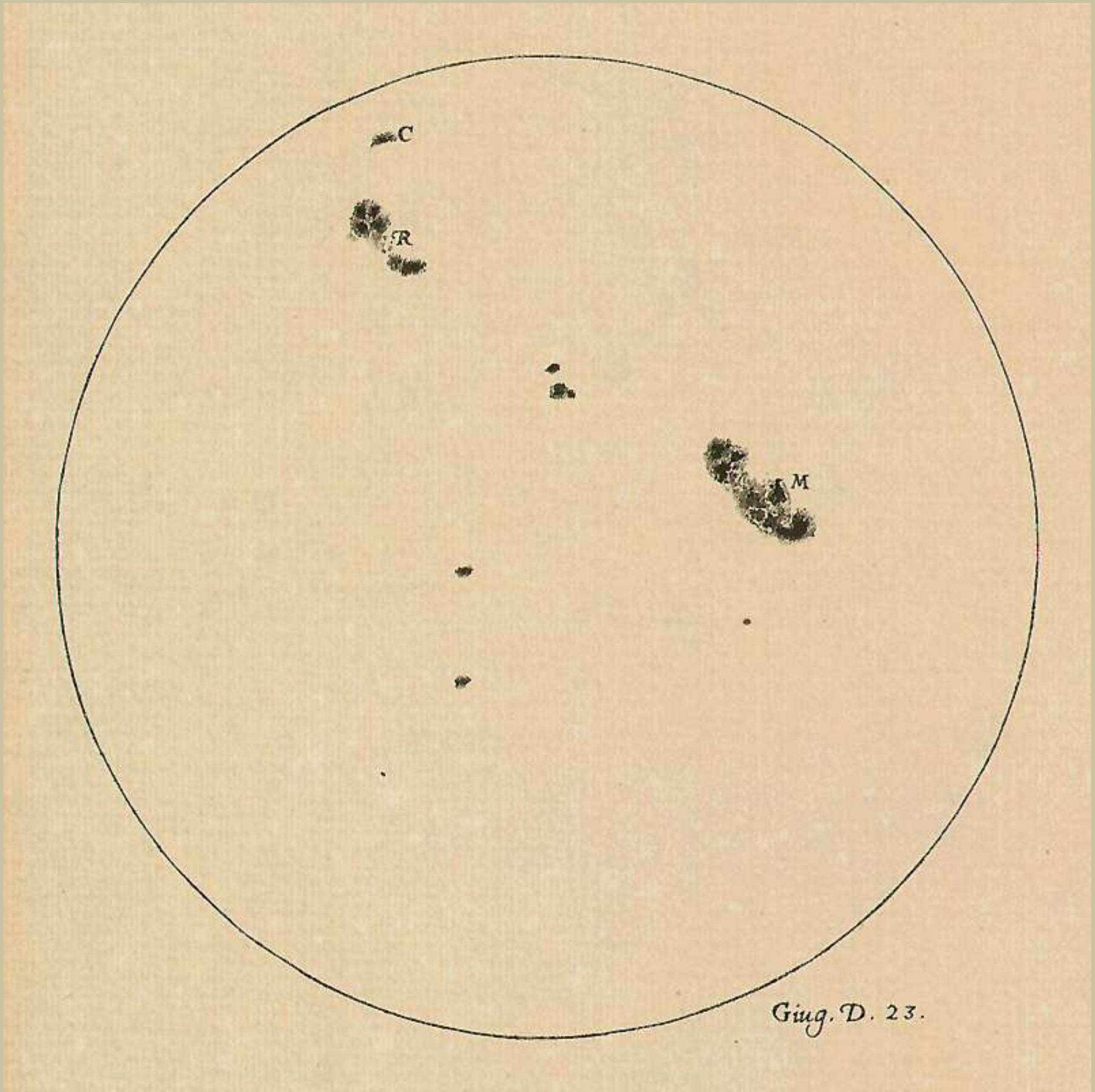


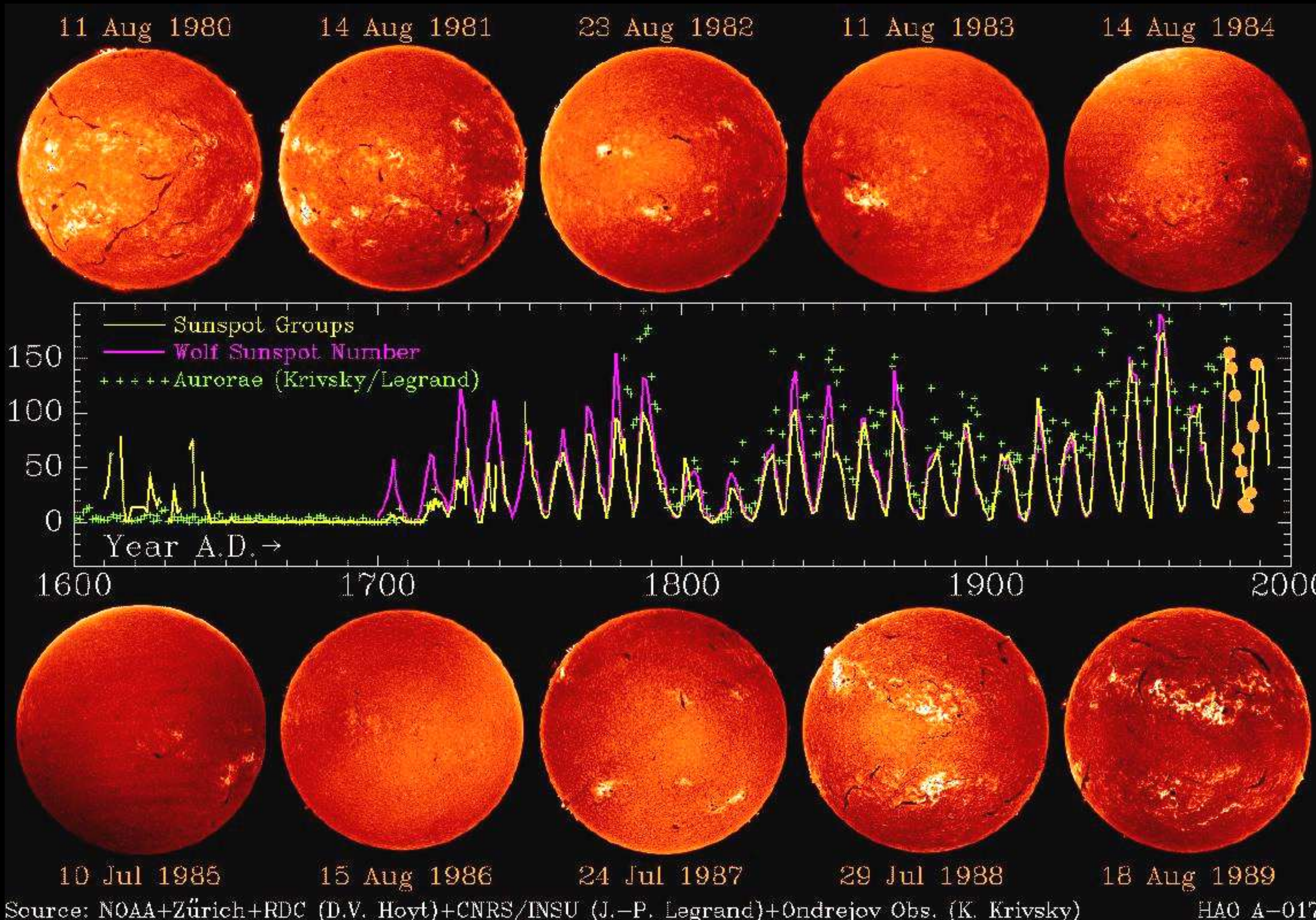


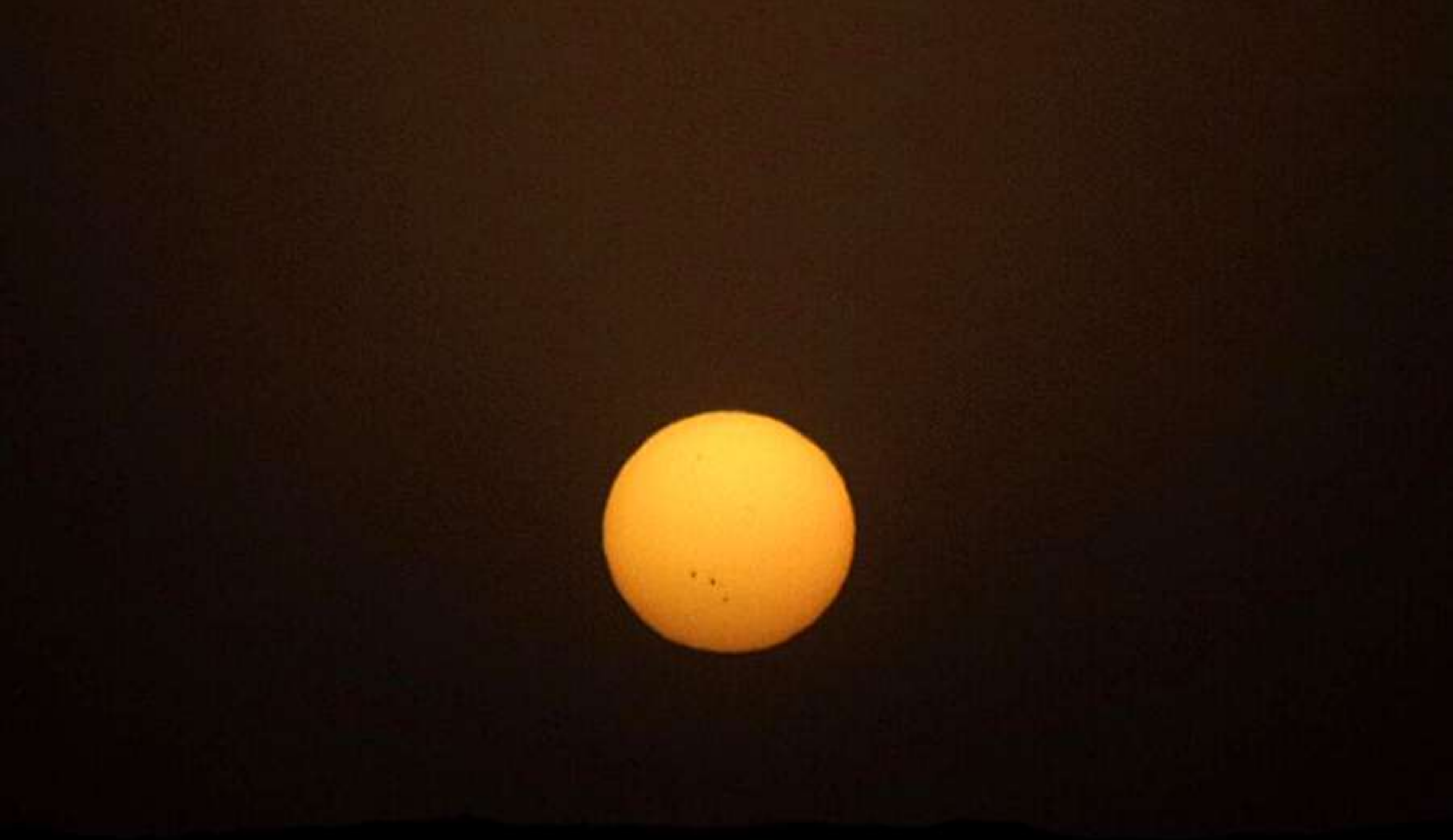
Galileo, 1610






C
R
M
Giug. D. 23.


11 Aug 1980
14 Aug 1981
23 Aug 1982
11 Aug 1983
14 Aug 1984
Sunspot Groups
Wolf Sunspot Number
+ + + + + Aurorae (Krivsky/Legrand)
150
100
50
0
Year A.D. →
1600
1700
1800
1900
2000
10 Jul 1985
15 Aug 1986
24 Jul 1987
29 Jul 1988
18 Aug 1989
Source: NOAA+Zürich+RDC (D.V. Hoyt)+CNRS/INSU (J.-P. Legrand)+Ondrejov Obs. (K. Krivsky)
HAO A-017



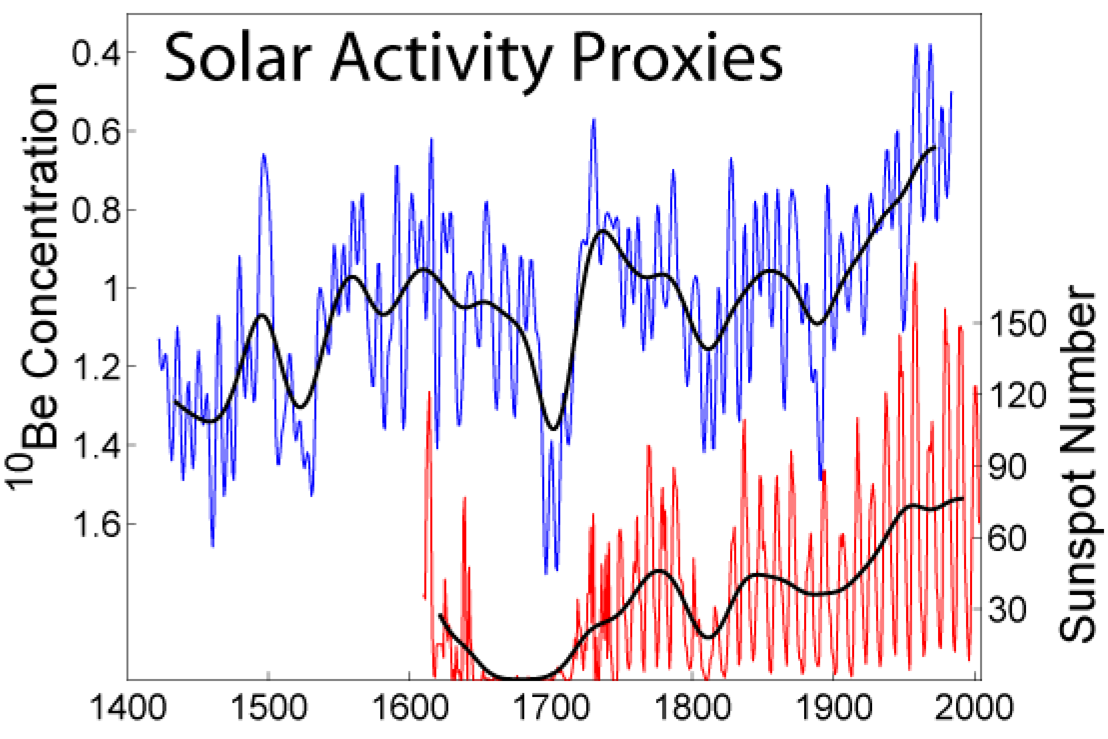
Pre-Galileo records of big sunspots visible to the unaided eye through dusty sunsets were recorded in China one or two thousand years ago.

Post-Galileo record of a big sunspot visible to the unaided eye through a smoky sunset recorded in Colorado ten years ago.

Proxies: Sunspot counts correlate with isotopes of Beryllium 10, Carbon 14, etc., found in trees, ice cores, ocean sediments, etc.

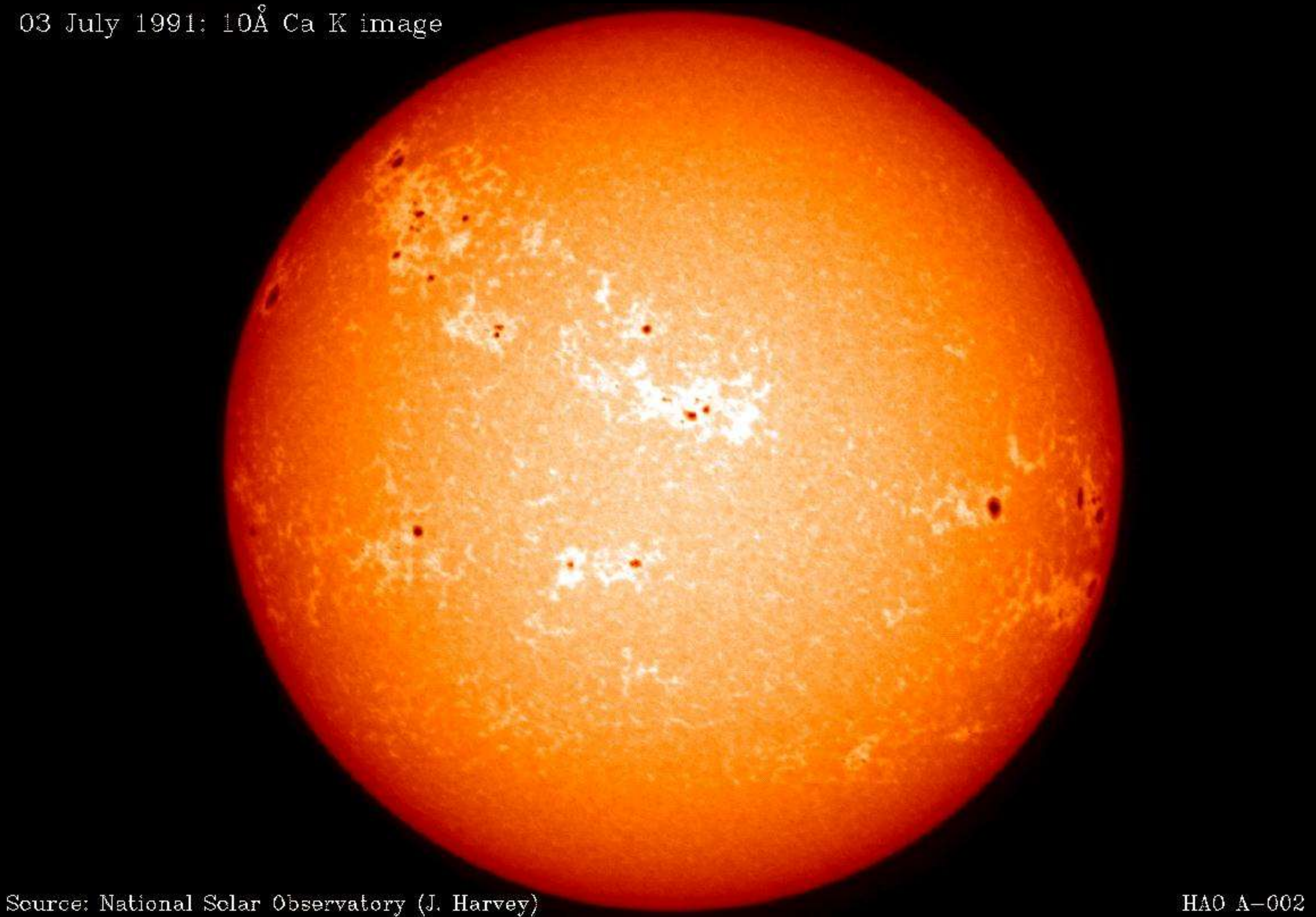
These indicate the Sun now (AD 2000) is brighter than any time in the past 600 (or 1000?) years

More later.

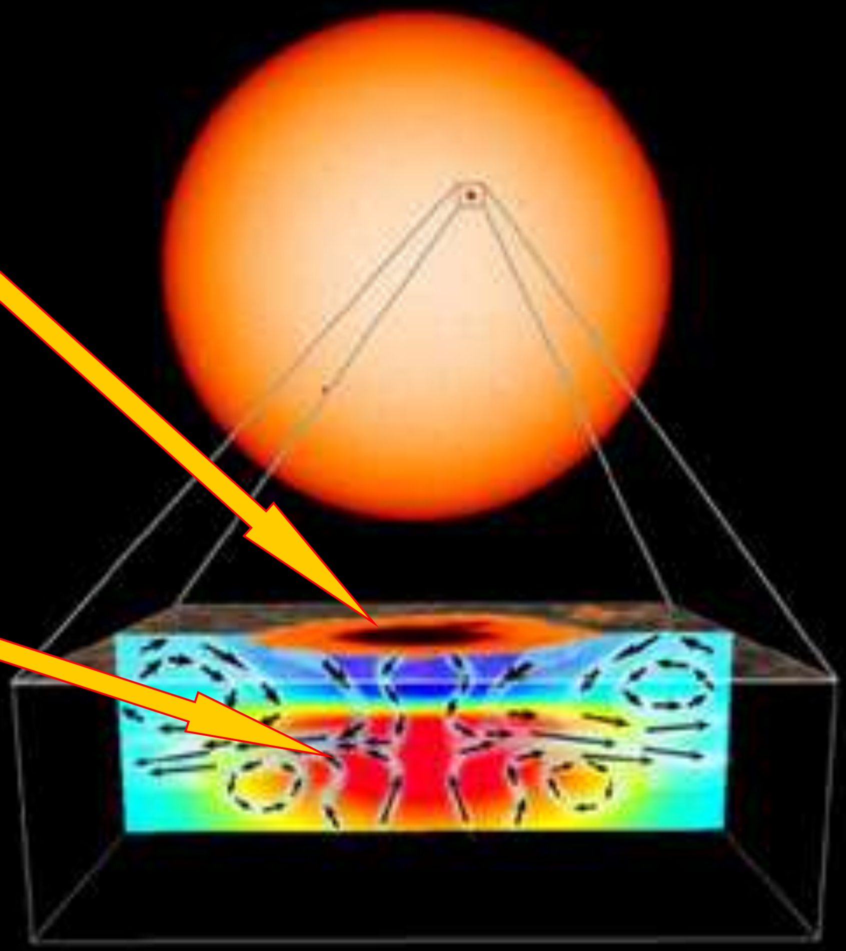


Do Sunspots make the Sun darker ?

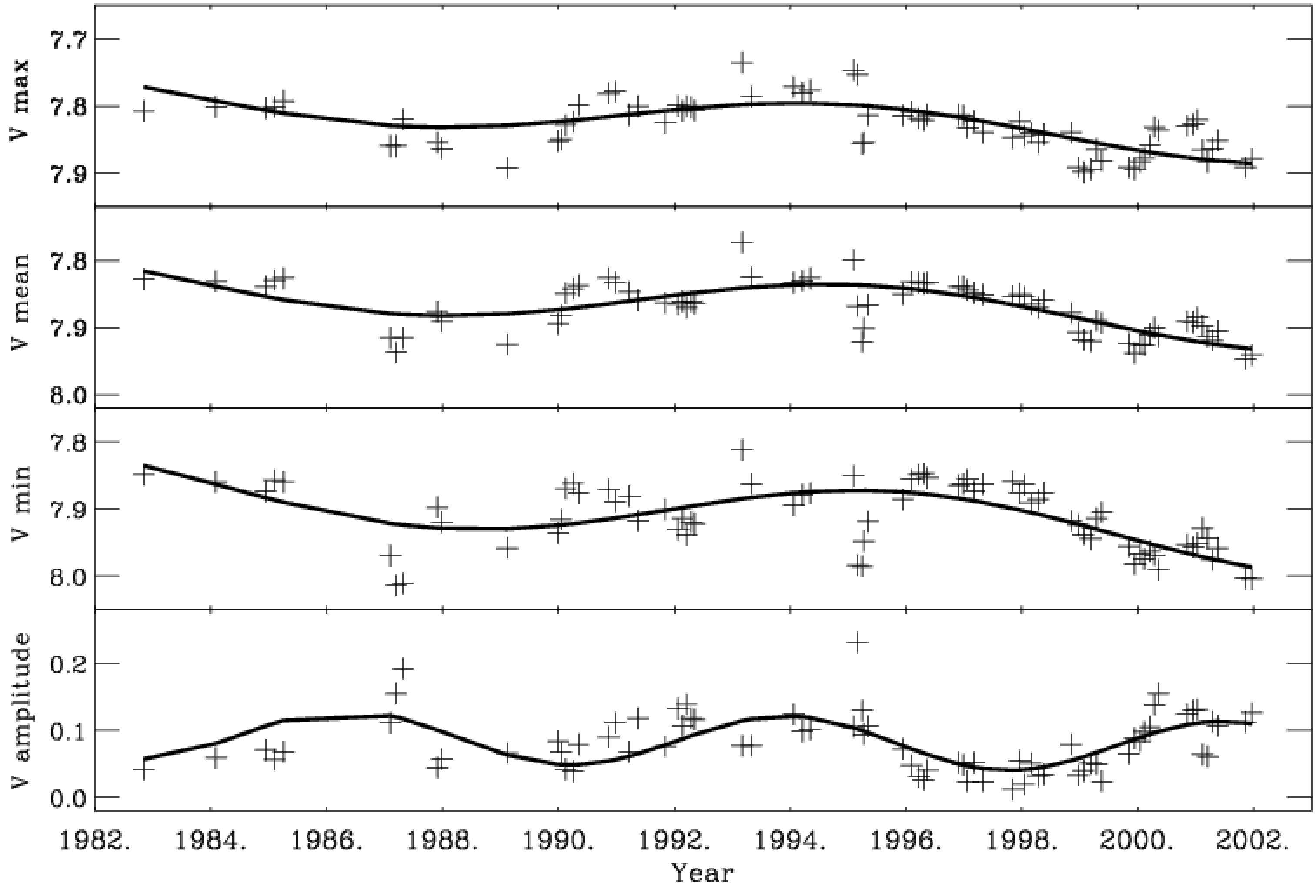
Dark spots become hot spots at different wavelengths and heights in the solar atmosphere. So more sunspots = brighter, hotter Sun



Even though sunspots are cooler than the rest of the Sun's surface, the Sun is hotter overall when there are more spots.



Other solar-type G2 stars vary similarly: LQ Hya

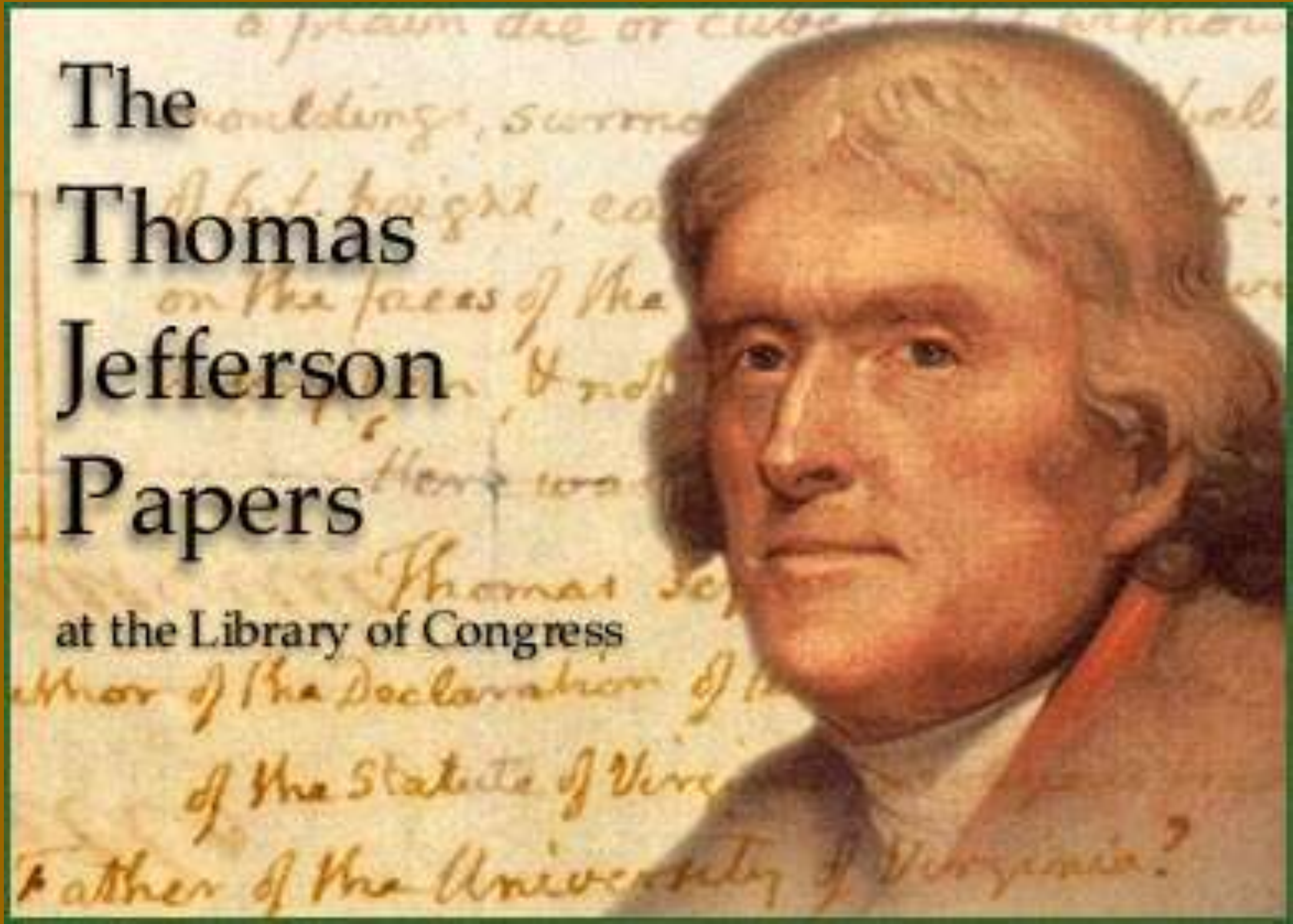


Climate
of the past millennium
- the cold facts
recorded by ice, trees, people.

"A change in our climate however is taking place very sensibly. Both heats and colds are become much more moderate within the memory even of the middle-aged. Snows are less frequent and less deep."

—Thomas Jefferson, *Notes on the State of Virginia*, 1781

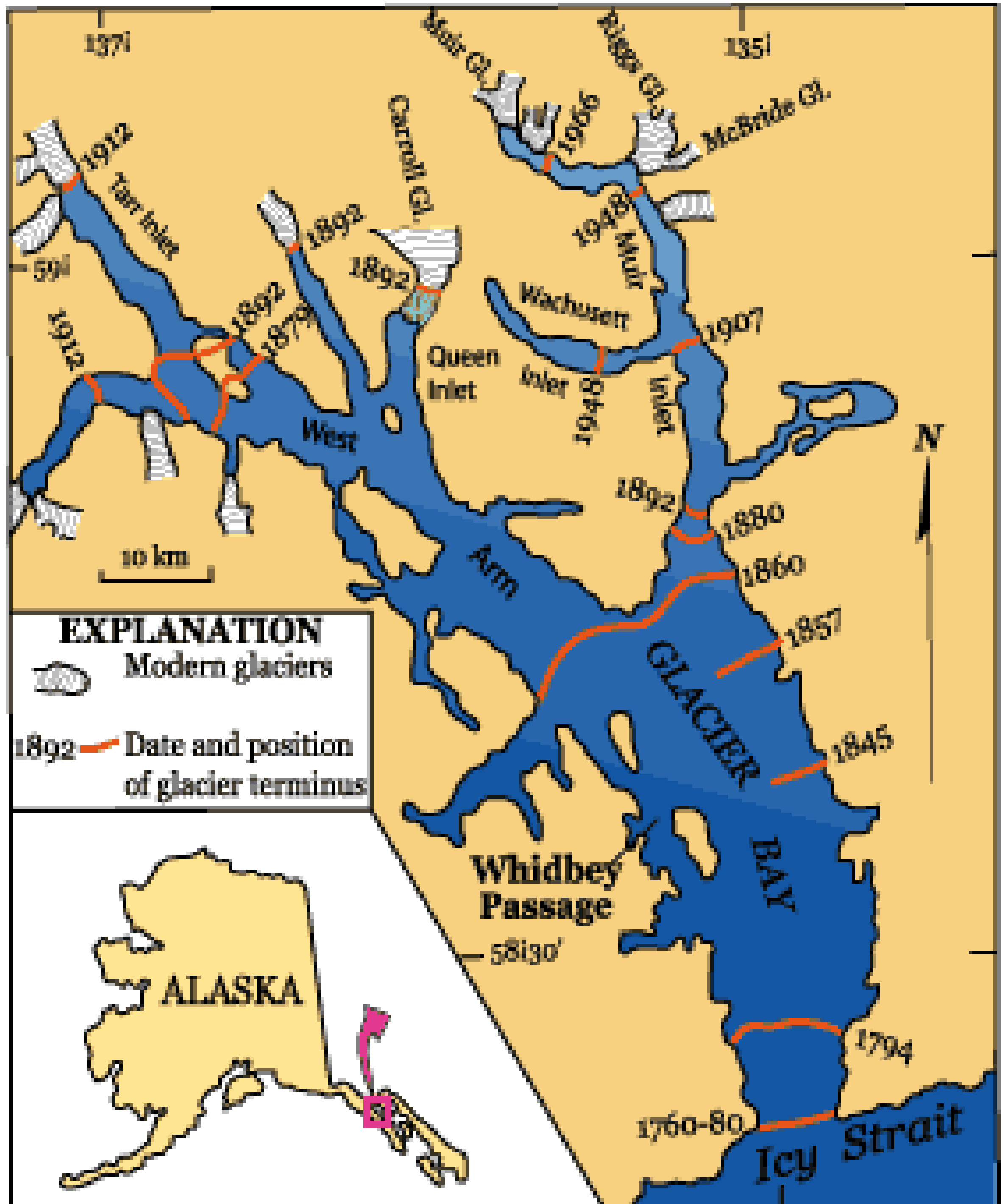
Noting the warming since 1700.



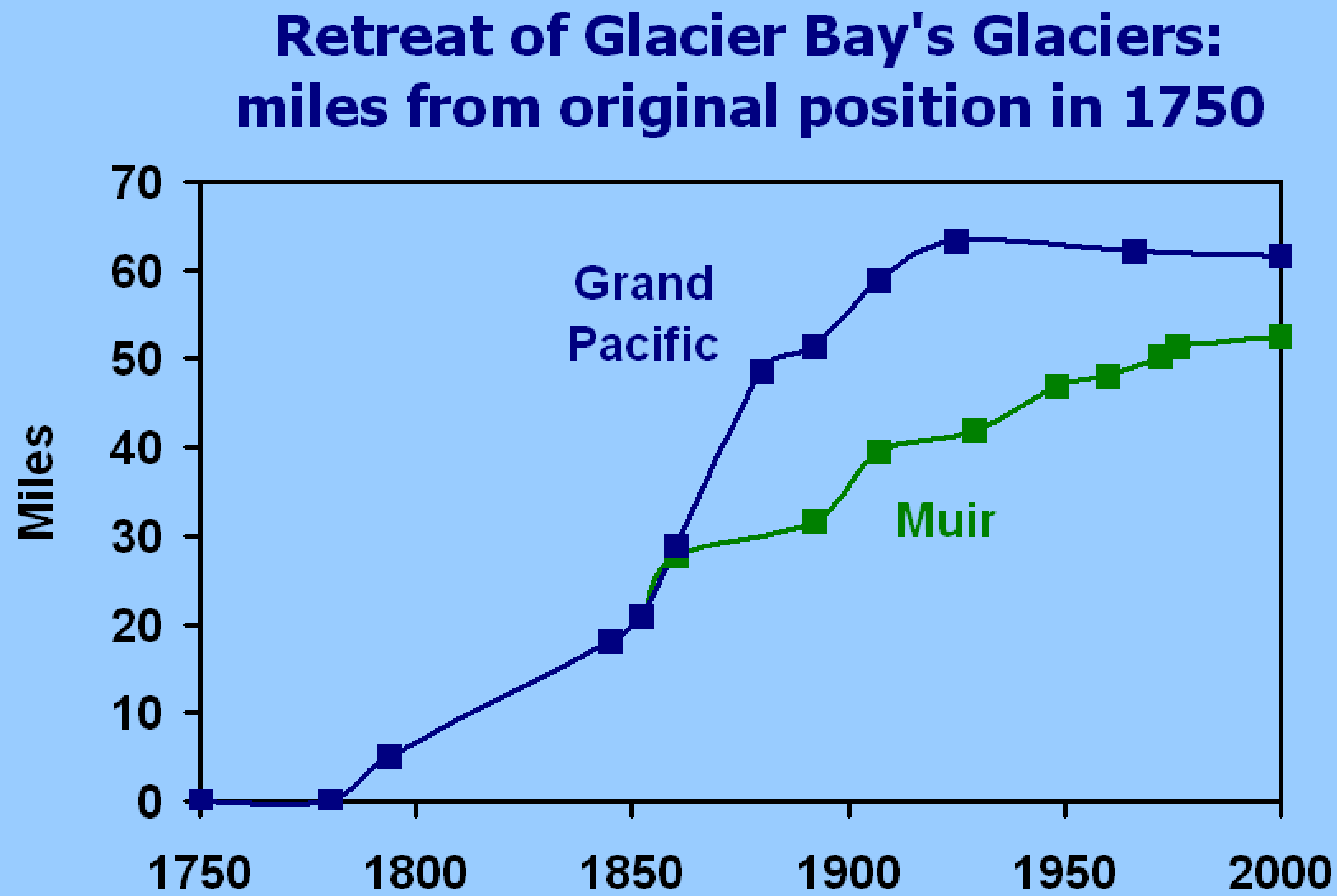
The story in ice - Glacier Bay, Alaska

Glacier Bay, Alaska.

Alaskan glaciers have been shrinking since the 1700's

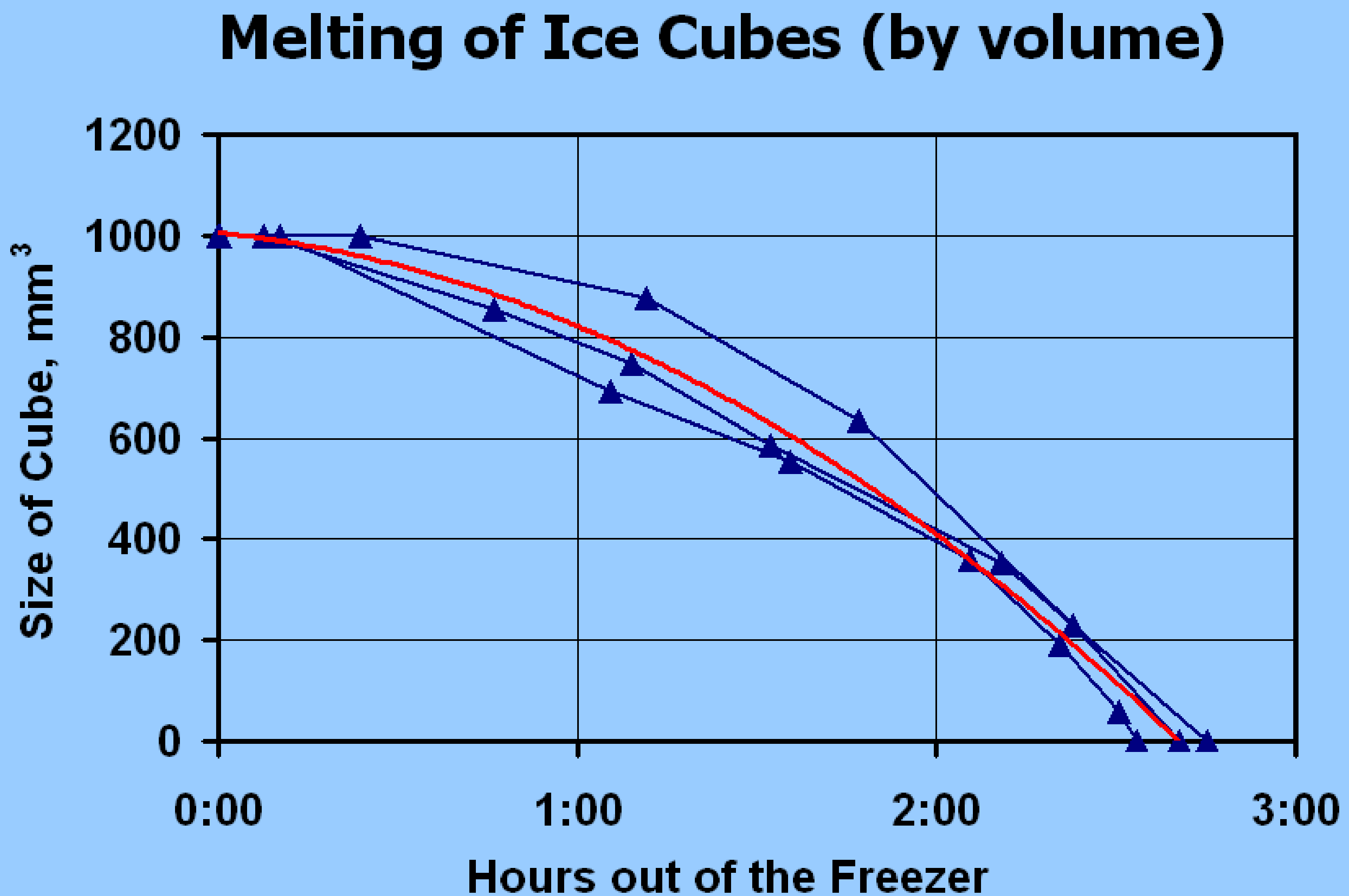


The glacier retreats slowly at first, then more quickly around 1900 – then levels off at a smaller size.



What happens to a small glacier when the climate changes?
Here's a lab model:

The ice cube melts slowly at first, but more and more quickly until it's *gone* – just like a big glacier, but quicker.



For an ice cube, the maximum rate of melt occurs <u>hours</u> after the climate changes!

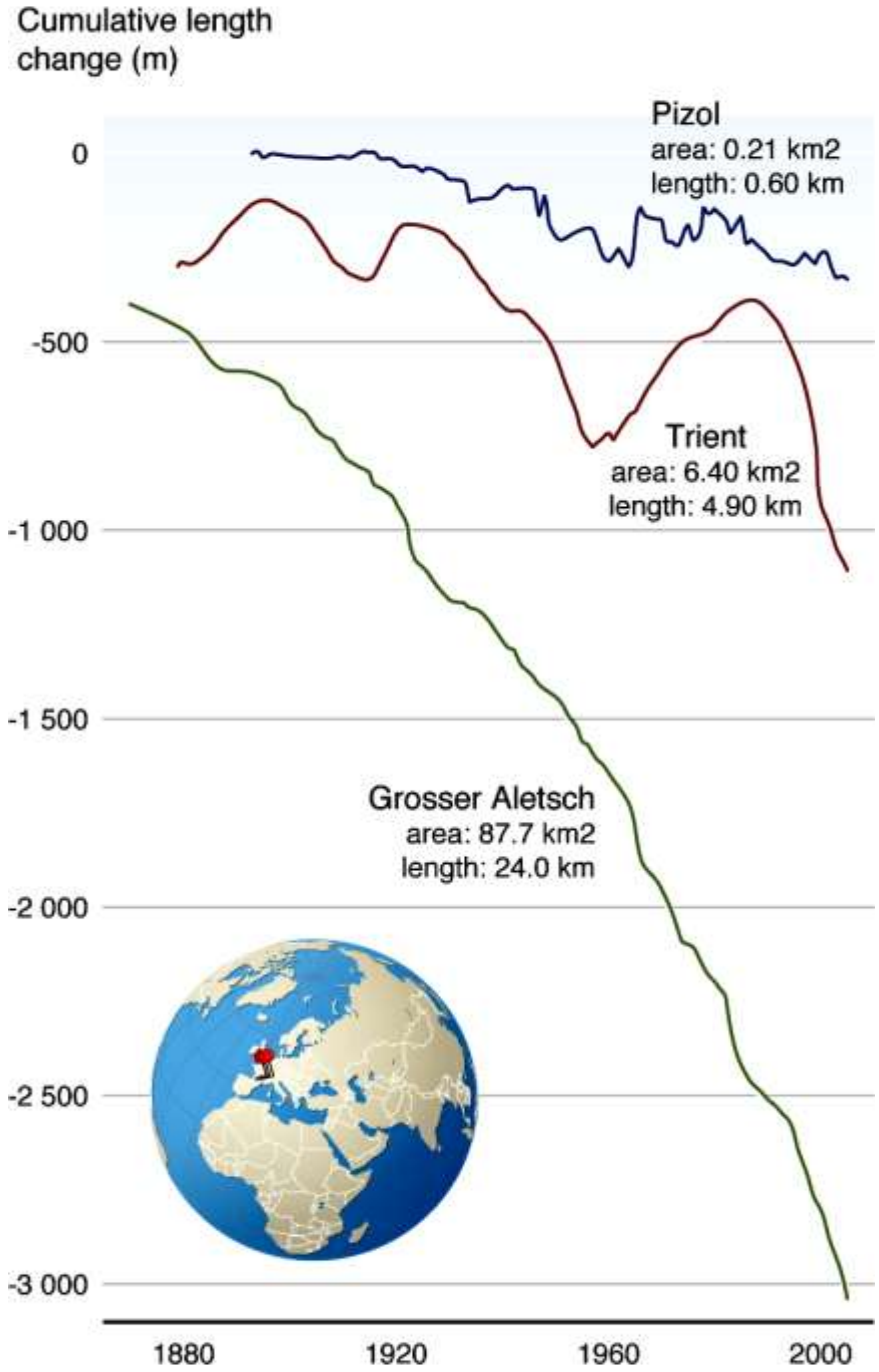
Glaciers are millions of times bigger than ice cubes.

Hours to an ice cube corresponds to centuries for a glacier.

Therefore, the rapid retreat of glaciers around 1900 is likely due to a climate changes around 1700.

Another:

The Great Aletsch Glacier in the Alps.



The Aletsch has been retreating since 1800, just like Glacier Bay glaciers.

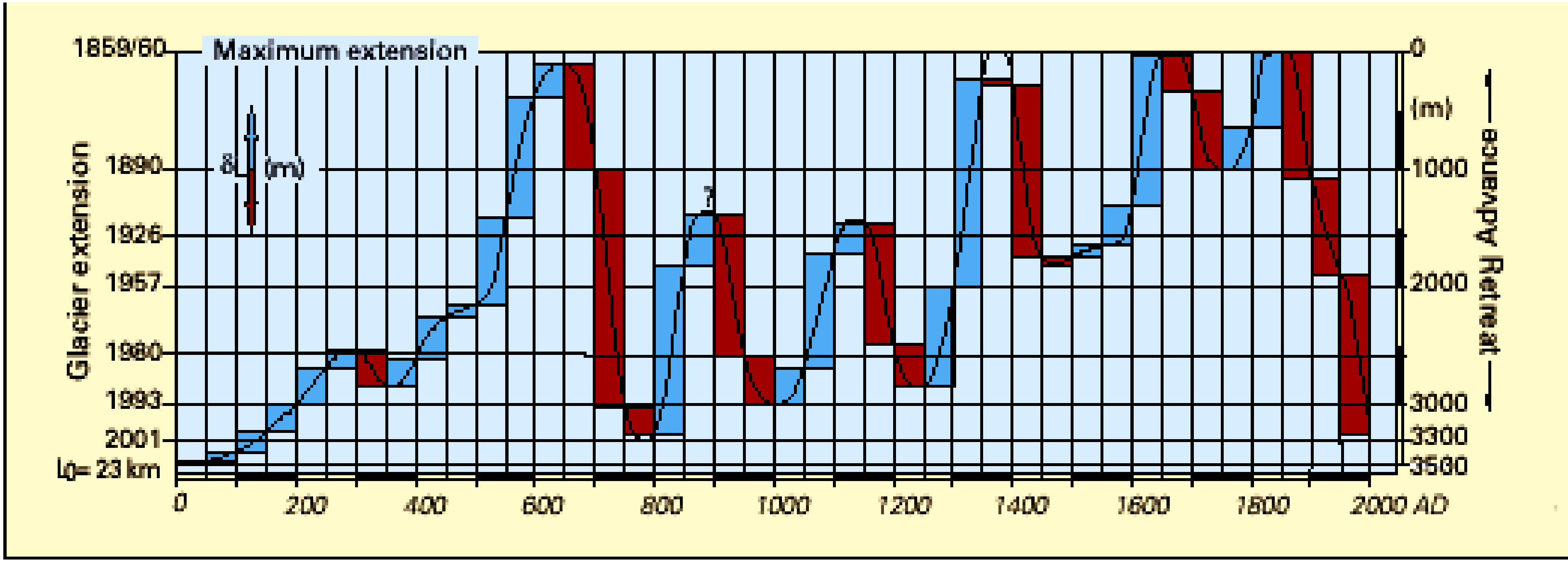


Fig. 2: Fluctuations of the Great Aletsch Glacier during the last 2000 years reconstructed with historical documents and dendrochronologically/absolutely dated fossil wood. Average mass balance calculated for time intervals of 50 years (on top) and of 100 years (below).

The Aletsch also retreated around 700 and 1400 A.D. - and GREW around 500, 1200 and 1600 A.D.

This means glaciers are currently retreating from a climate warming that occurred around 1700 - 1800.

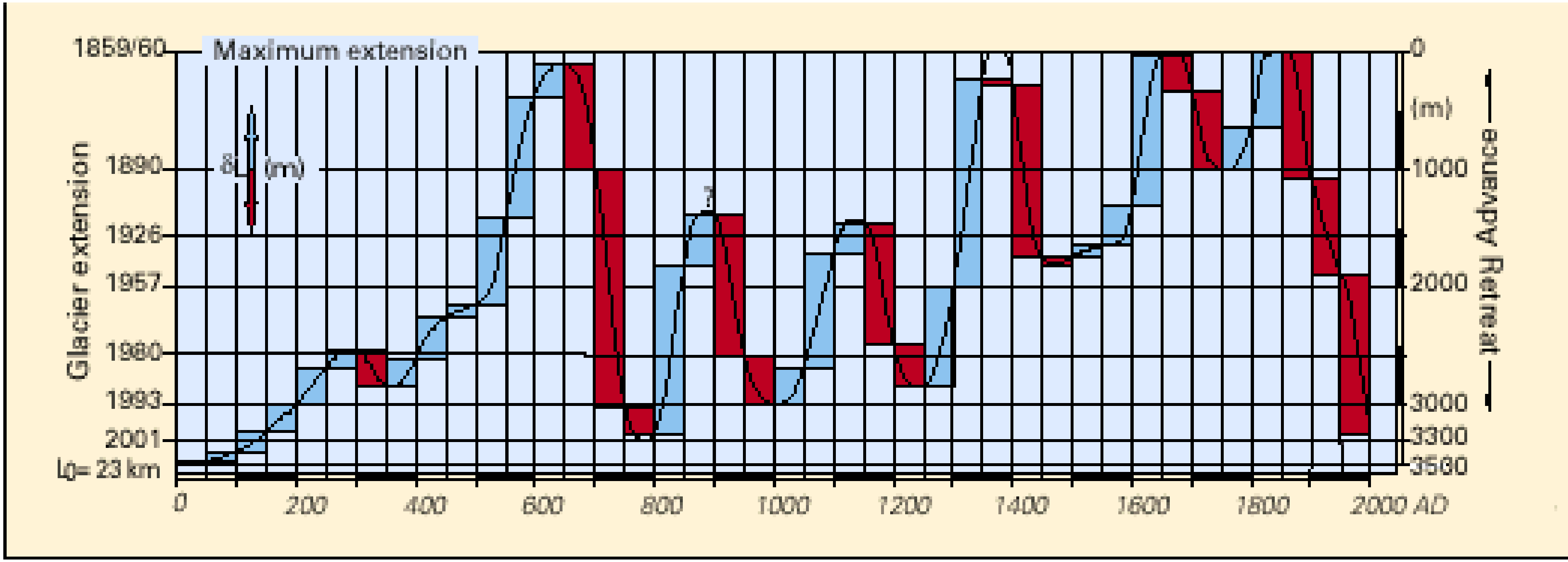


Fig. 2: Fluctuations of the Great Aletsch Glacier during the last 2000 years reconstructed with historical documents and dendrochronologically/absolutely dated fossil wood. Average mass balance calculated for time intervals of 50 years (on top) and of 100 years (below).

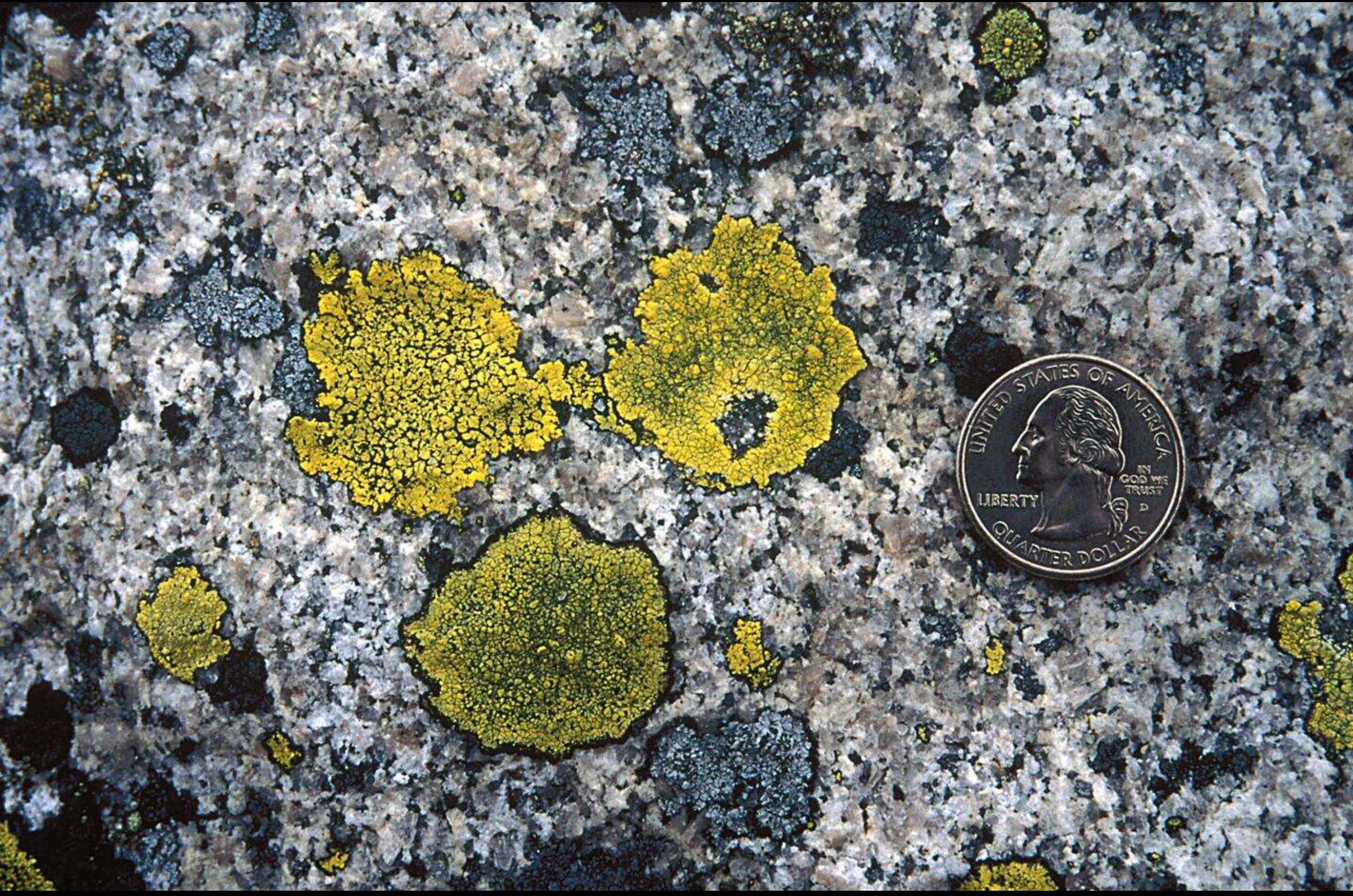
The glacier retreat of the past 200 years is the most recent of glacier retreats.

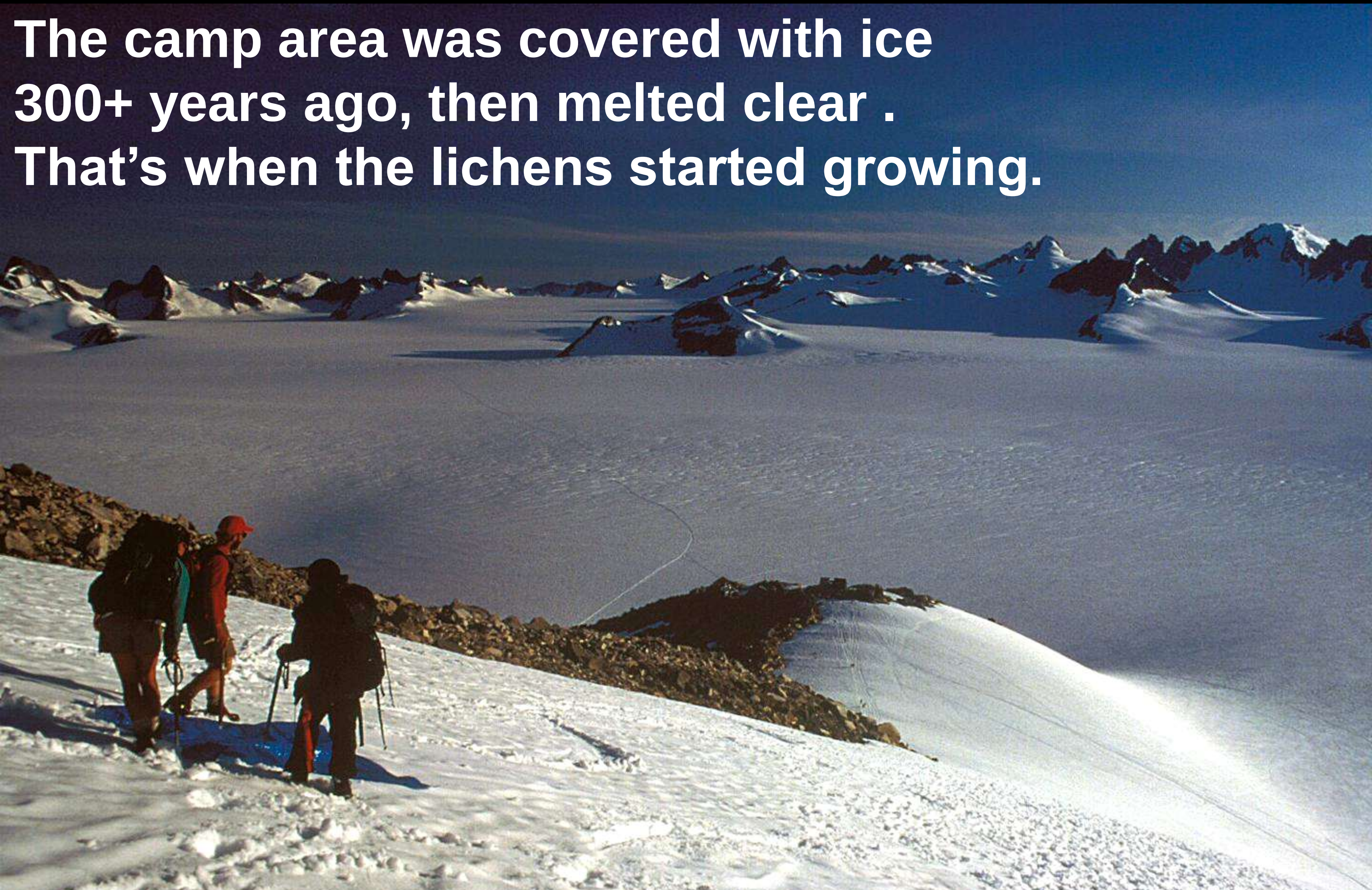
Note evidence of ~200 and ~1000 year cycles.

Juneau Ice Field, Alaska

Lichens

3 cm Lichens are 3 centuries old




The camp area was covered with ice
300+ years ago, then melted clear .
That’s when the lichens started growing.

Much evidence points to a cool global climate, 1400-1800 AD.
So about the warm before the cool…

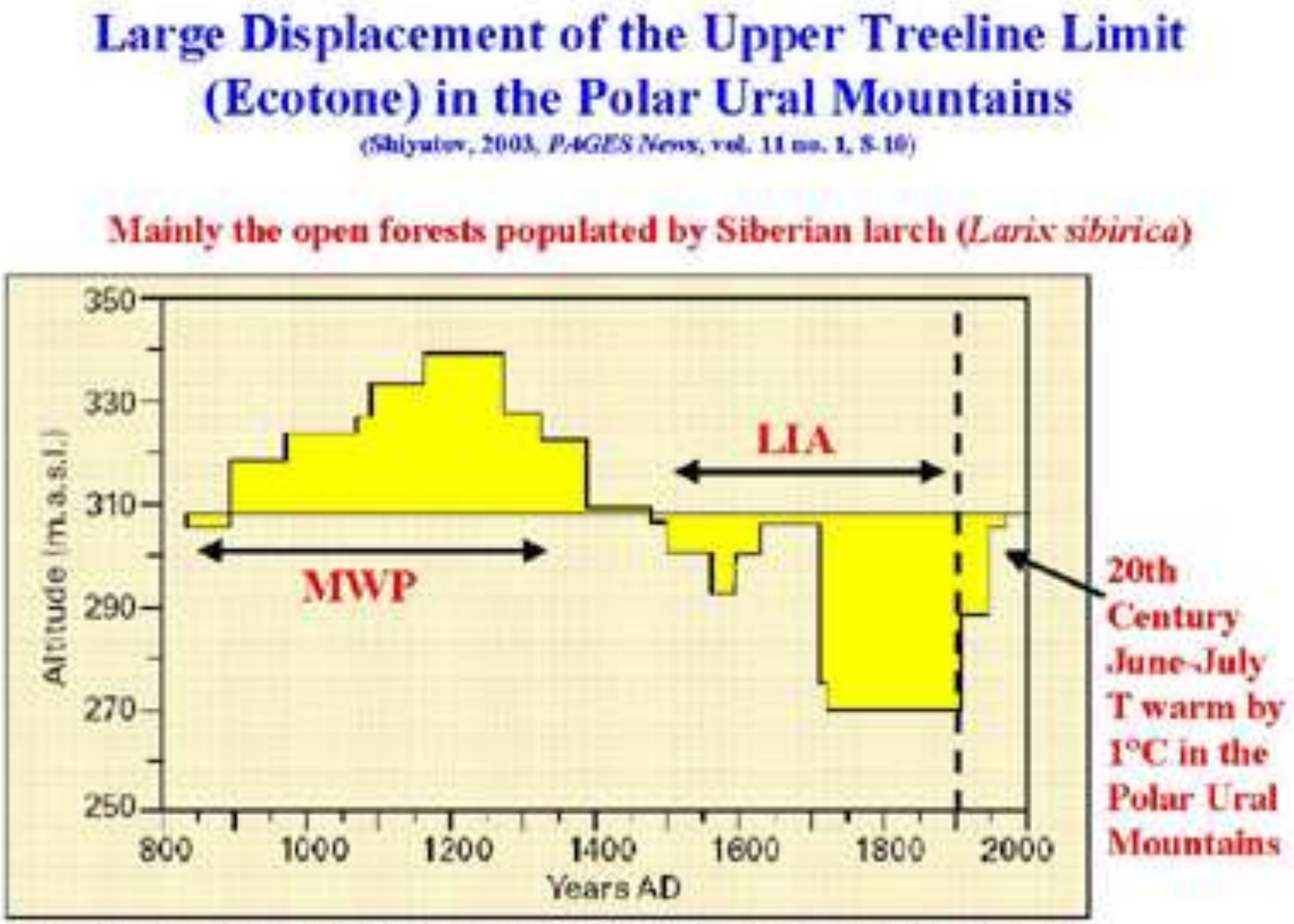
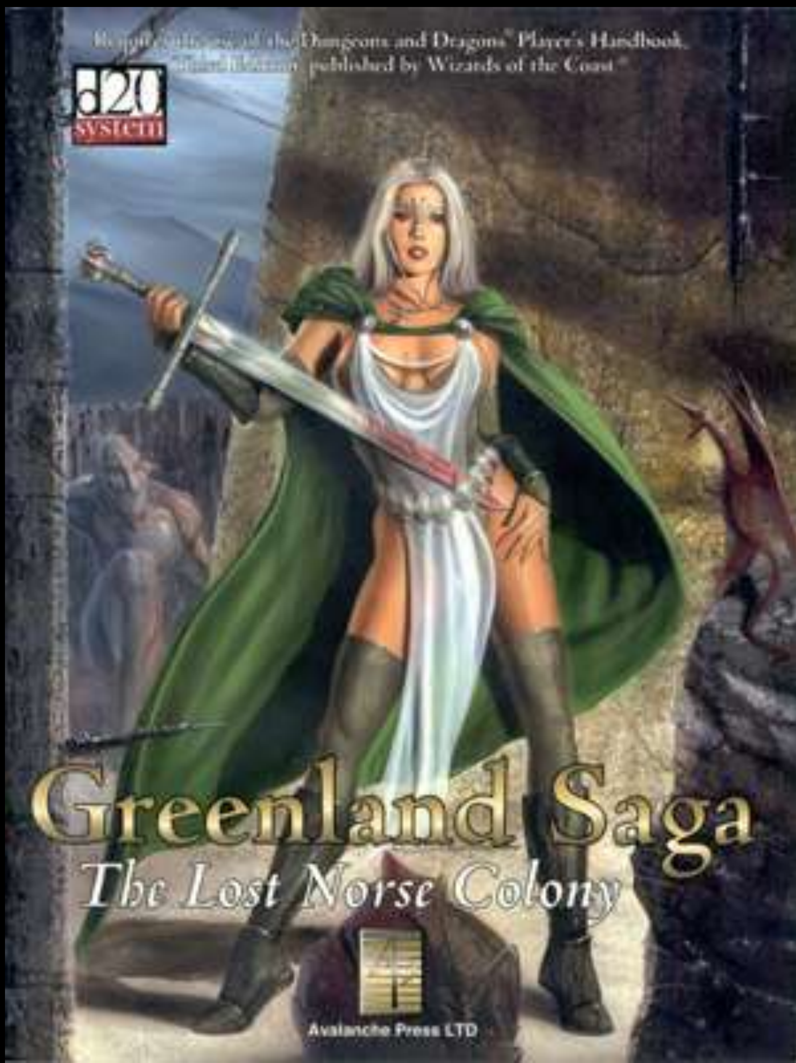


Fig. 1. Altitudinal displacement of the upper treeline in the Polar Ural Mountains during the last 1150 years

The human story: Vikings moved to a mild Greenland around 1000 AD, stayed and made beer for 350 years, then disappeared.



First, Eric the Red, followed by many more

THE NORTHWEST PASSAGE
LANCASTER SOUND & BOOTHIA PENINSULA
FOXE BASIN AND FURY & HECLA STRAIT
Bellot Strait
Fury & Hecla Straits
Cape Dyer
Hudson Strait
Bergen
Gokstad
Oseberg
Skuldelev
Roskilde
Sumba
Foula Island
Fair Island
Thurso (Mainland)
L'Anse aux Meadows
LEGEND
LONG-HAUL ROUTES
SHORT-HAUL ROUTES
COASTAL ROUTES
ARRIVAL/DEPARTURE POINTS
STAGING/SUPPORT AREAS?
THE NORTHWESTERN APPROACHES

Then (left) and now

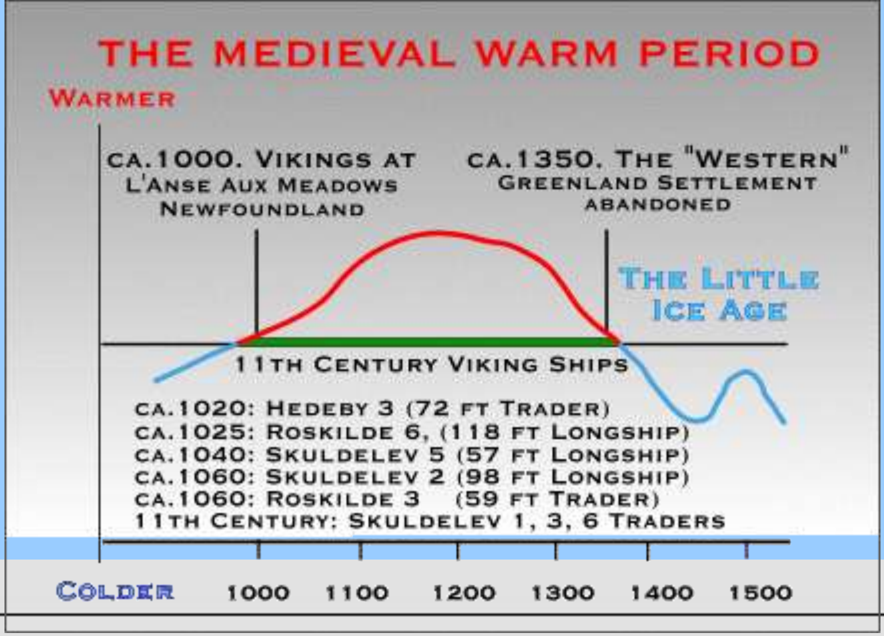

KALAALLIT NUNAAT
4,50
GRØNLAND

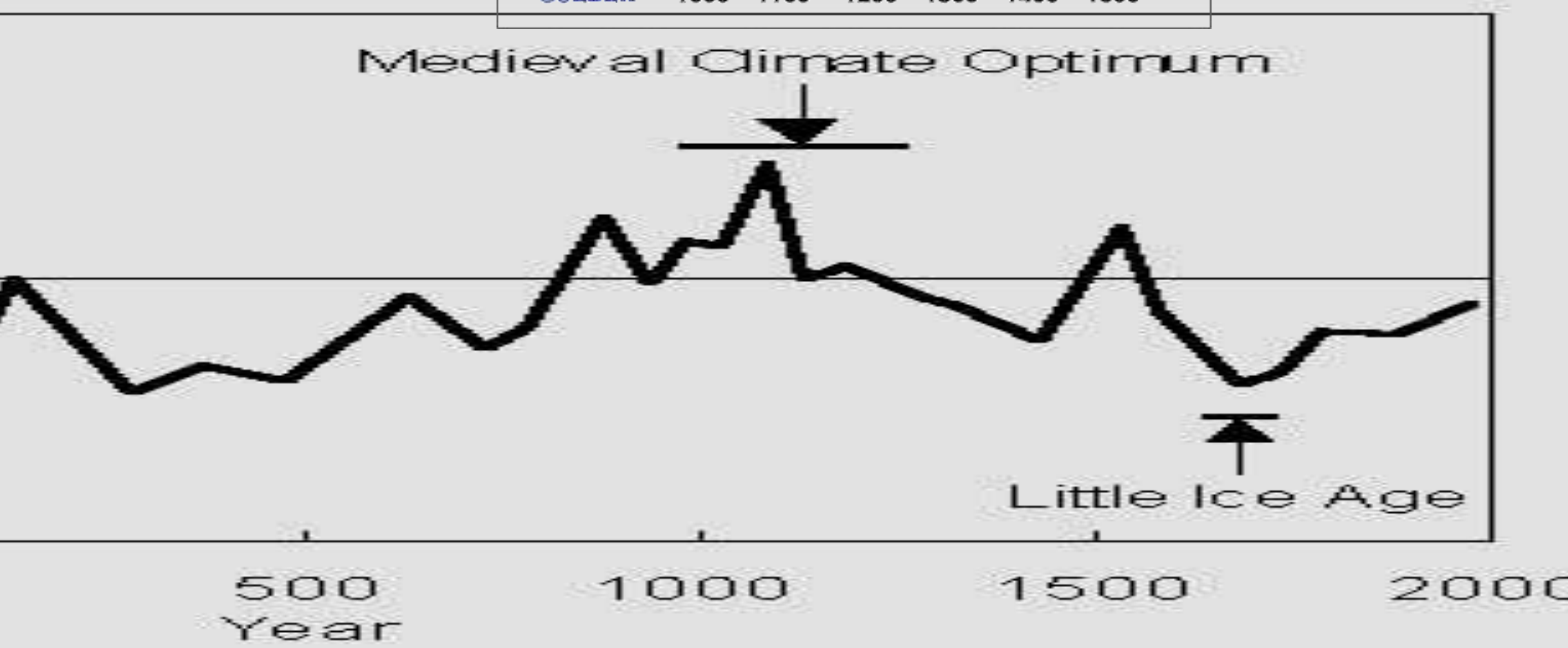

KALAALLIT NUNAAT
GRØNLAND
4,75


KALAALLIT NUNAAT
5,75
GRØNLAND

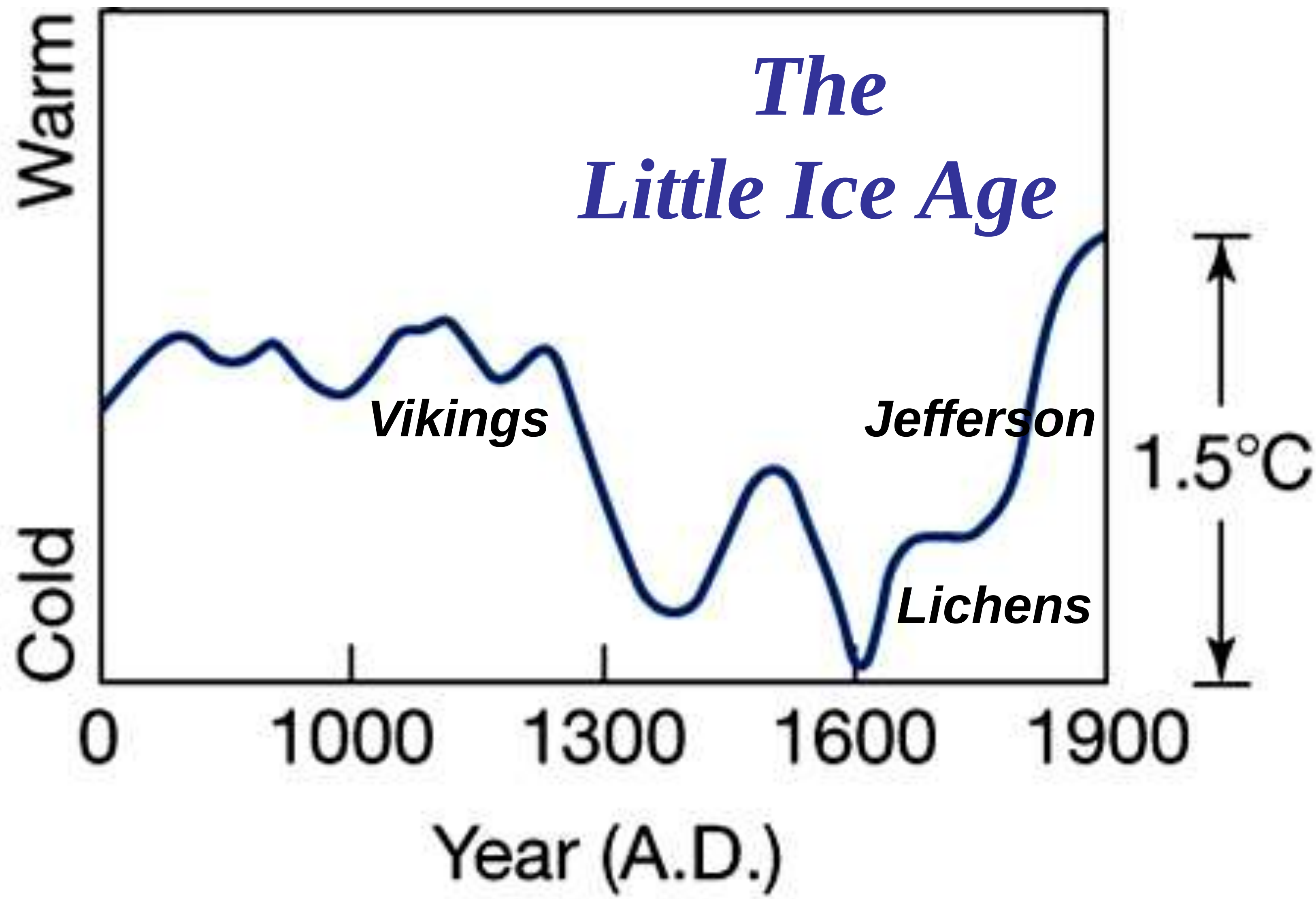

KALAALLIT NUNAAT
8,00
GRØNLAND

The Vikings enjoyed Greenland during the Medieval Warm Period





Piecing it all together…

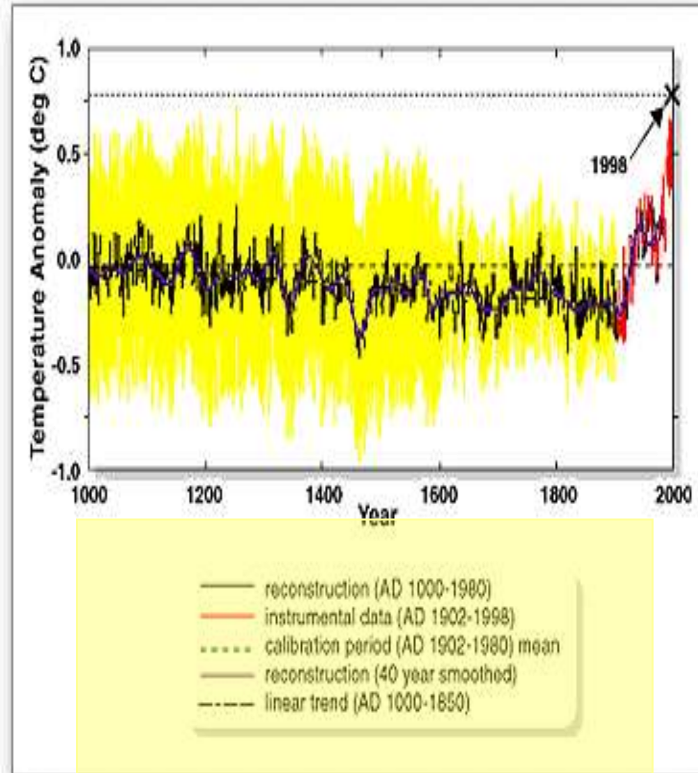


Two versions of the past 1000 years

Was the MWP warmer or cooler than present ?

Most histories (based on trees, ice, coral, silt, historical records) have the MWP a bit warmer than present.

What caused it ? Ask a tree.



A 2000-Year Global Temperature Reconstruction Based on Non-Treering Proxies 1053

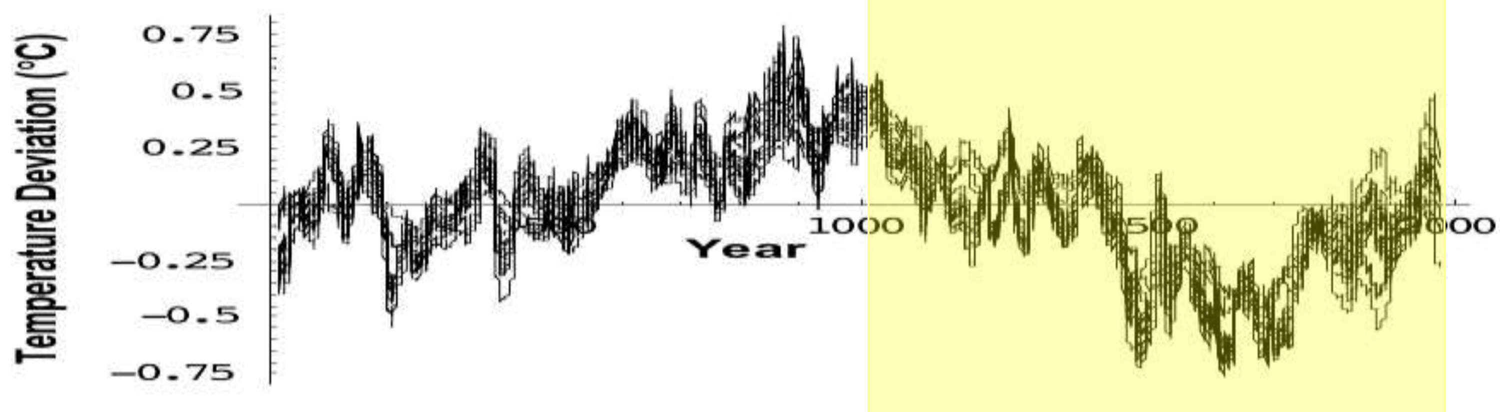
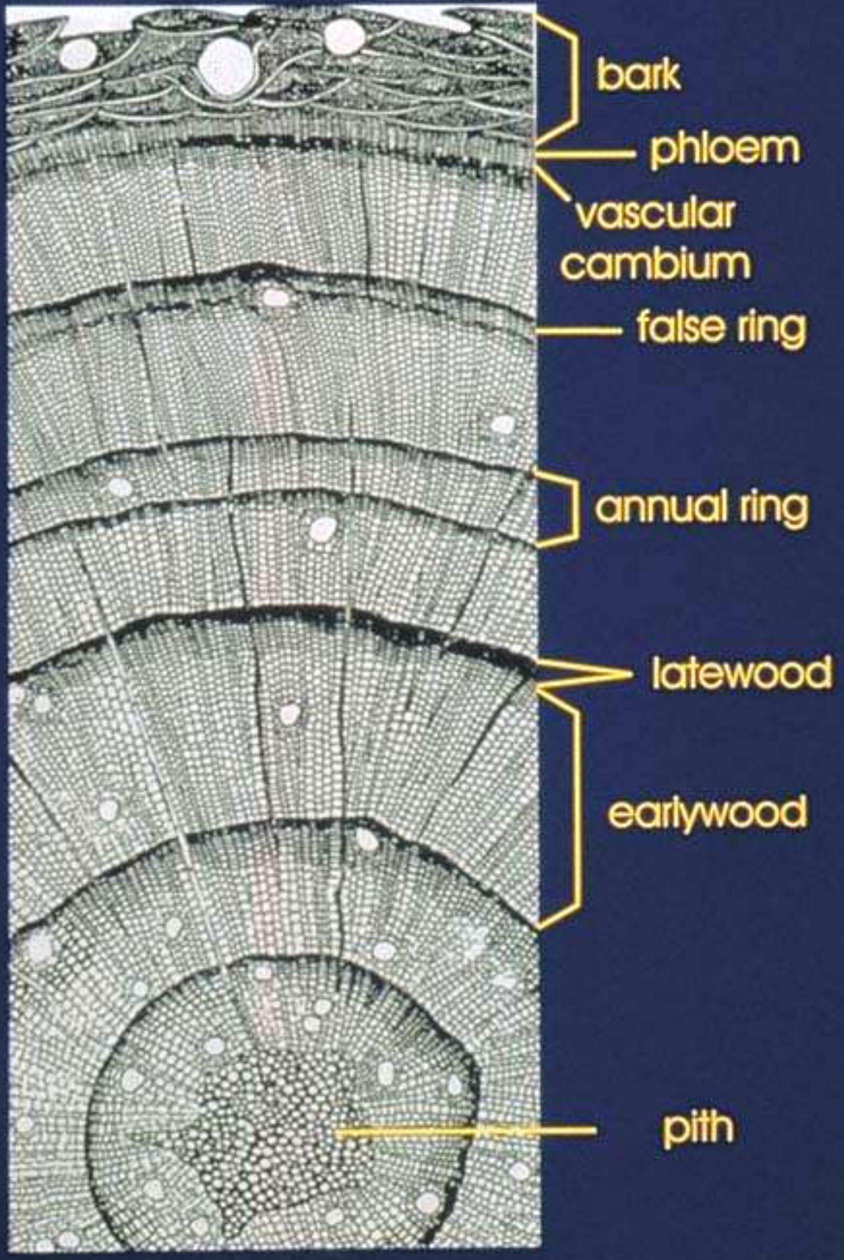
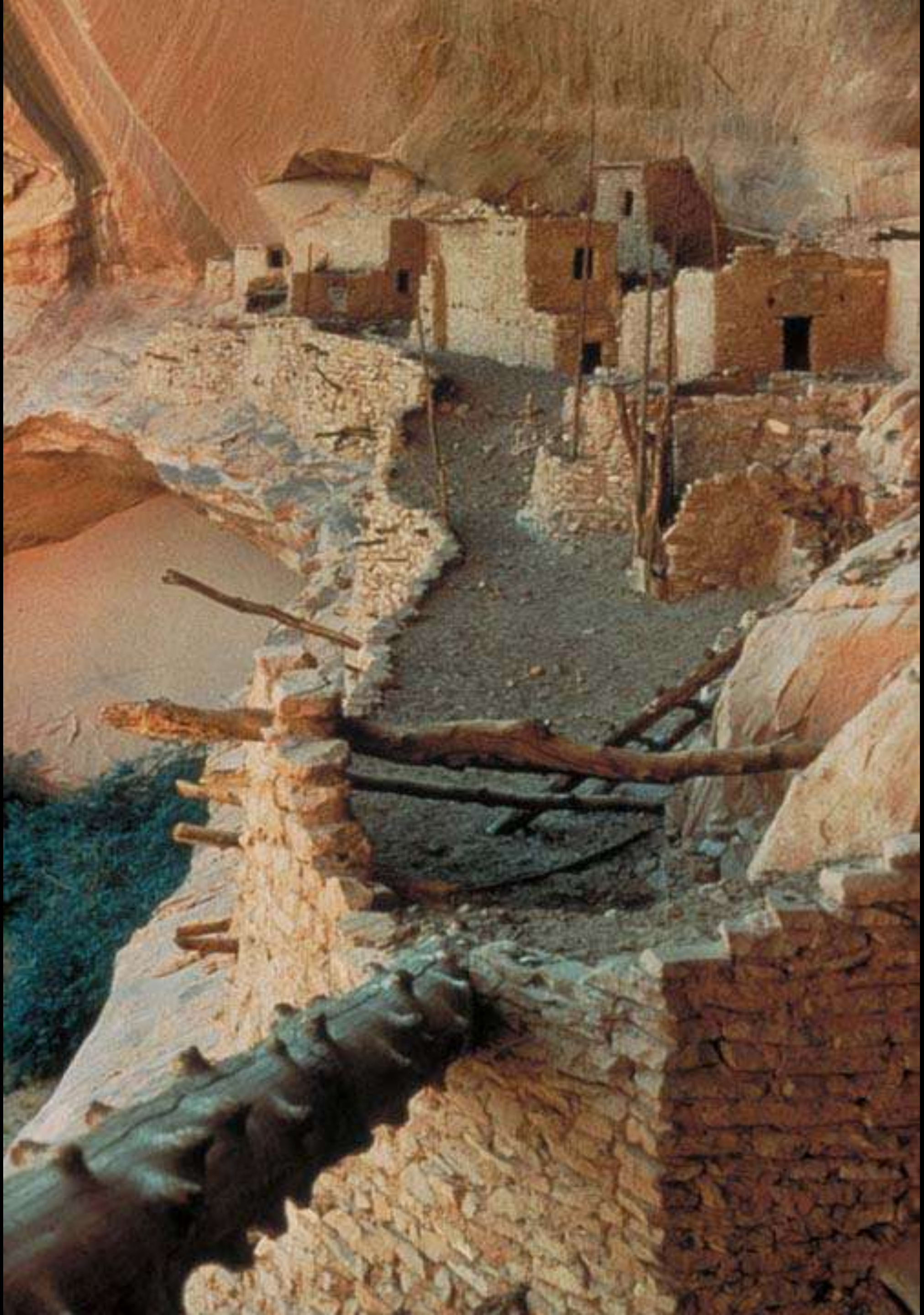


Figure 3. Random selection of 14 data sets at a time without duplicates, repeated 18 times, then overlaid, showing robustness of the pattern.

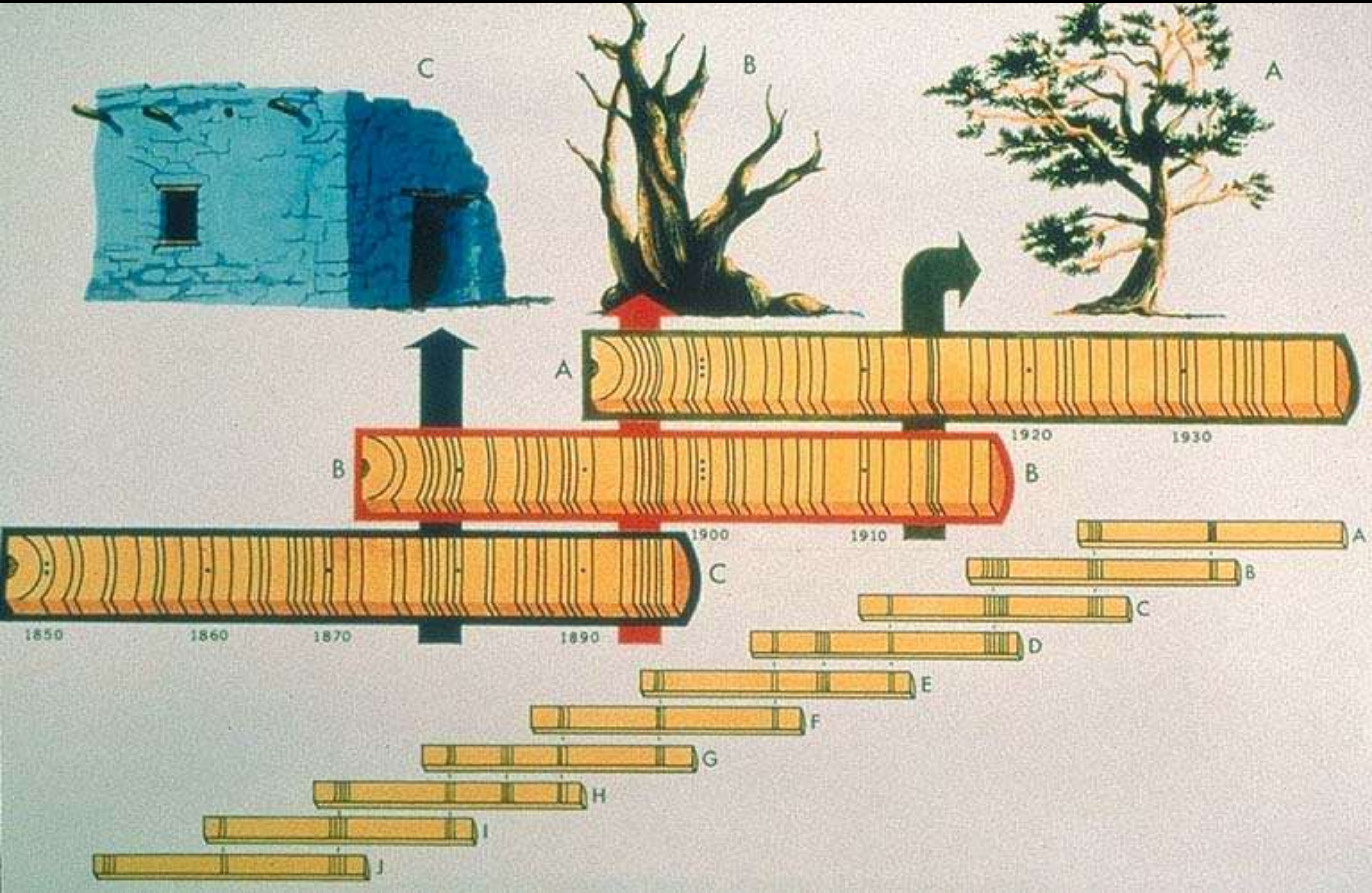

Bristlecone Pines

CROSS SECTION of a CONIFER

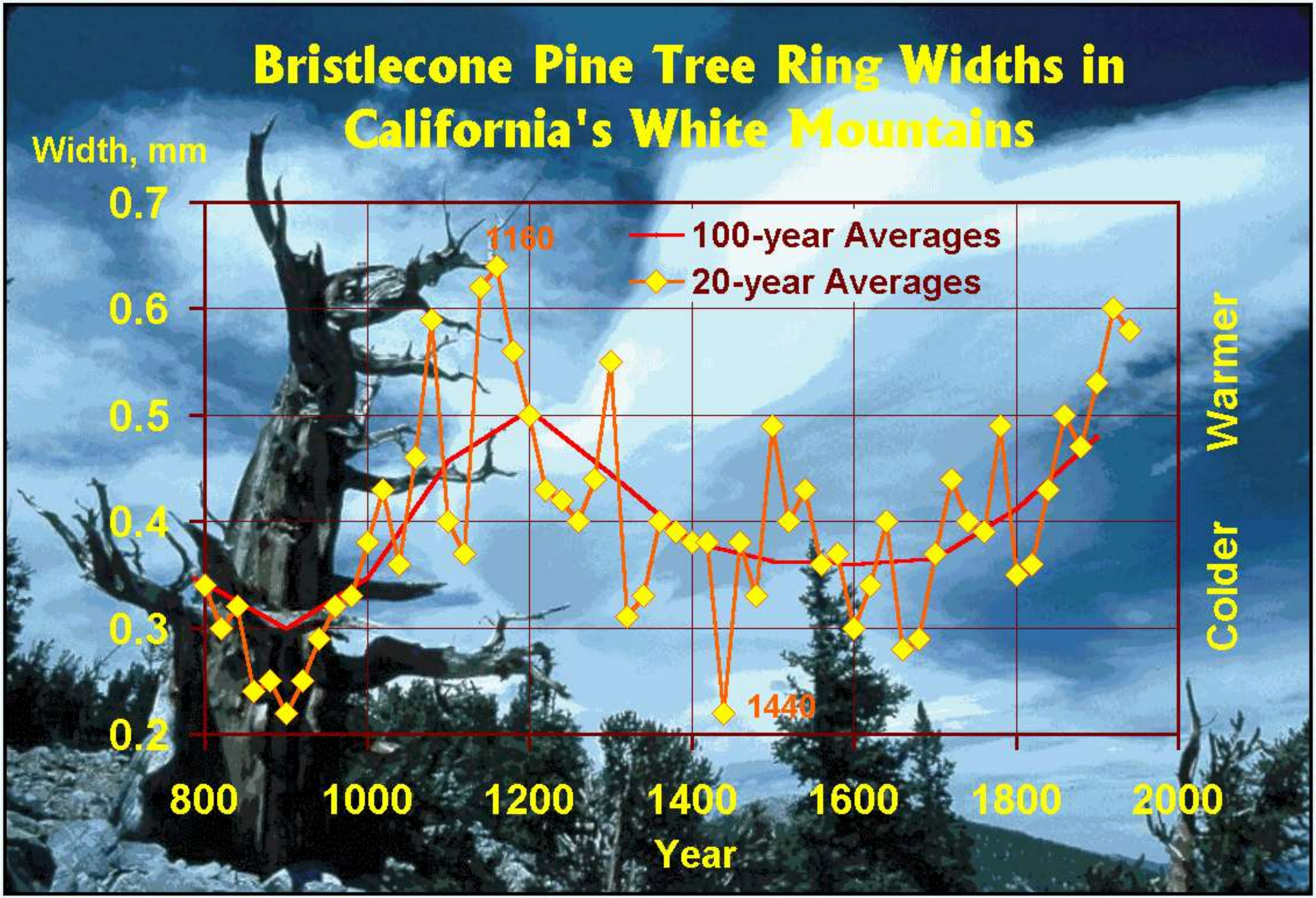




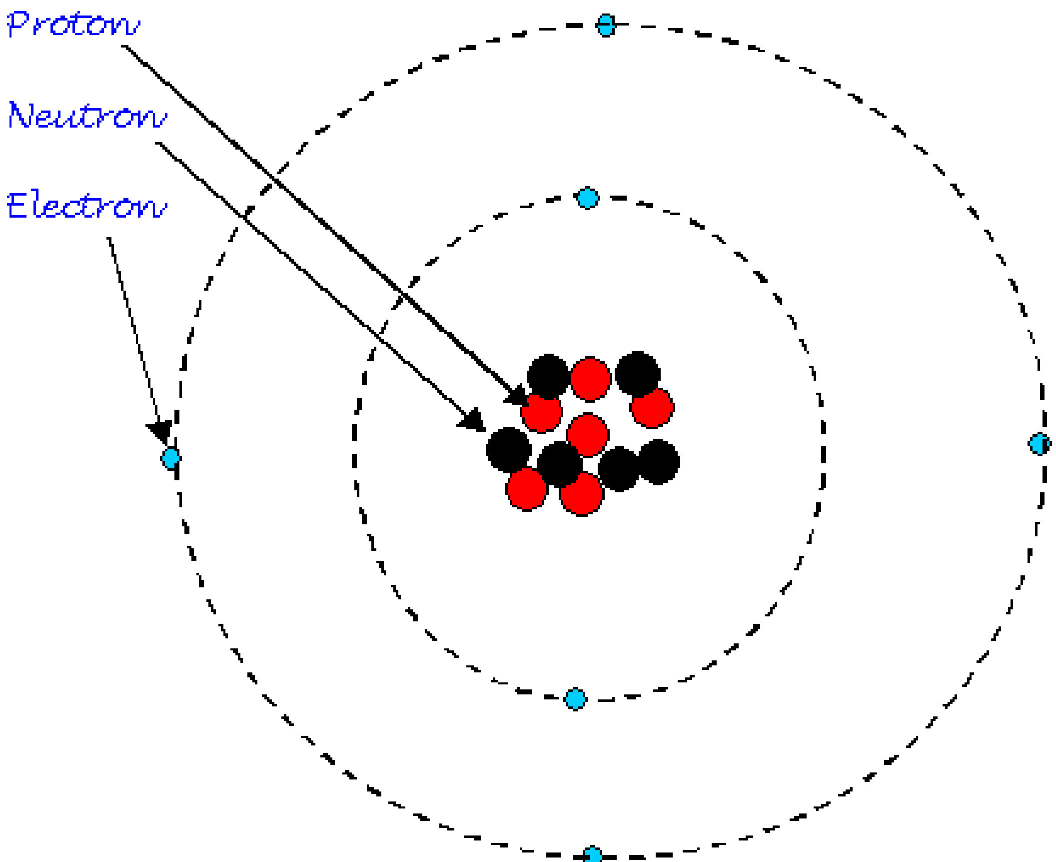
Dendrochronology – "Tree Timeline"



Tree rings are affected by temperature, rainfall, and other factors



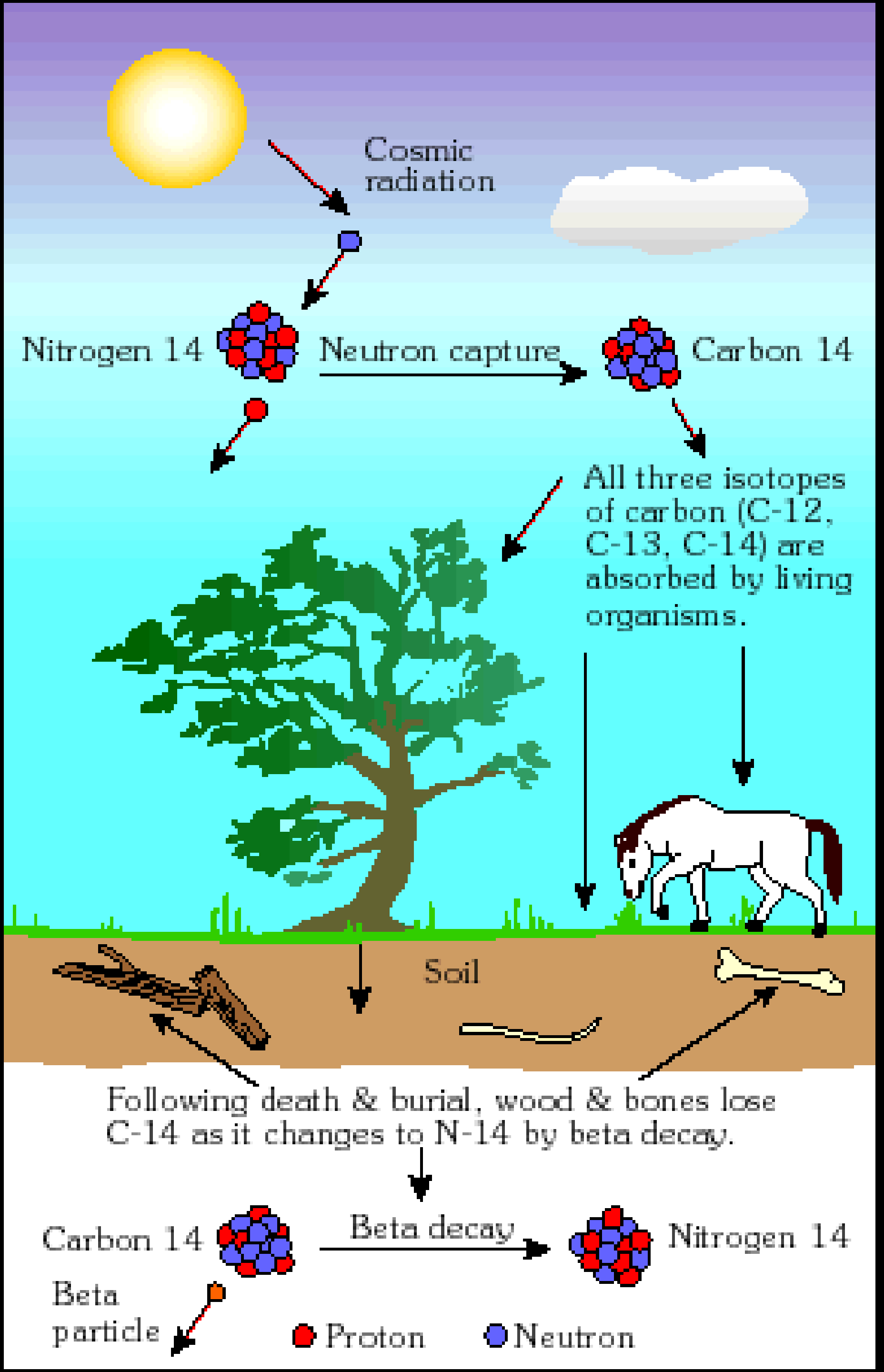
What else do trees tell you ?
Trees rings are made out of, among other stuff, Carbon – which has:
6 protons, 6 neutrons, 6 electrons
Air (Nitrogen) has 7, 7, 7

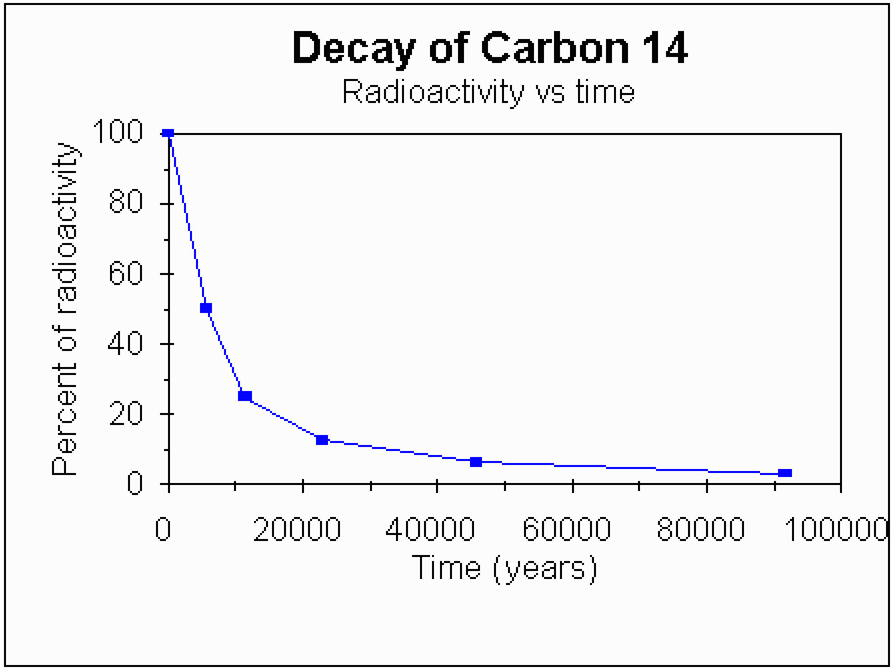


Alchemy:

Zap some Nitrogen with a neutron, and the Nitrogen becomes a Carbon-14 isotope, or ^{14}C.

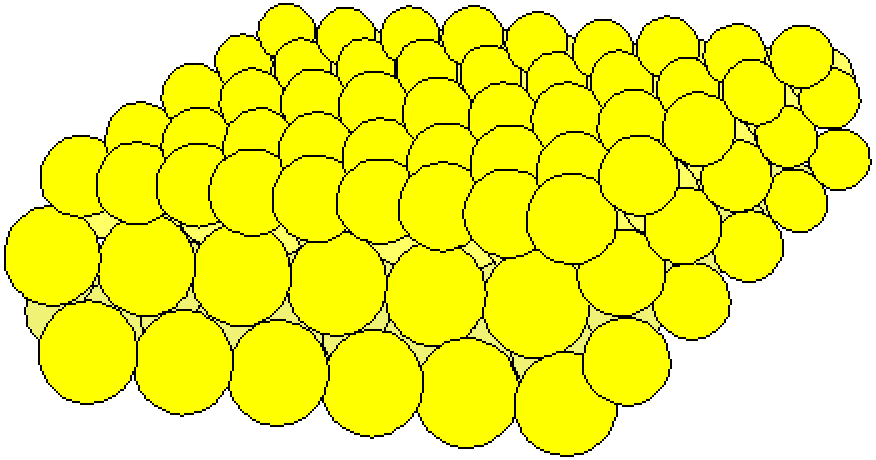
This becomes part of a tree, along with much more “normal” carbon.





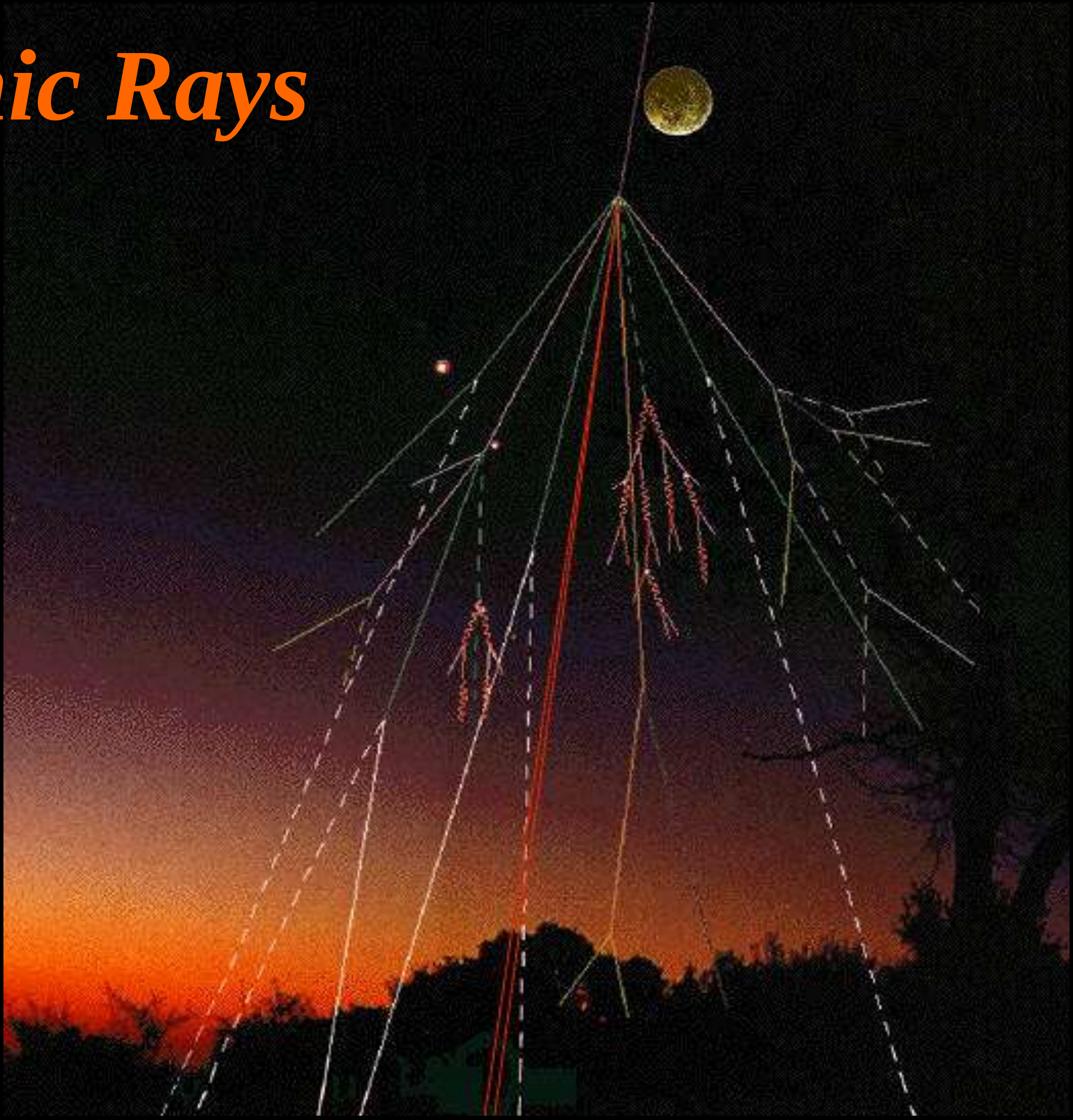
Years on, most of the tree's ^{14}C decays back into Nitrogen.

Measure the ^{14}C in the tree today, and knowing the decay rate of ^{14}C, you can tell

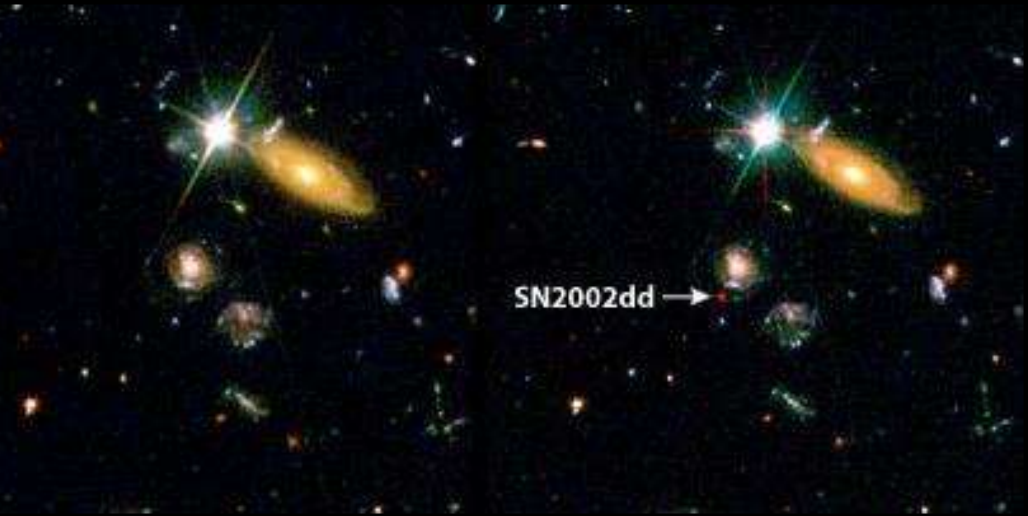


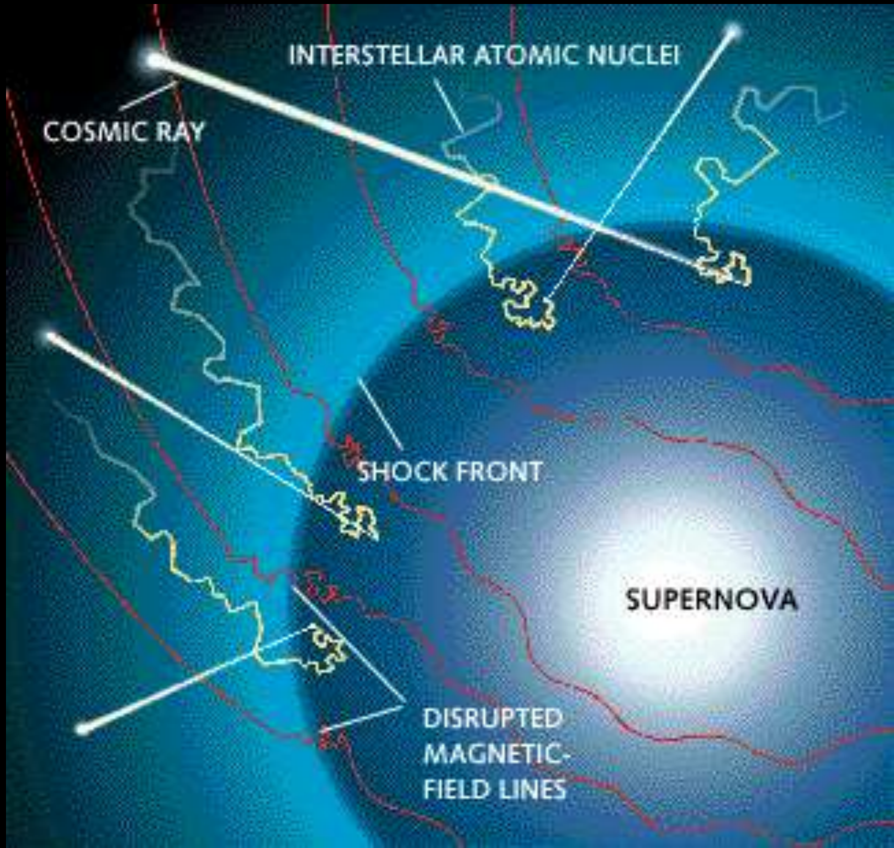
1. How old the tree is
2. How much ^{14}C it had when it grew

Cosmic Rays



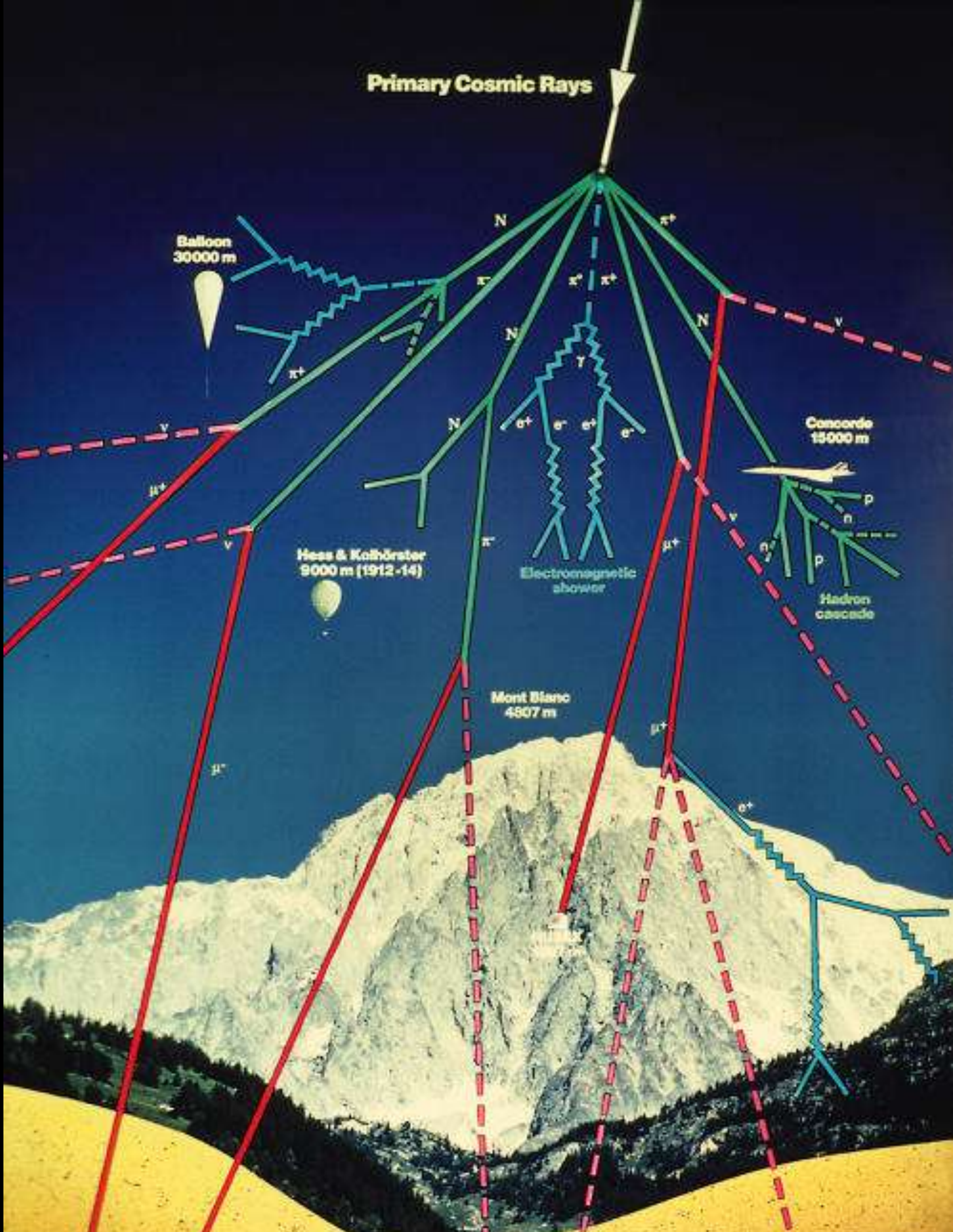
Cosmic Rays are very energetic sub-atomic particles from black holes, quasars, supernovas, and galaxies far, far away…



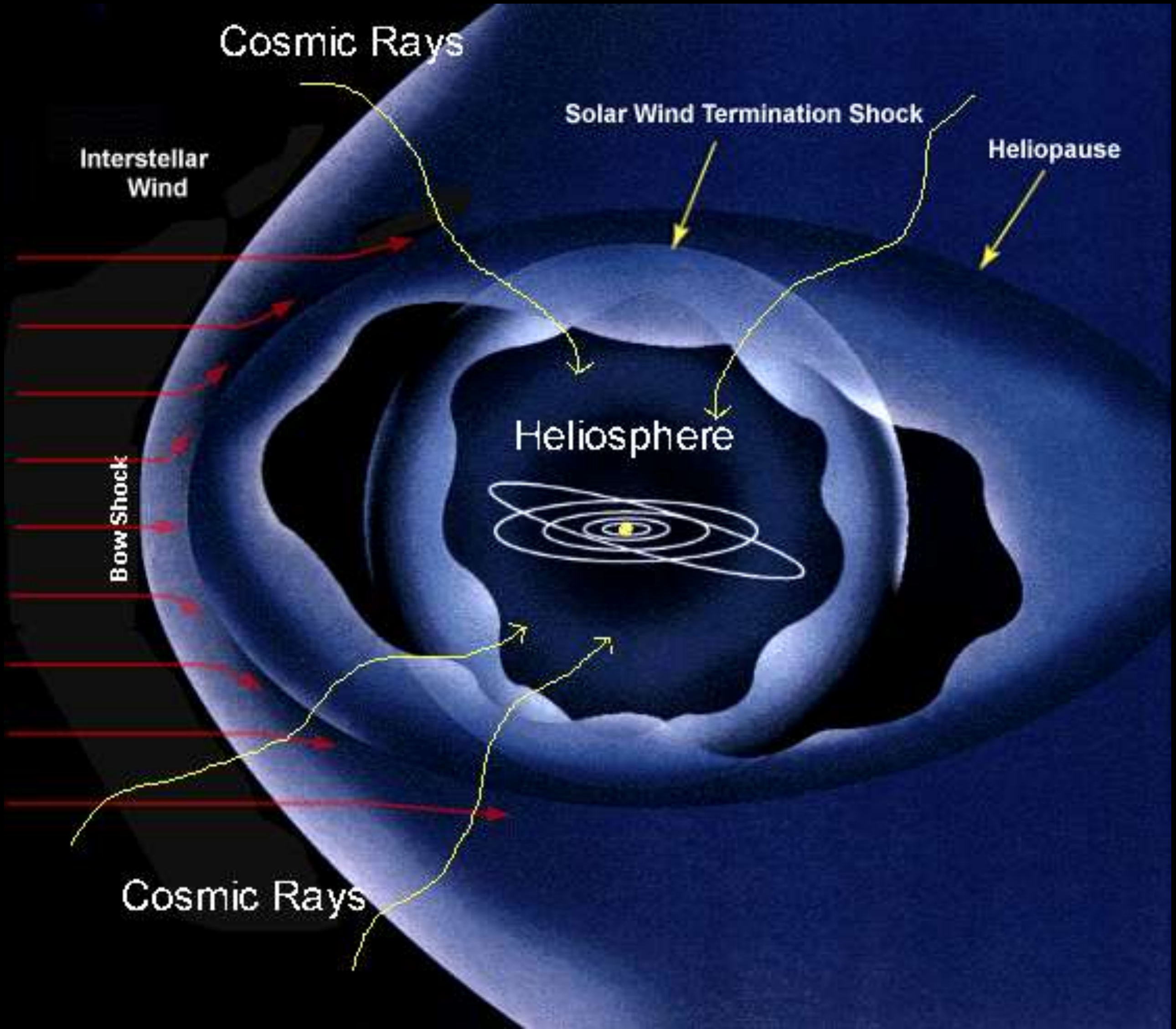


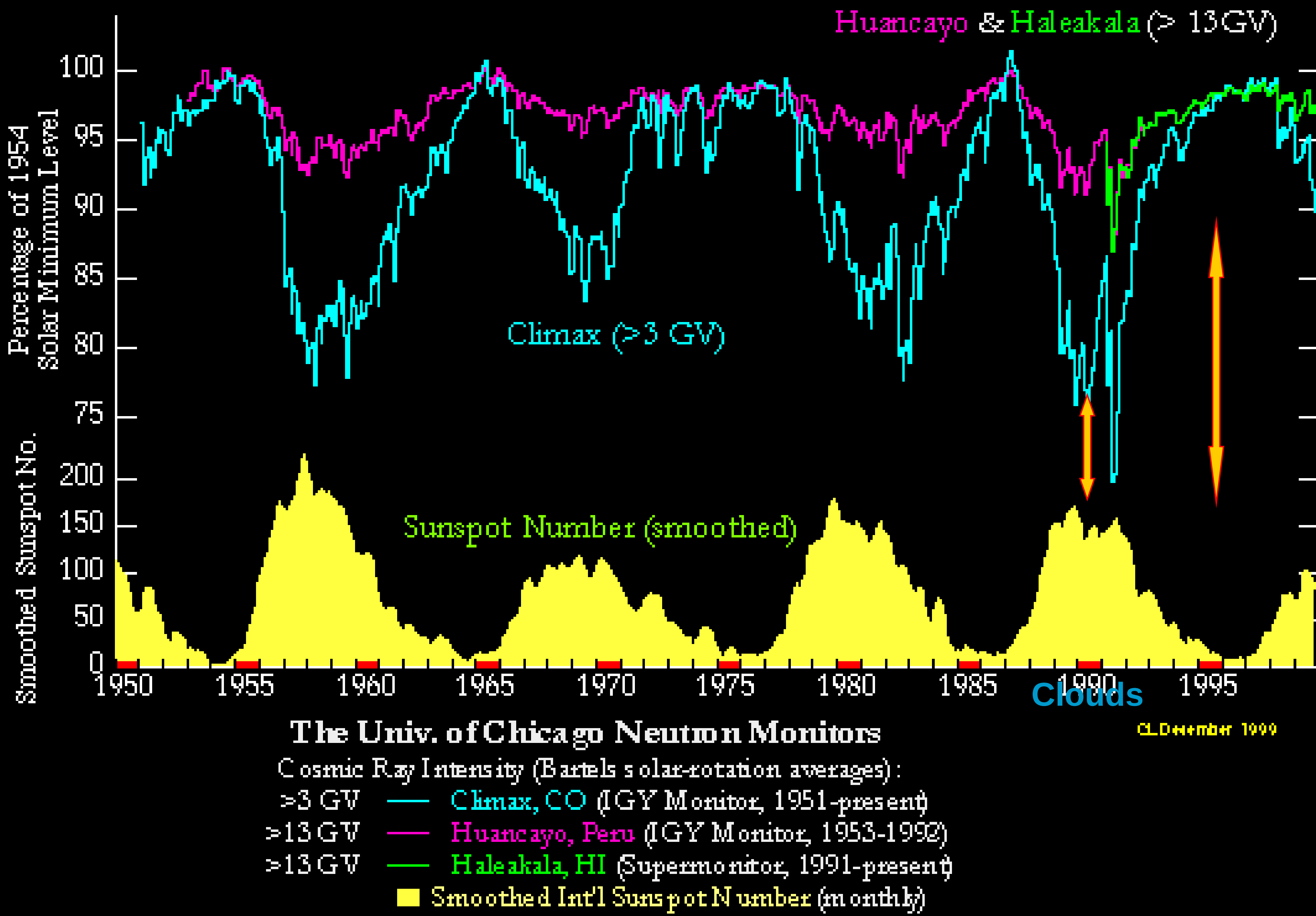
… that make Carbon-14

Even though cosmic rays come from other galaxies, their numbers are affected by the Sun.
This, in turn, affects the amount of Carbon 14, or ^{14}C, in the air (and trees).

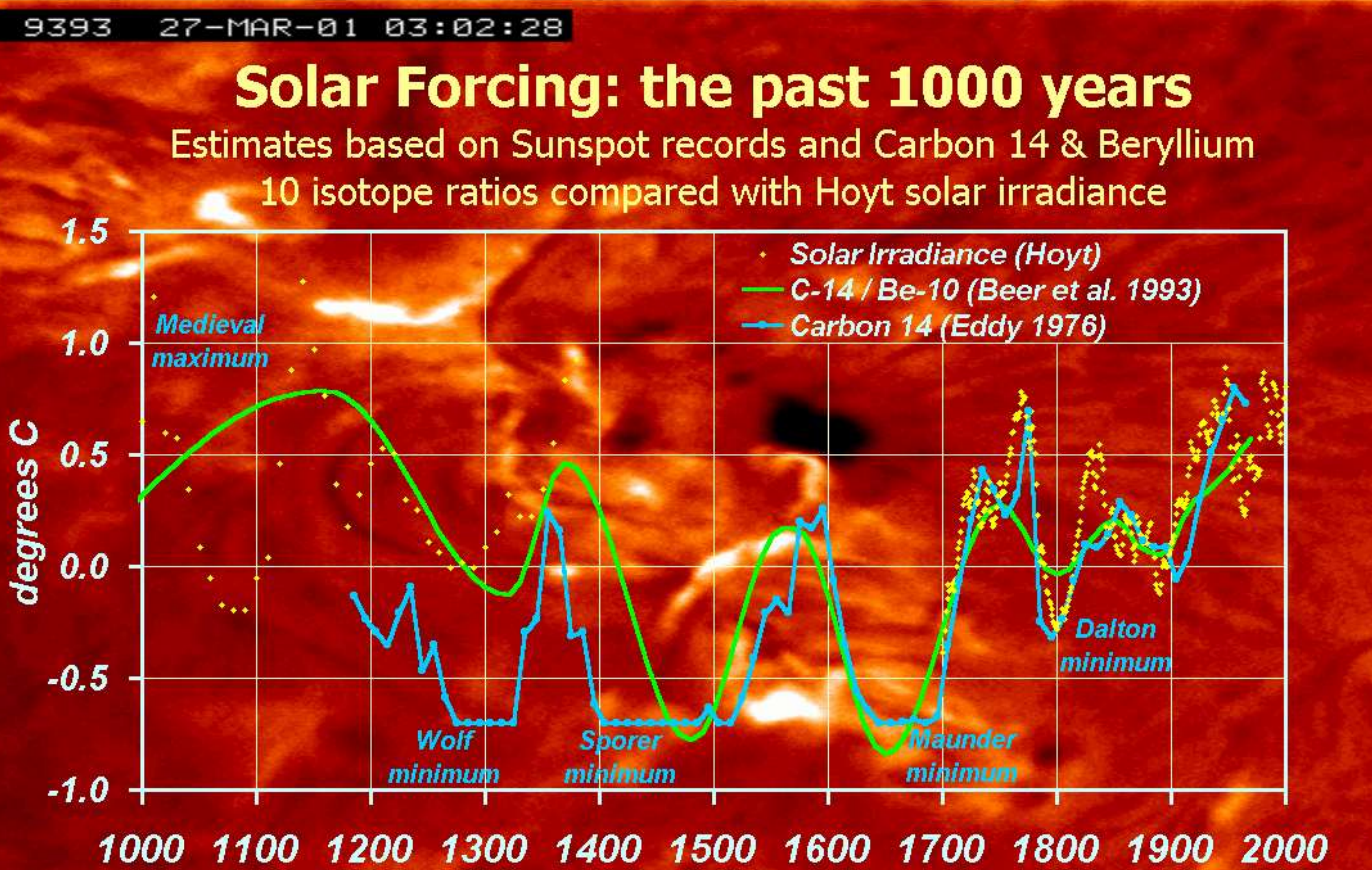


The Sun shields the Earth from cosmic rays, and the more active the Sun is, the more it shields us. Active Sun (Solar Max) = fewer cosmic rays

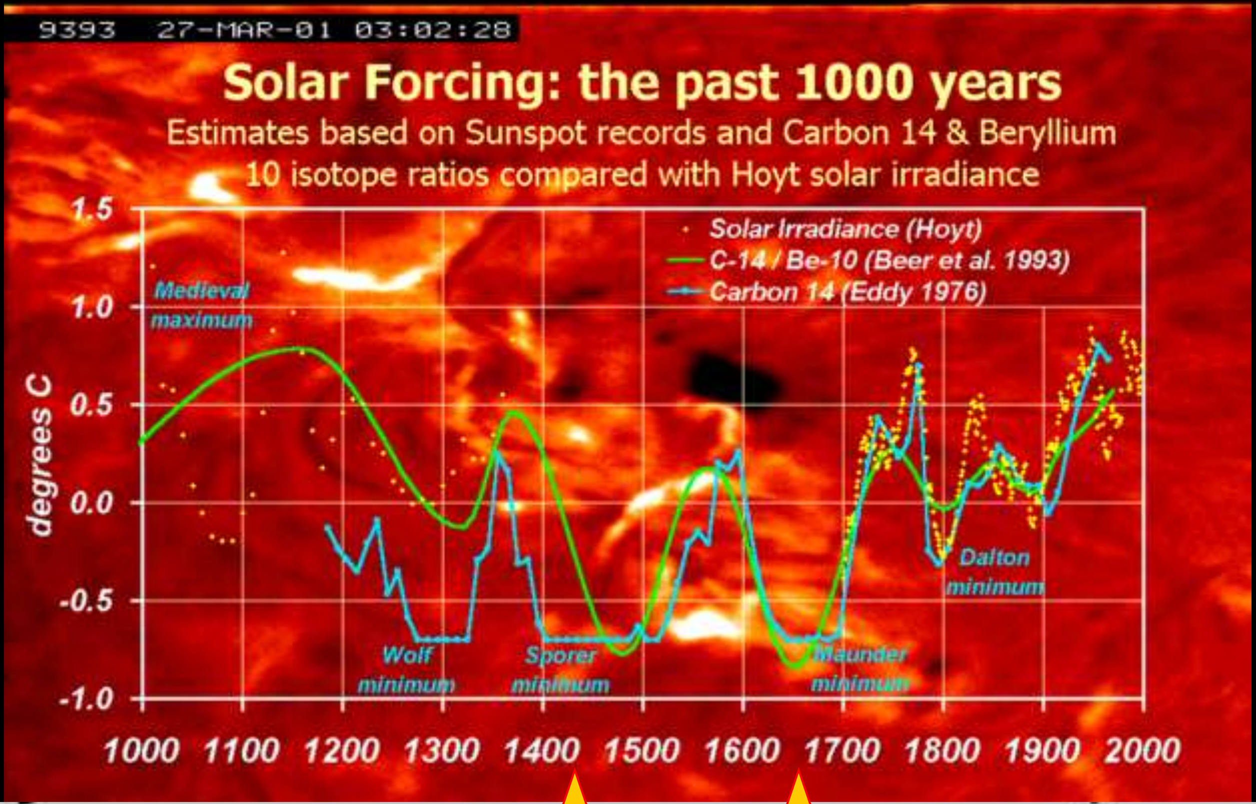


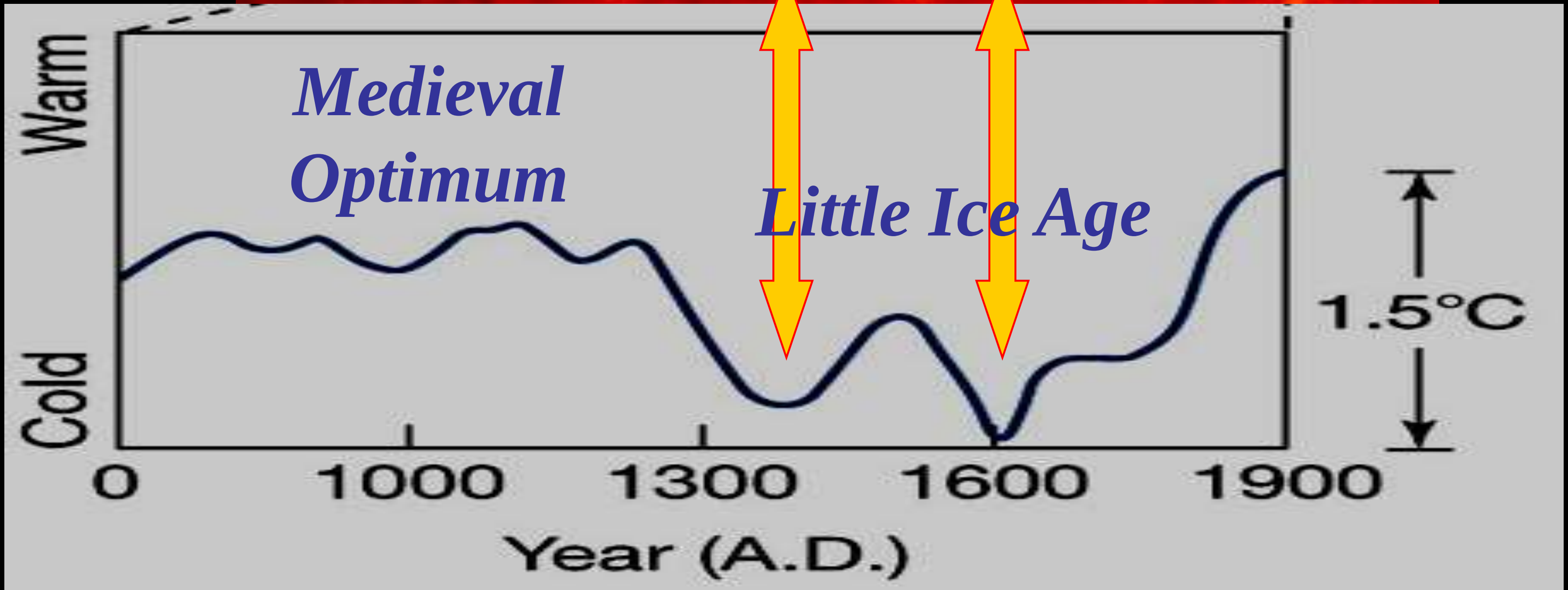

Huancayo & Haleakala (> 13GV)
Percentage of 1954 Solar Minimum Level
100
95
90
85
80
75
Climax (>3 GV)
Smoothed Sunspot No.
200
150
100
50
0
Sunspot Number (smoothed)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Clouds
CLD ecember 1999
The Univ. of Chicago Neutron Monitors
Cosmic Ray Intensity (Bartels solar-rotation averages):
>3 GV Climax, CO (IGY Monitor, 1951-present)
>13 GV Huancayo, Peru (IGY Monitor, 1953-1992)
>13 GV Haleakala, HI (Supermonitor, 1991-present)
Smoothed Int'l Sunspot Number (monthly)

^{14}C and other isotopes show 200 & 1000 year solar cycles peaking around 2000 AD

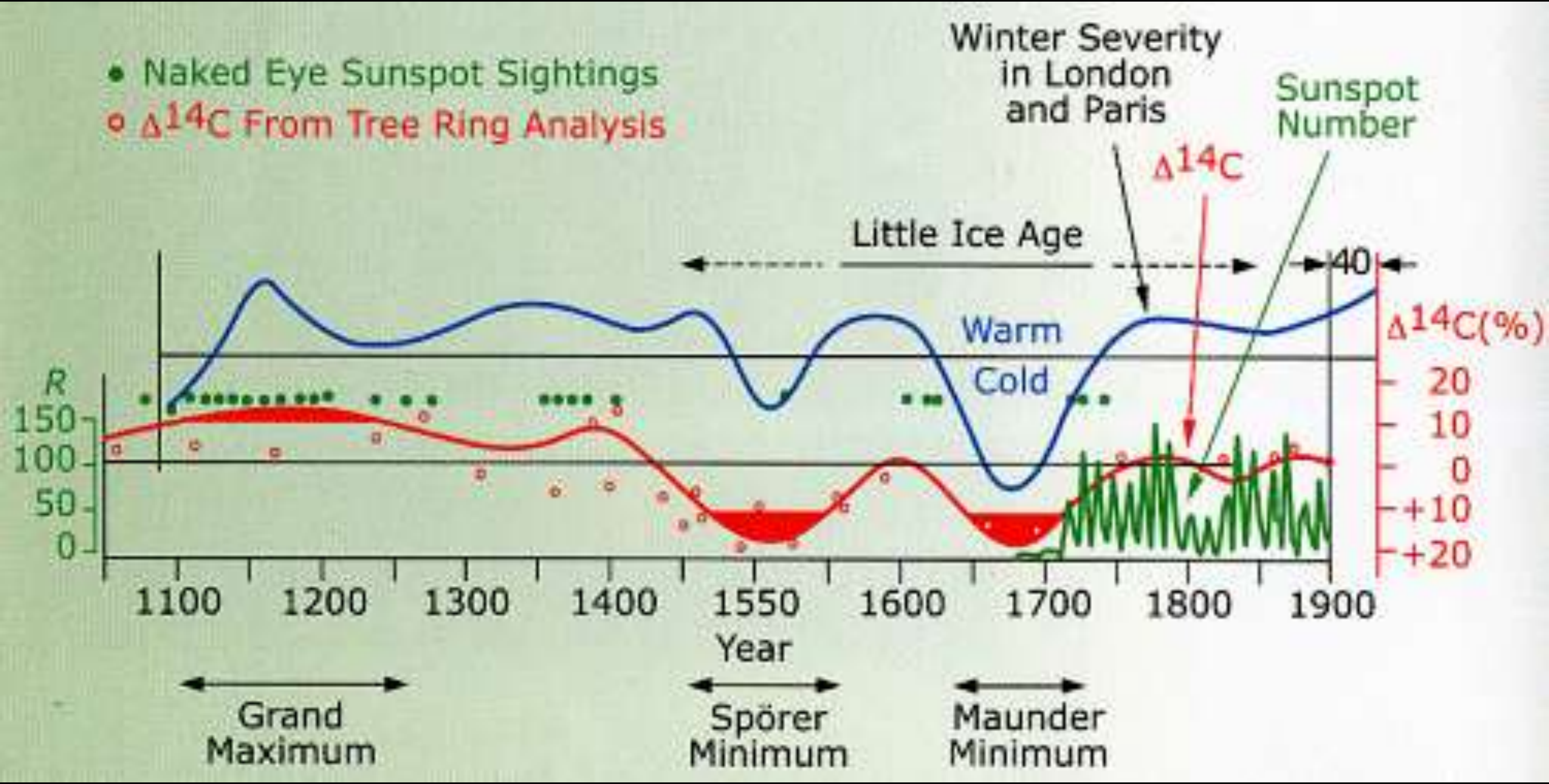


Solar and Climate cycles line up

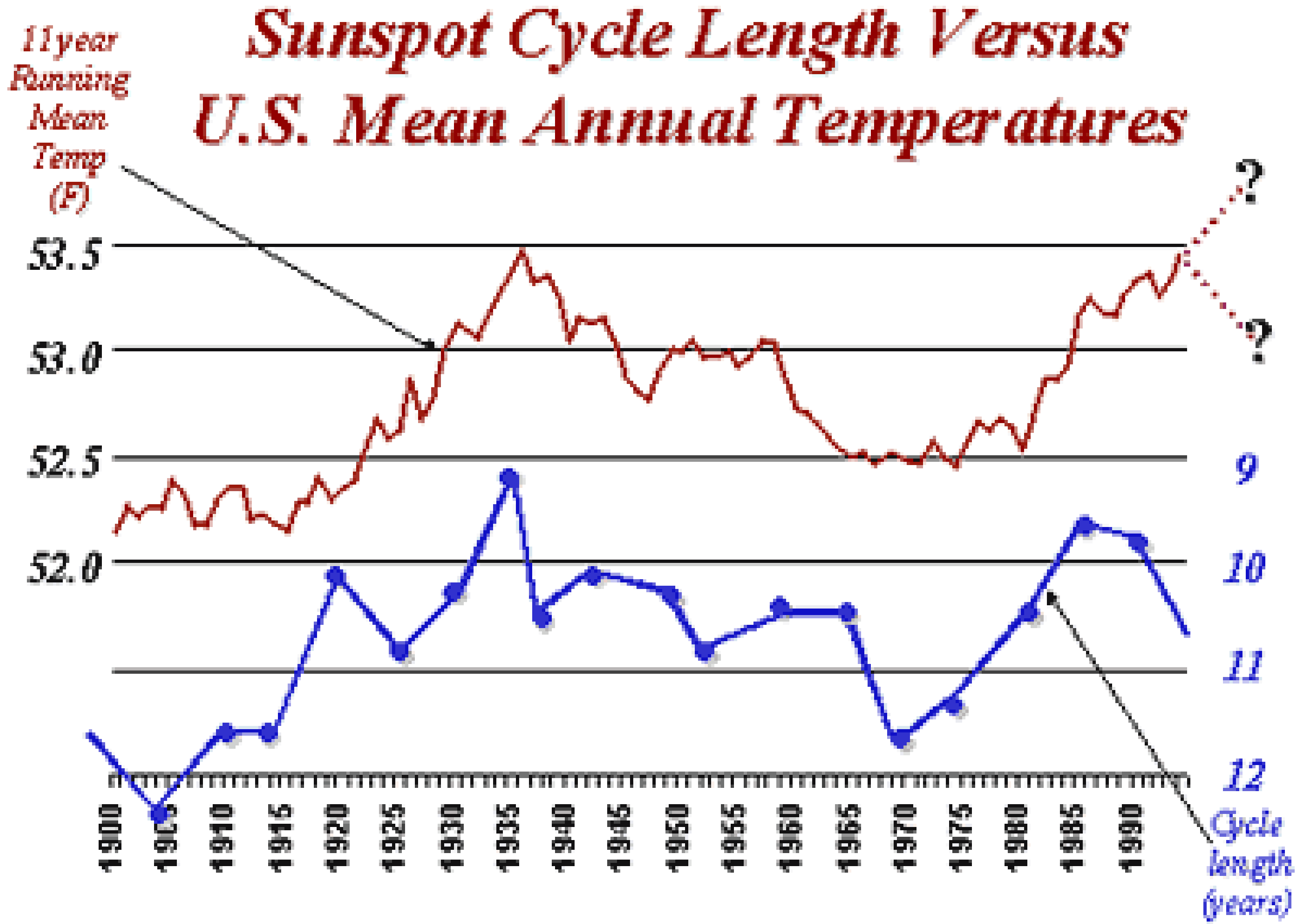


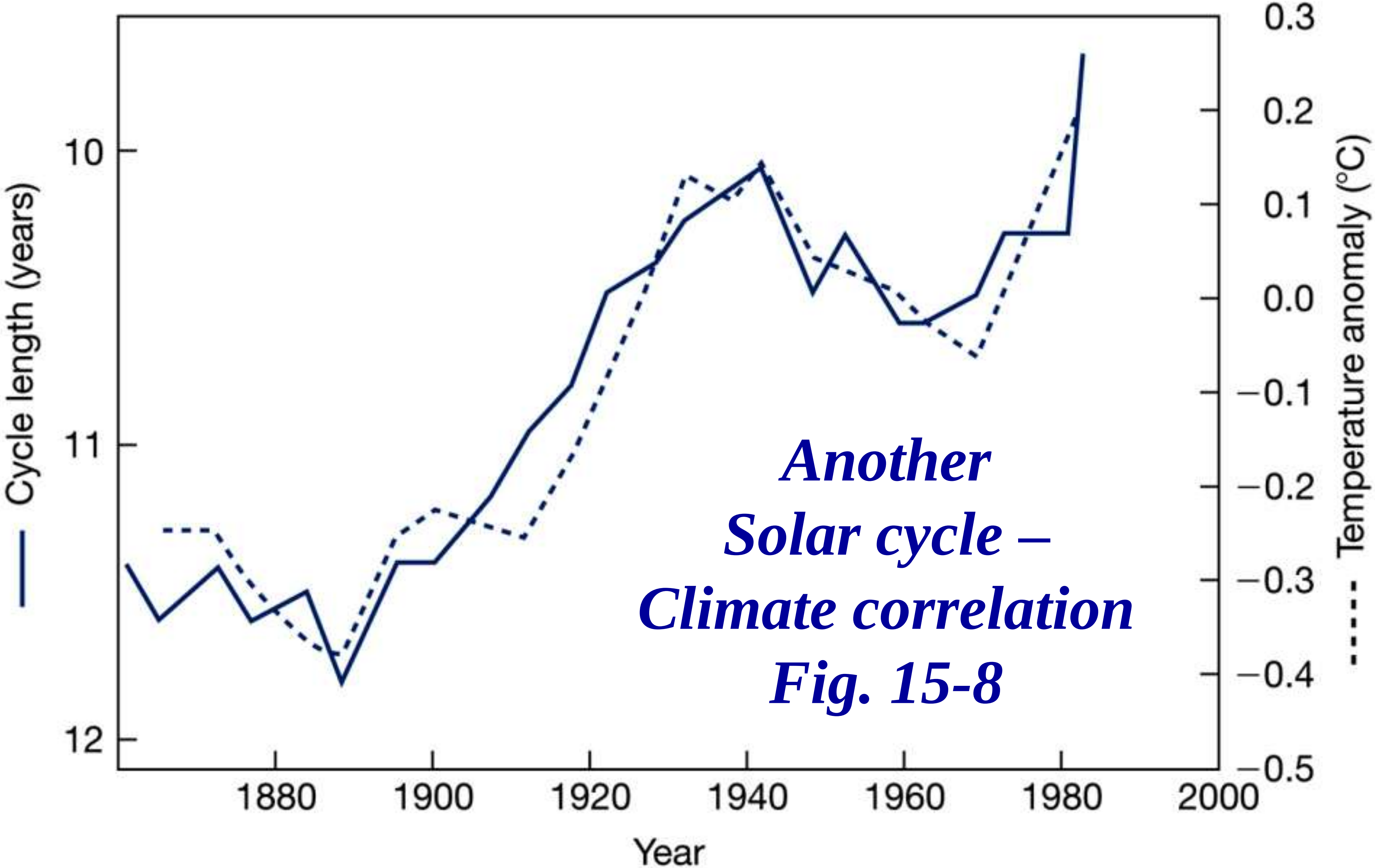


Jack Eddy's grand chart: Great correlations of solar variability with the Medieval warm period and the stages of the Little Ice Age.



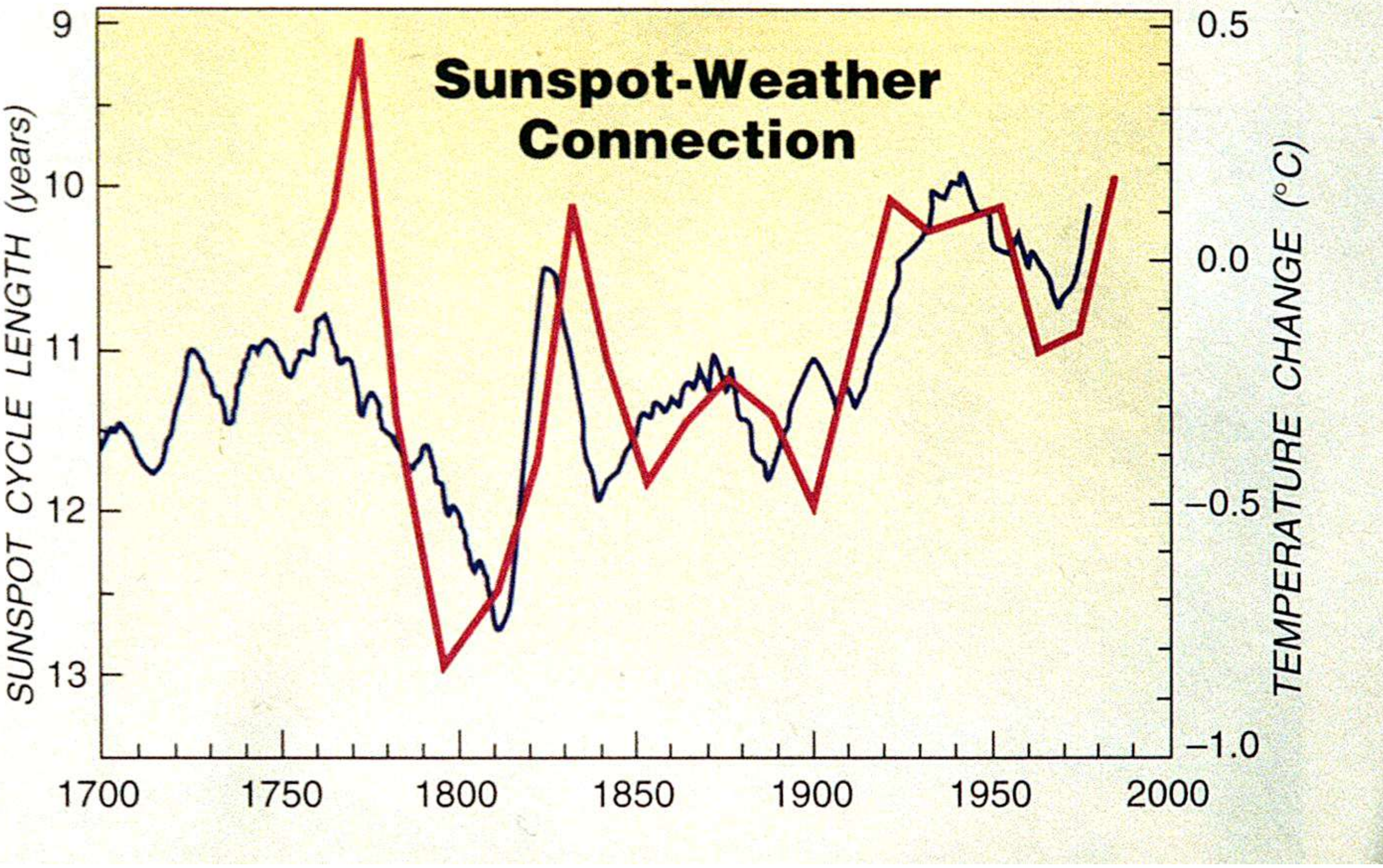
As with other solar type G stars, longer cycles = dimmer star





Another Solar cycle – Climate correlation Fig. 15-8

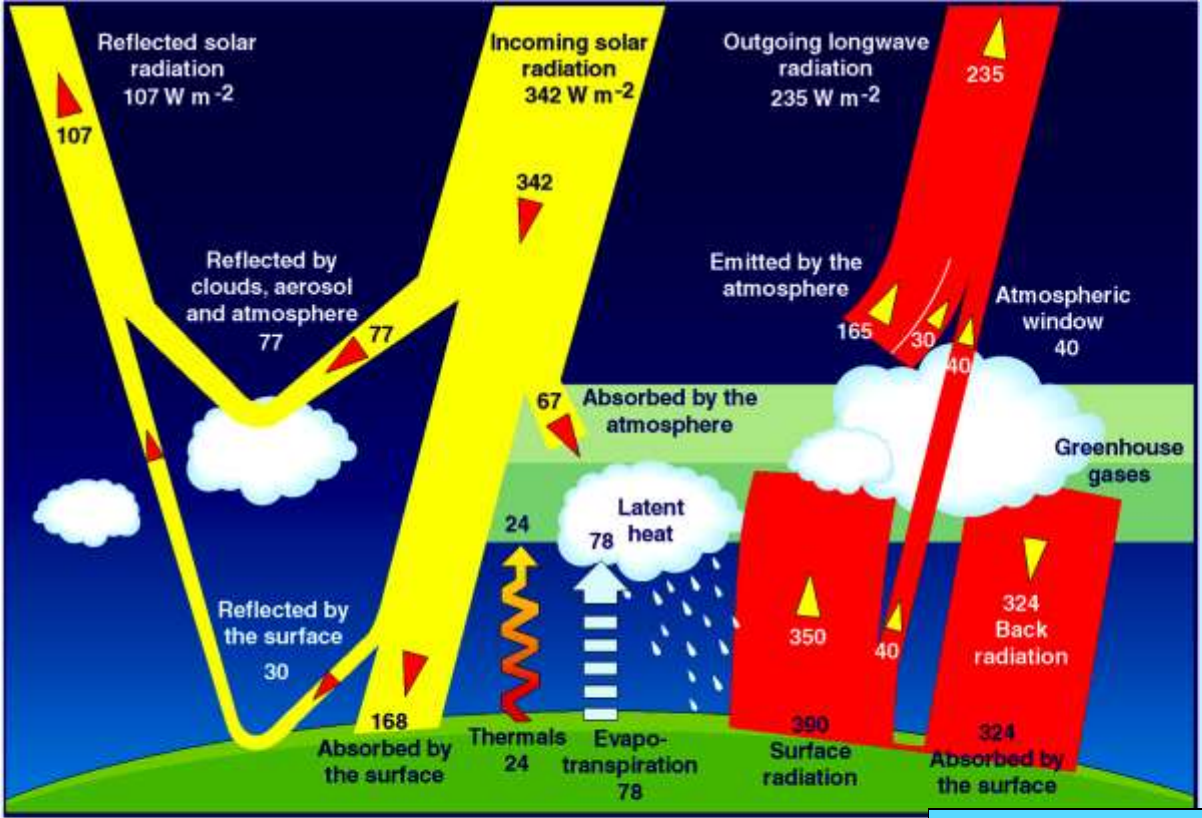
And another – there's a lot more where these came from.



Problem

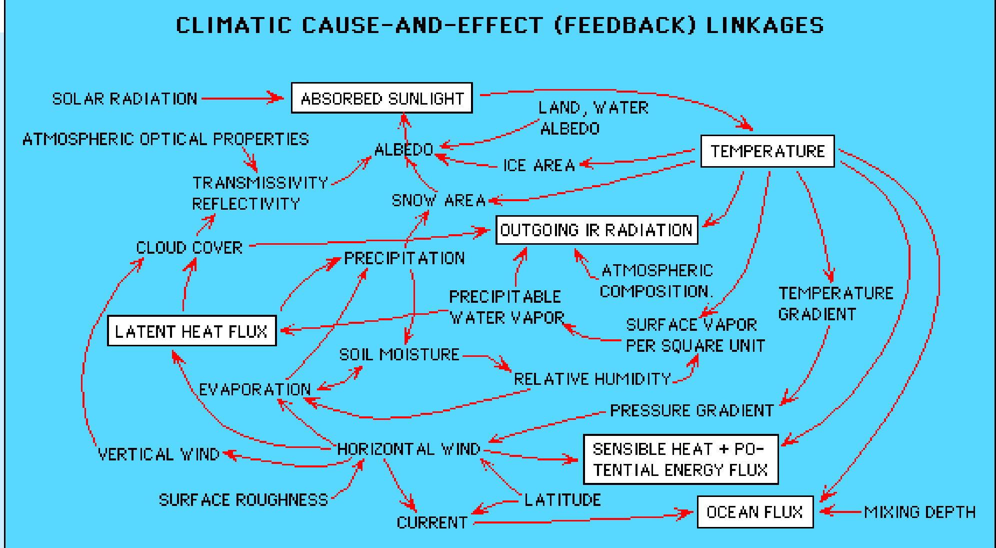
The variations in solar brightness are several times too small to cause the observed ½ to 1 °C climate variations.

We need a positive feedback – a multiplier effect - that can increase the Earth's response to solar changes.



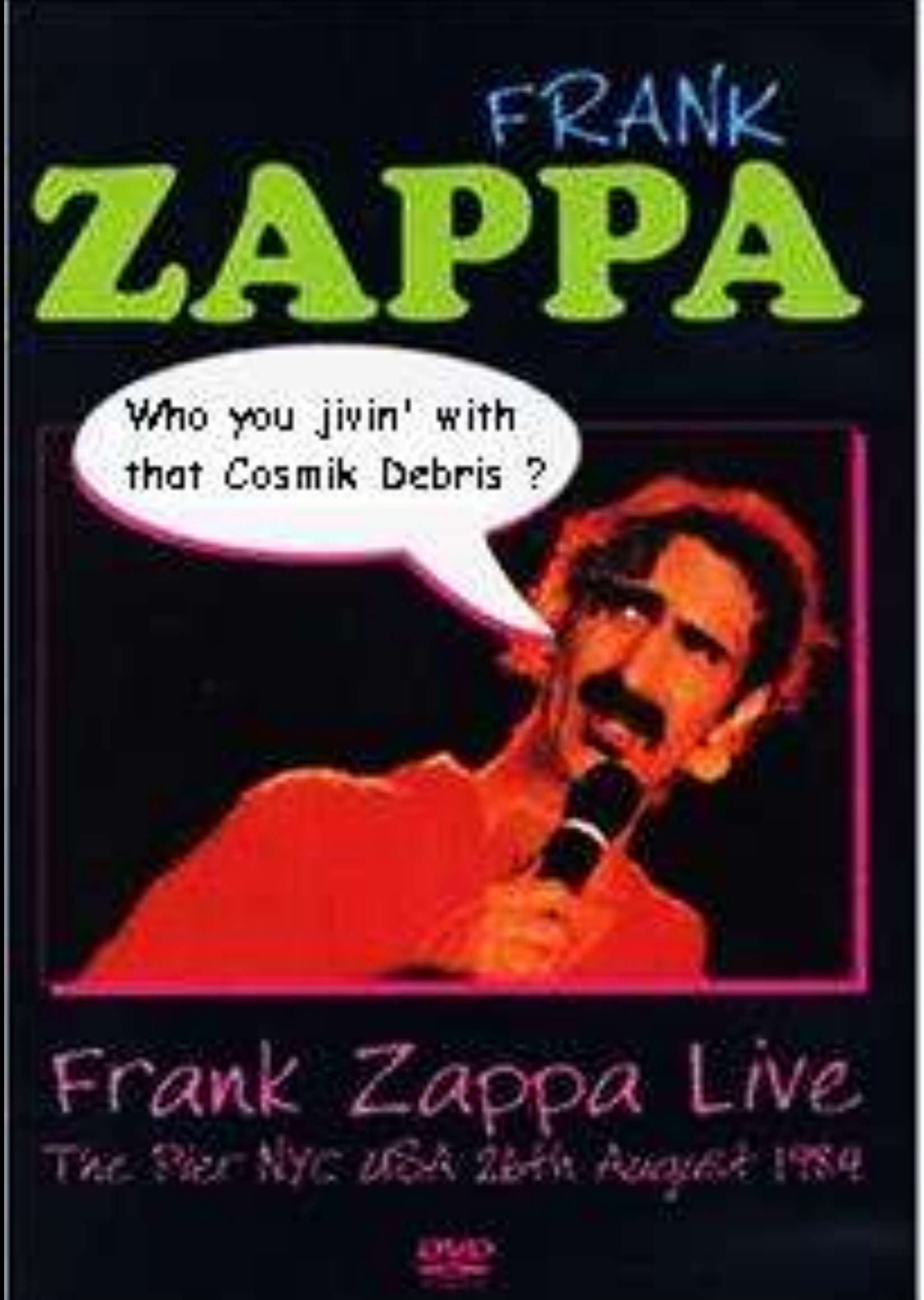
Radiation Balance of the Earth (Jeffrey T. Kiehl)

Earth's energy budget and feedbacks – the short versions. What else could be involved ?

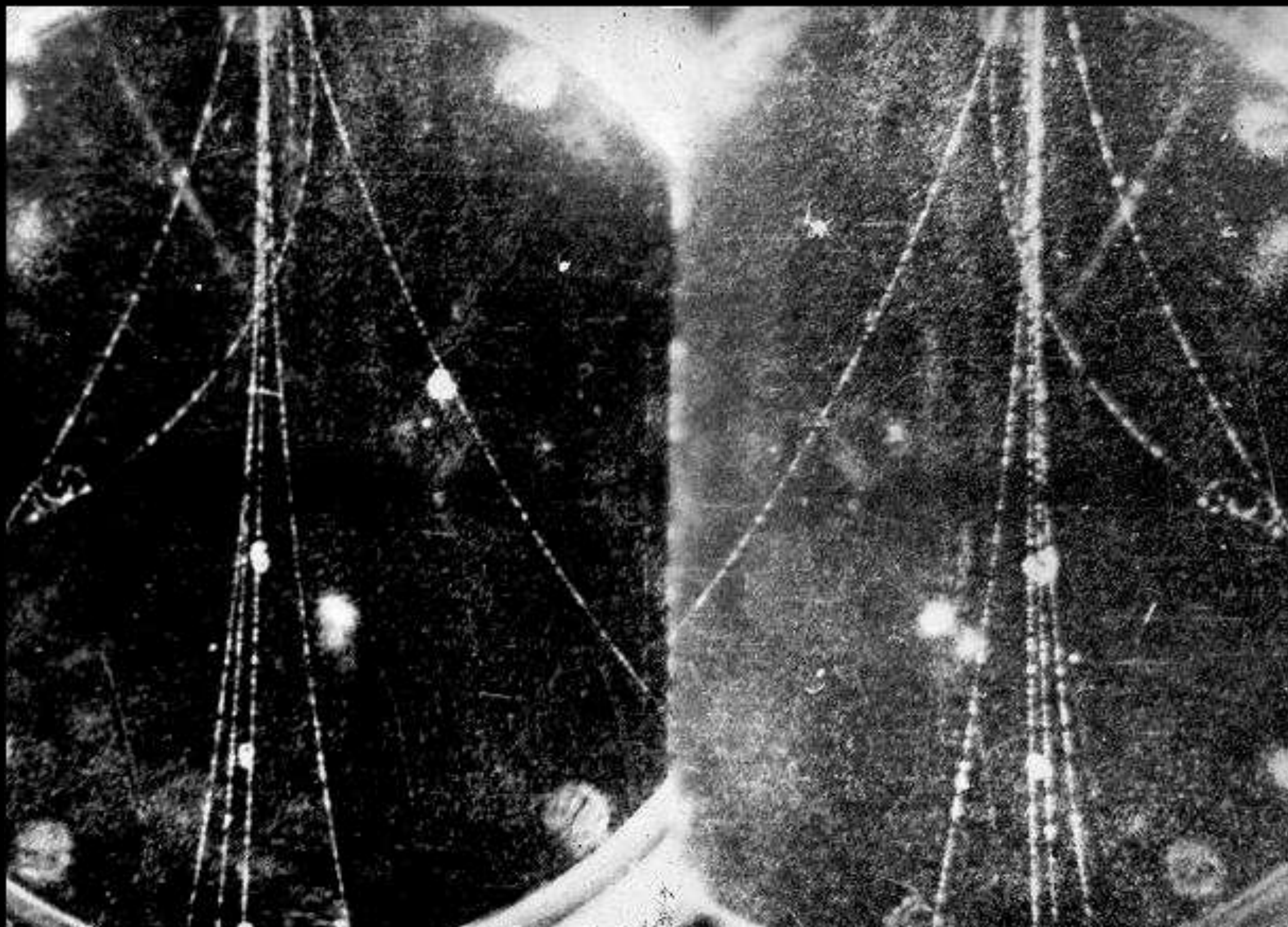


A diagram by Sellers shows the many cause-and-effect linkages that must be accounted for in a comprehensive climate model.

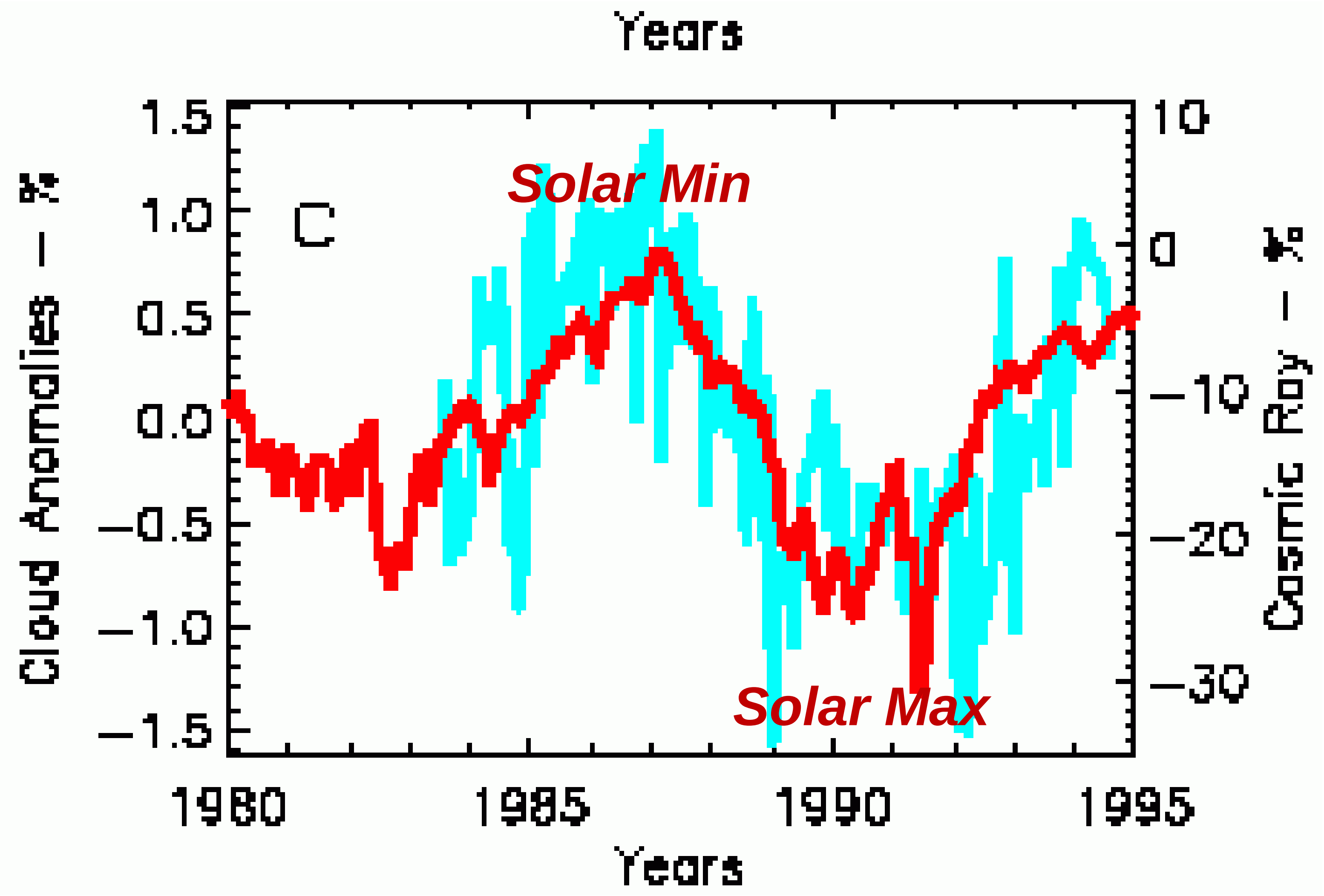
Our old friend, cosmic rays



Cosmic Rays pass through the atmosphere and make little curvy tracks (twisted by magnetic fields) inside cloud chambers. Little clouds made by little particles.



Big clouds made by lots of little particles.
More cosmic rays (red) correlate with more oceanic stratus clouds, like California coastal clouds (blue)



Sun – Cosmic Ray cycle

Brighter Sun
► Fewer cosmic rays
► Fewer clouds
► More of the brighter sunlight heats ground
► Hotter climate
► CR effect amplifies effect of the Sun

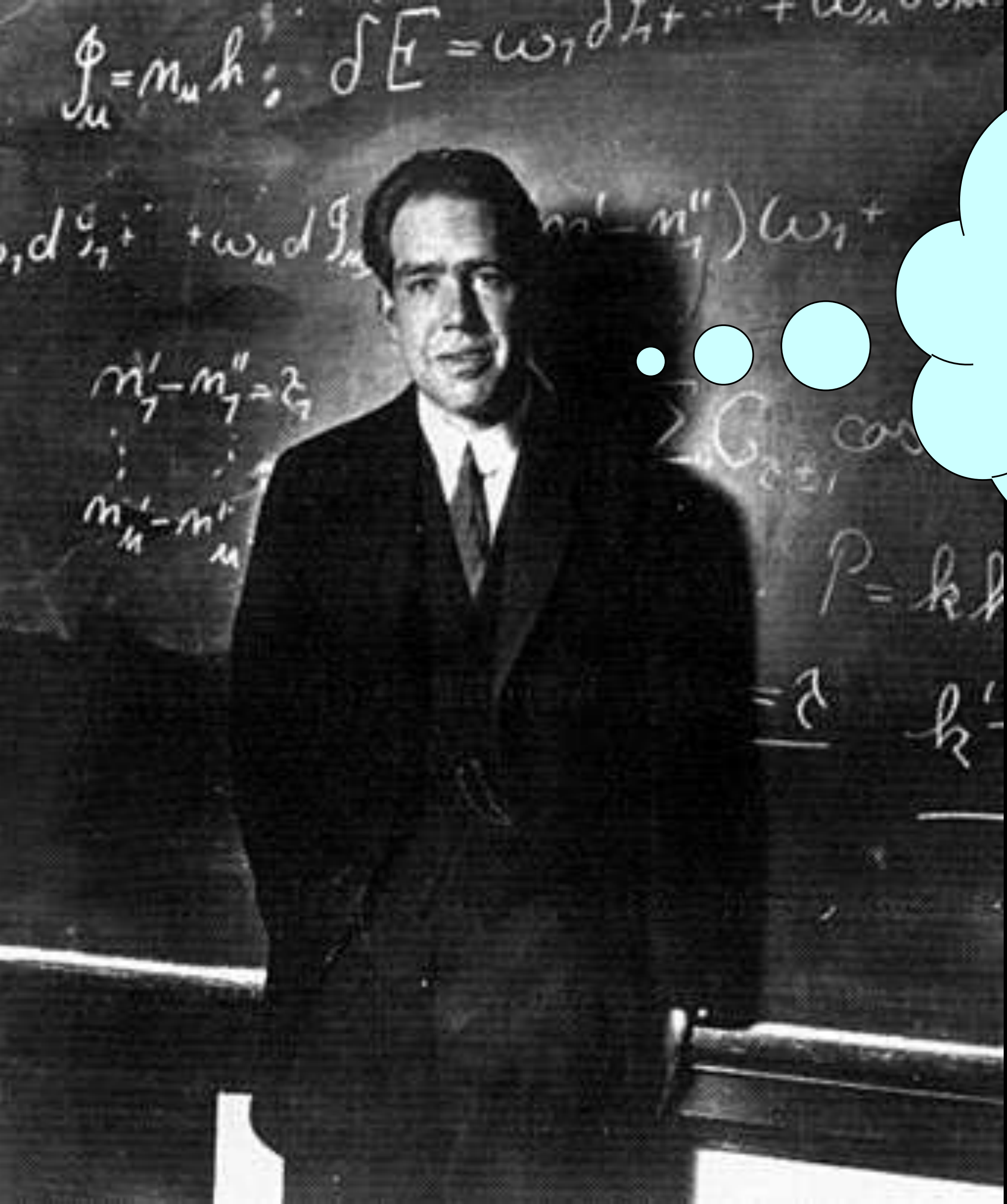
There's a pretty good statistical case for a Sun-Climate connection.

The Medieval Maximum, Little Ice Age, and other temperature cycles of the past 1000 years correlate nicely with observed solar changes.

However, we're not sure how the small variations in total solar irradiance (TSI) can cause such large climate fluctuations.

Cosmic rays MIGHT be the mechanism.
So could Solar UV heating the stratosphere, causing winds that work their way down to the troposphere.

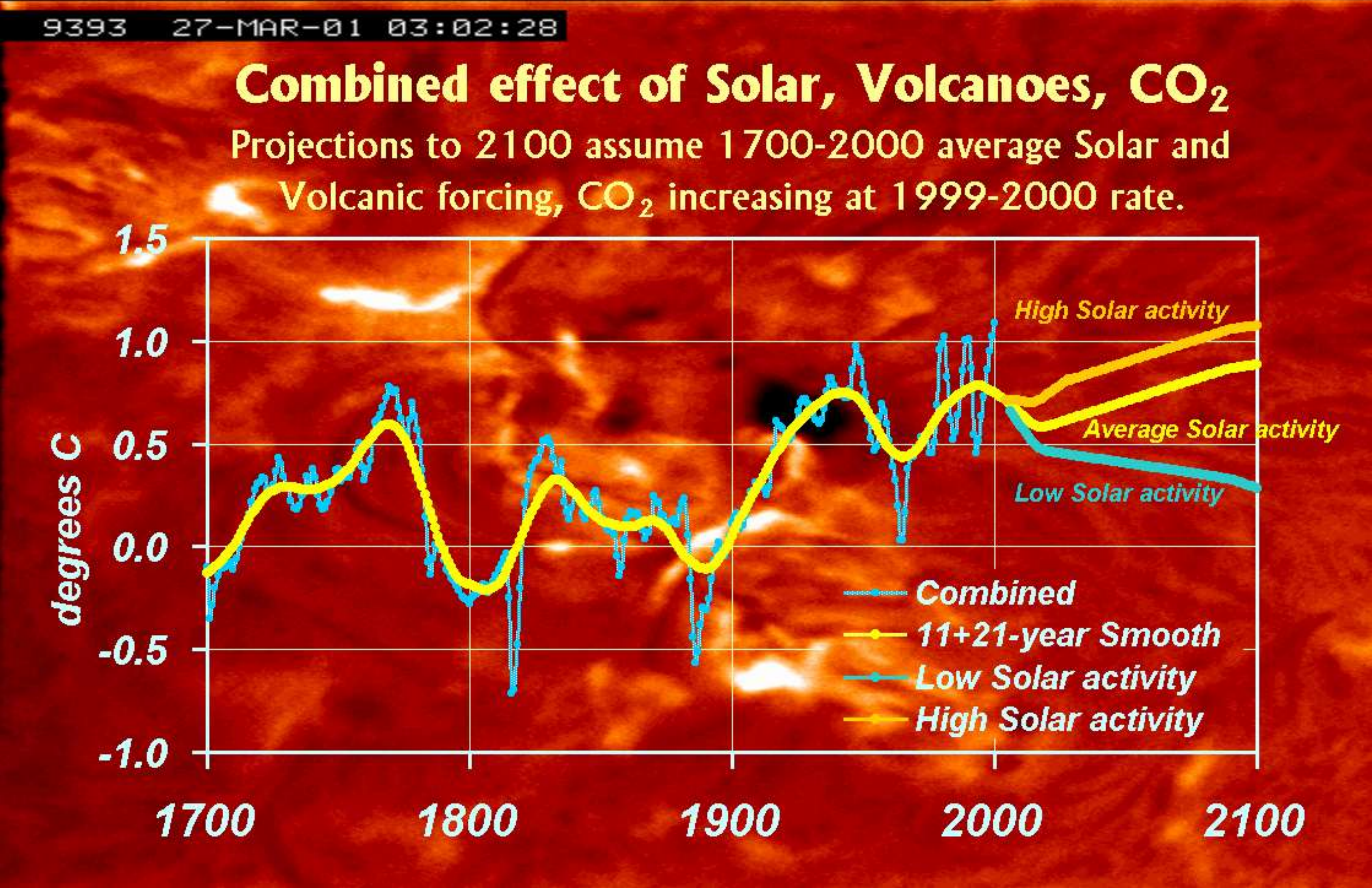
The Future isn't what it used to be.



Prediction is very difficult, especially about the future.

Niels Bohr
Danish physicist
(1885 - 1962)

My forecast from ten years ago, based on 200 & 1000 year solar cycles



Millennium-Scale Sunspot Number Reconstruction: Evidence for an Unusually Active Sun since the 1940s

Ilya G. Usoskin*
Sodankylä Geophysical Observatory (Oulu unit), University of Oulu, FIN-90014 Oulu, Finland

Now, the Grand Solar Max of 2000…

Sami K. Solanki and Manfred Schüssler
Max-Planck Institut für Aeronomie, Katlenburg-Lindau, Germany

Kalevi Mursula and Katja Alanko

VOLUME 91, NUMBER 21 PHYSICAL REVIEW LETTERS week ending 21 NOVEMBER 2003

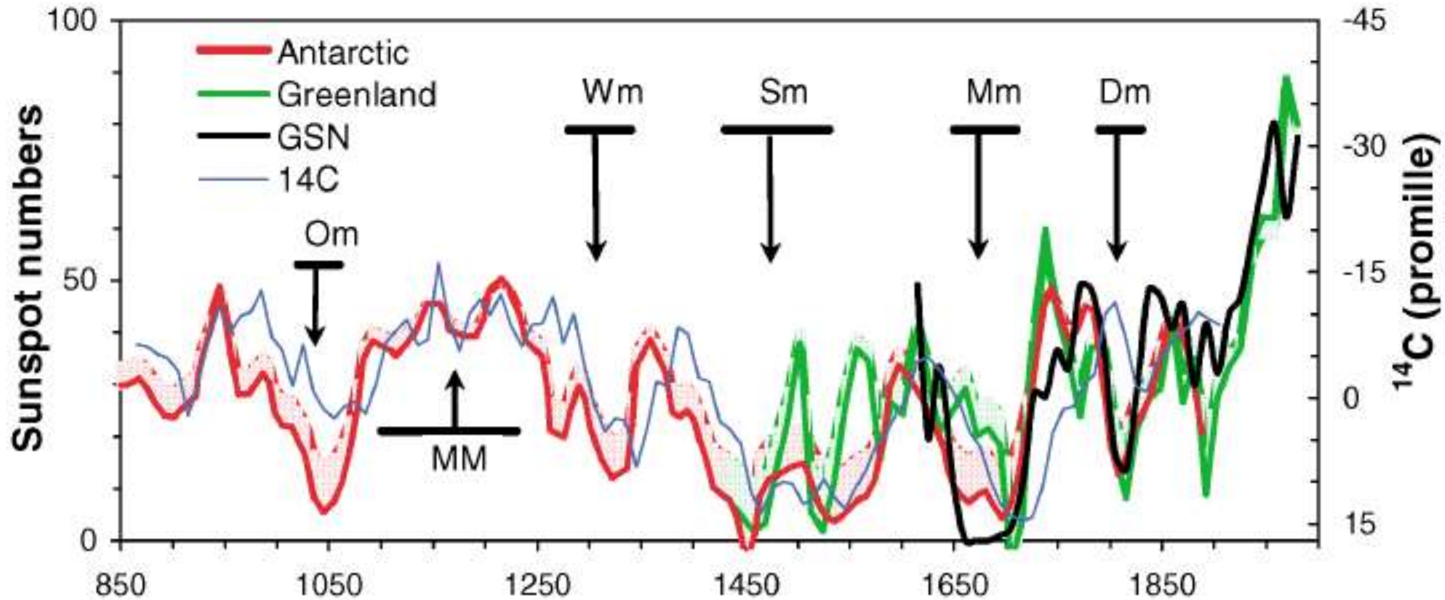
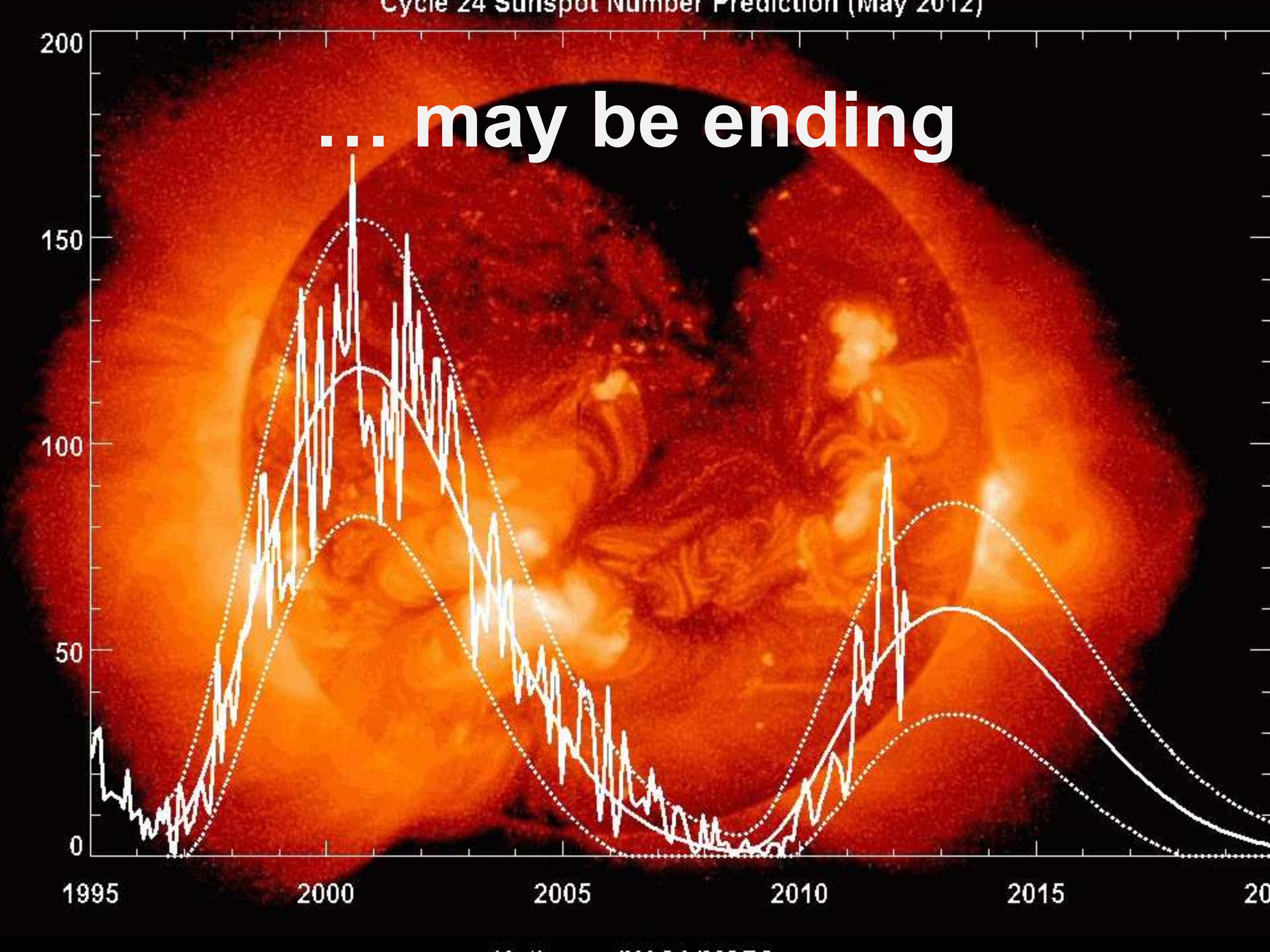


FIG. 2 (color). Time series of the sunspot number as reconstructed from ^{10}Be concentrations in ice cores from Antarctica (red) and Greenland (green). The corresponding profiles are bounded by the actual reconstruction results (upper envelope to shaded areas) and by the reconstructed values corrected at low values of the SN (solid curves) by taking into account the residual level of solar activity in the limit of vanishing SN (see Fig. 1). The thick black curve shows the observed group sunspot number since 1610 and the thin blue curve gives the (scaled) ^{14}C concentration in tree rings, corrected for the variation of the geomagnetic field [20]. The horizontal bars with attached arrows indicate the times of great minima and maxima [21]: Dalton minimum (Dm), Maunder minimum (Mm), Spörer minimum (Sm), Wolf minimum (Wm), Oort minimum (Om), and medieval maximum (MM). The temporal lag of ^{14}C with respect to the sunspot number is due to the long attenuation time for ^{14}C [19].


Cycle 24 Sunspot Number Prediction (May 2012)
… may be ending
200
150
100
50
0
1995
2000
2005
2010
2015

Absence of the Corona at Eclipse

John A. Eddy

They are descriptions of the corona from the eclipses of 1652, 1698, 1706, and 1708, the only contemporary firsthand descriptions of the sun eclipsed that I can find (*66*). They were written, in general, by amateurs and nonconformists who watched the spectacle with eyes open to all of it. None describes the corona as showing structure. Not one mentions the streamers which at every eclipse in the present time are so easily seen with the naked eye to stretch as much as a degree or more above the solar limb. All describe the corona as very limited in extent: typically only 1 to 3 arc minutes above the solar limb. In each case the corona is described as dull or mournful, and often as reddish. No drawings were made. Every account is consistent with our surmise of what the zodiacal light would look like at eclipse, were the true corona really gone.

Kepler himself reported that at the eclipse of 1604 (*70*): "The whole body of the Sun was effectually covered for a short time. The surface of the Moon appeared quite black; but around it there shone a brilliant light of a reddish hue, and uniform breadth, which occupied a considerable part of the heavens." None of these or any other descriptions that I can find fit a rayed or structured corona;

No real corona during the Maunder Min !!!

By 1715, the annual sunspot number had reached 26 and was climbing. At the eclipse of that year, at the end of the Maunder Minimum, the corona is fairly well described, and for the first time we have drawings of it. For the first time distinct coronal structures are described

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