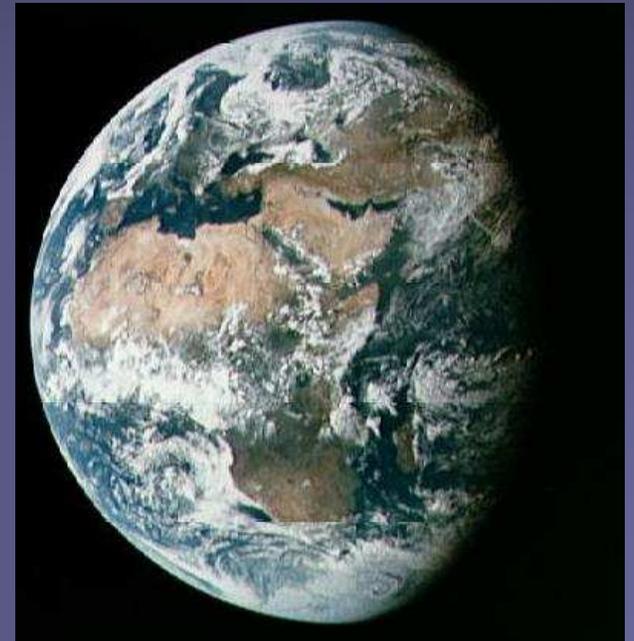


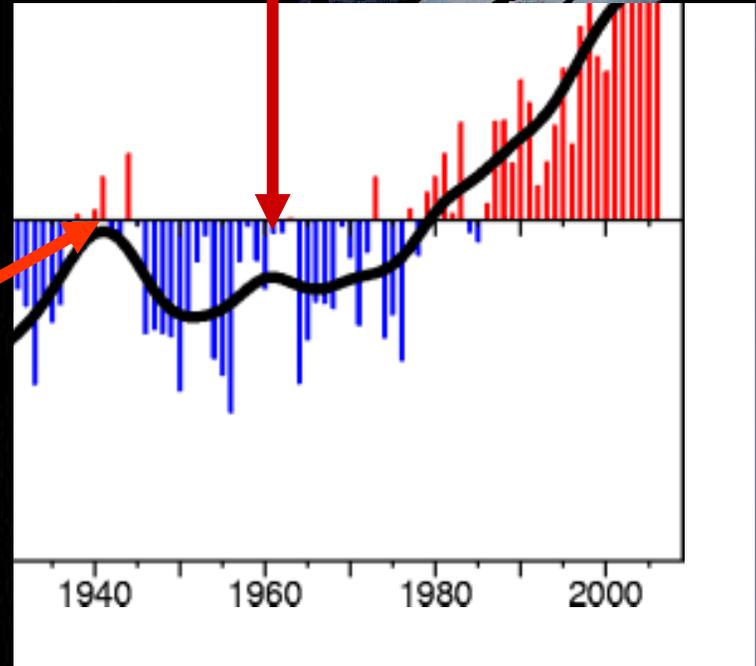
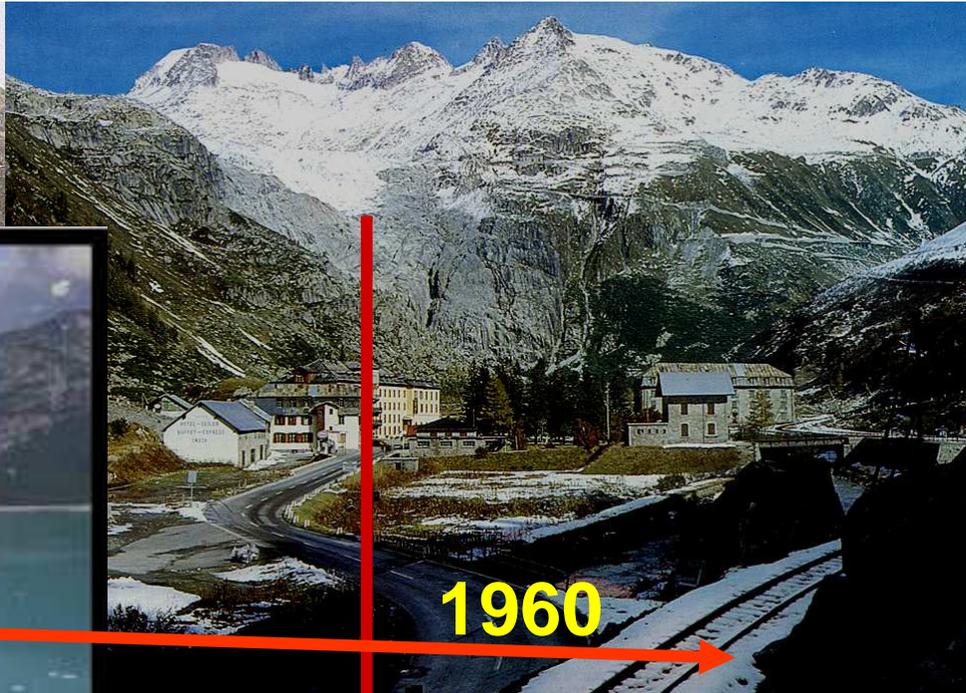
Global Climate Change: is the Sun to Blame?



Sami K. Solanki

Max-Planck-Institut für
Sonnensystemforschung





Is there Proof for Global Warming?

Positive proof of global warming.



**18th
Century**

1900

1950

1970

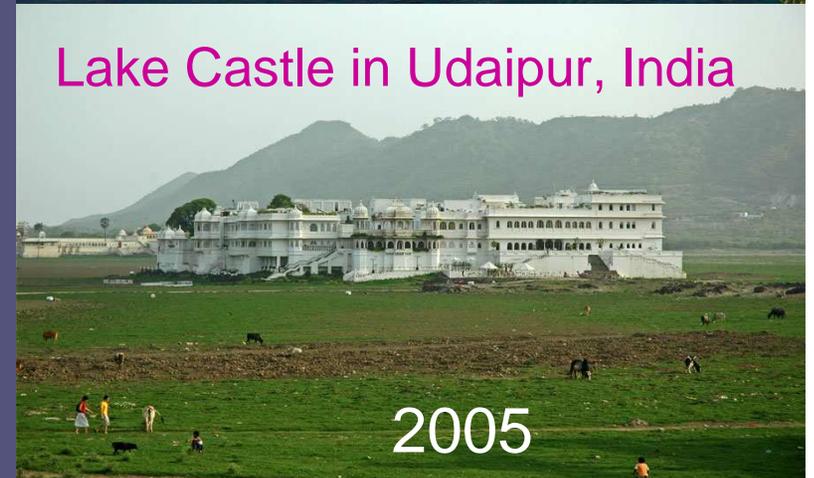
1980

1990

2008

More illustrations of global change

Muir and Riggs Glaciers



Extreme weather events



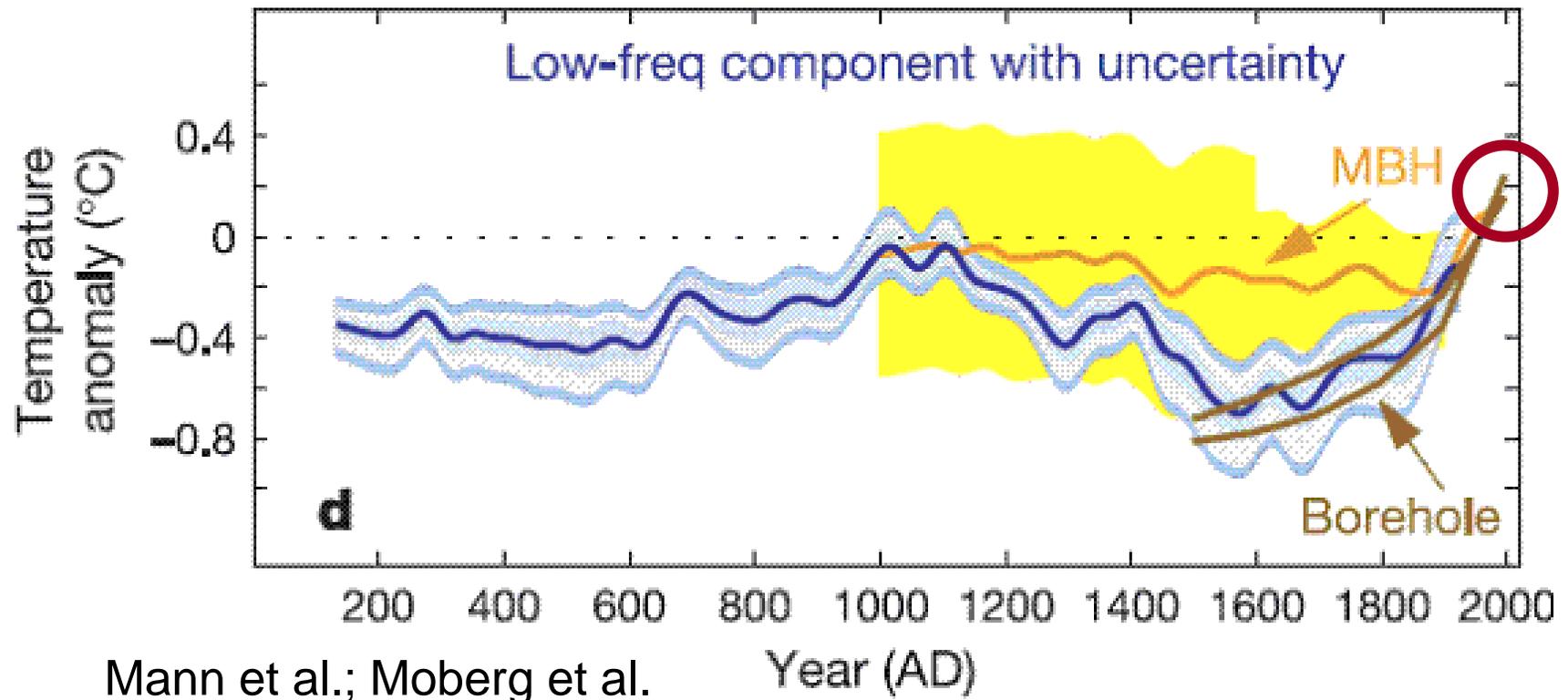
**Some
Consequences
of Global
Climate Change**

Rising sea level

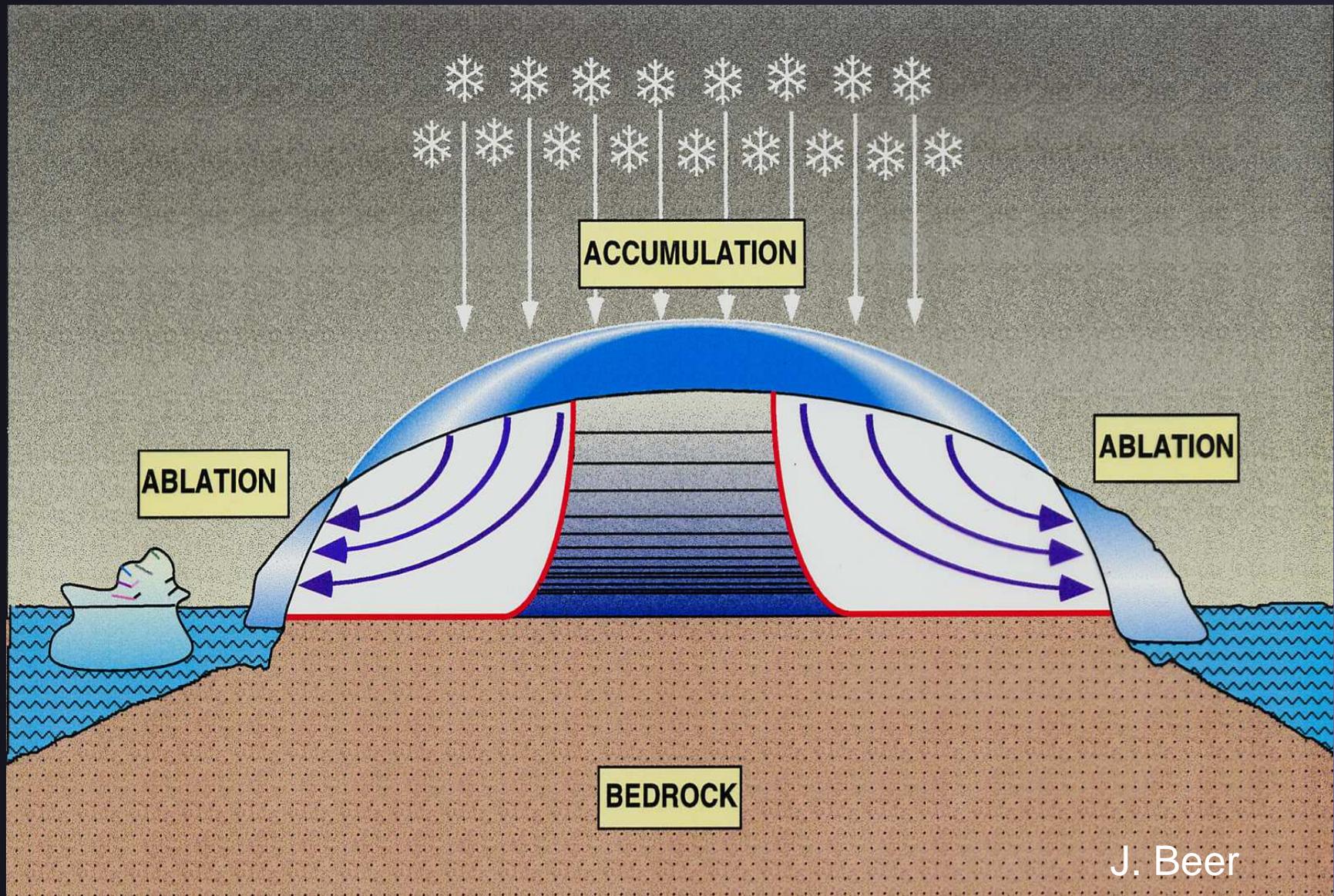


Is the Recent Temperature Rise Extraordinary?

Various temperature reconstructions suggest that the Earth is hotter now than in the last 2000 years

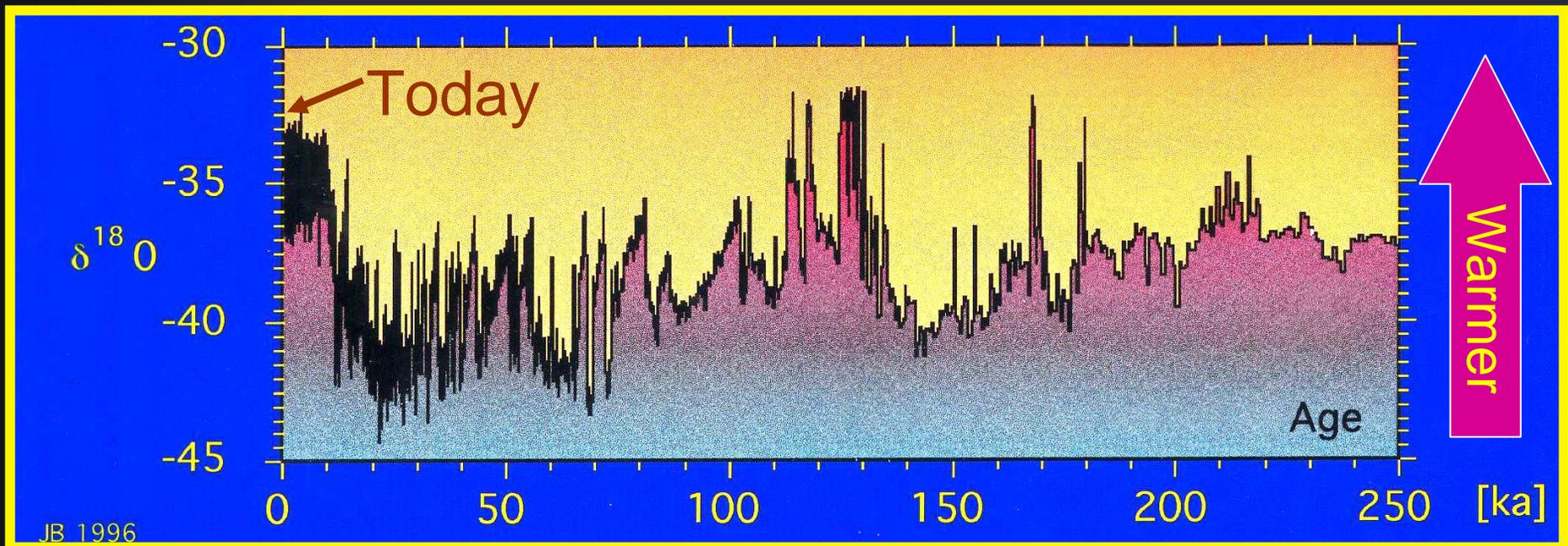


The Life Story of Greenland Ice



J. Beer

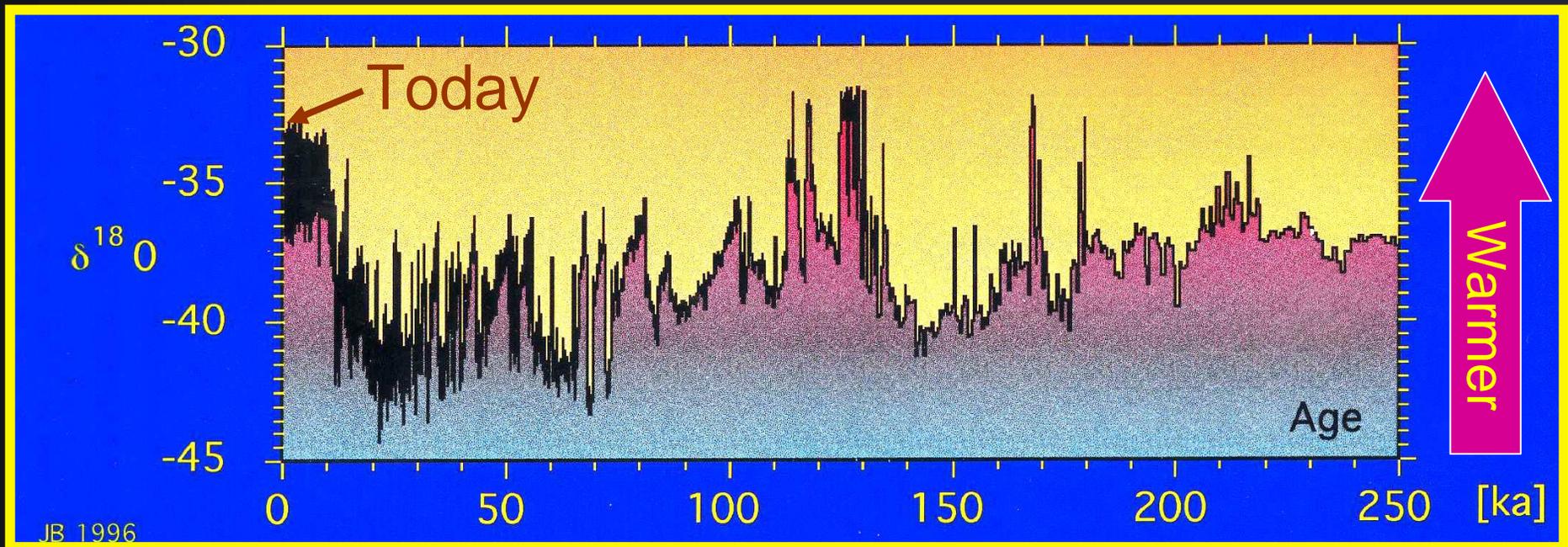
Larger Temperature Fluctuations were Common Prior to the Holocene



We live in a (rare) Interglacial period. Transitions are dramatic and abrupt.

Human civilization developed during the present Interglacial, the Holocene

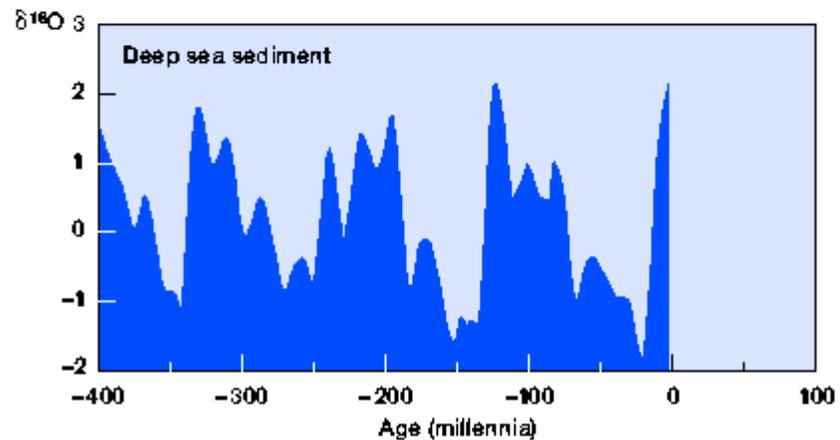
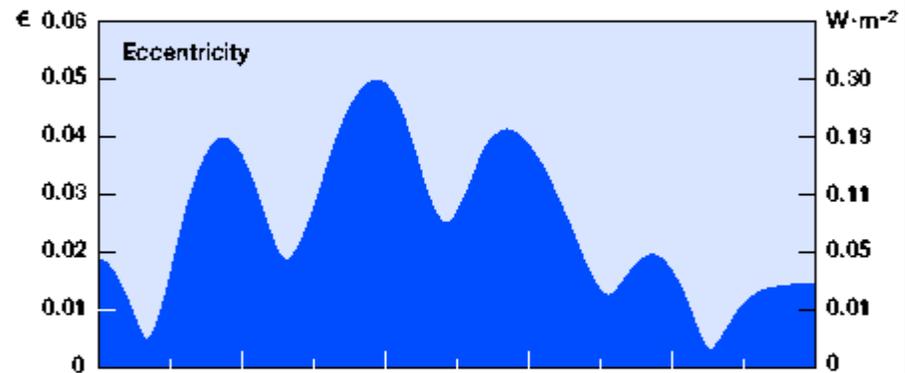
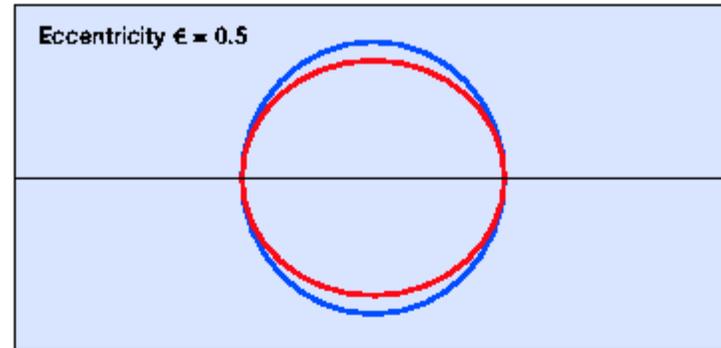
Ice Ages and Interglacials

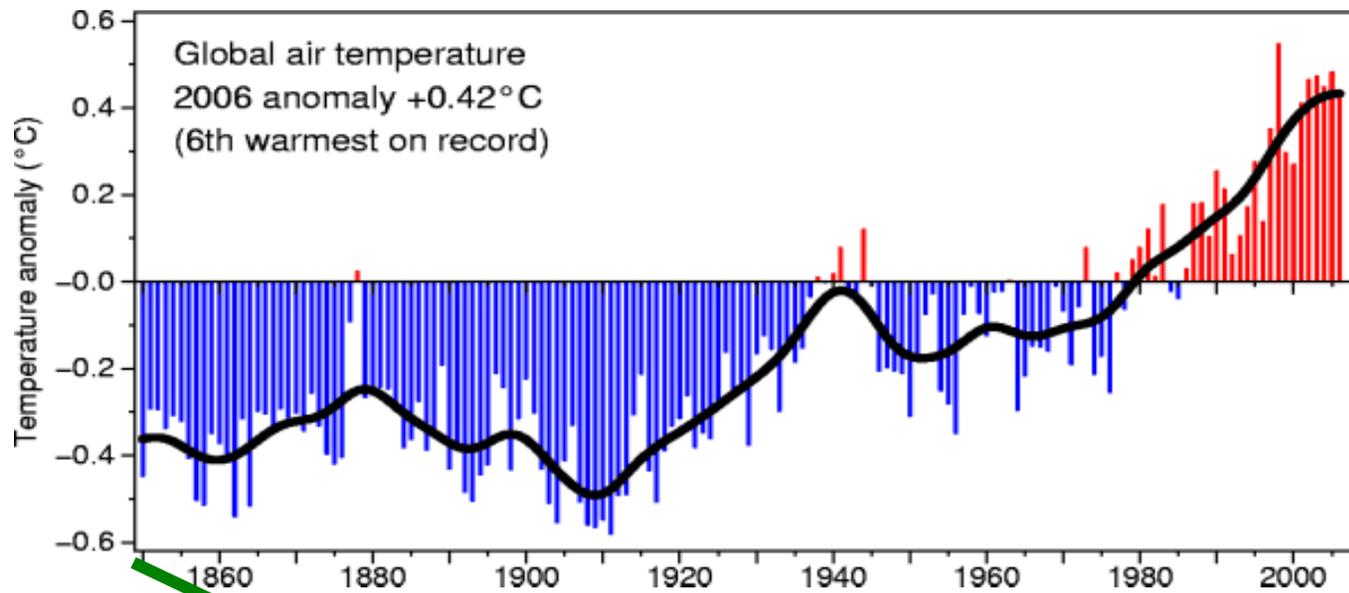


We live in a (rare) Interglacial period. Transitions are dramatic and abrupt.

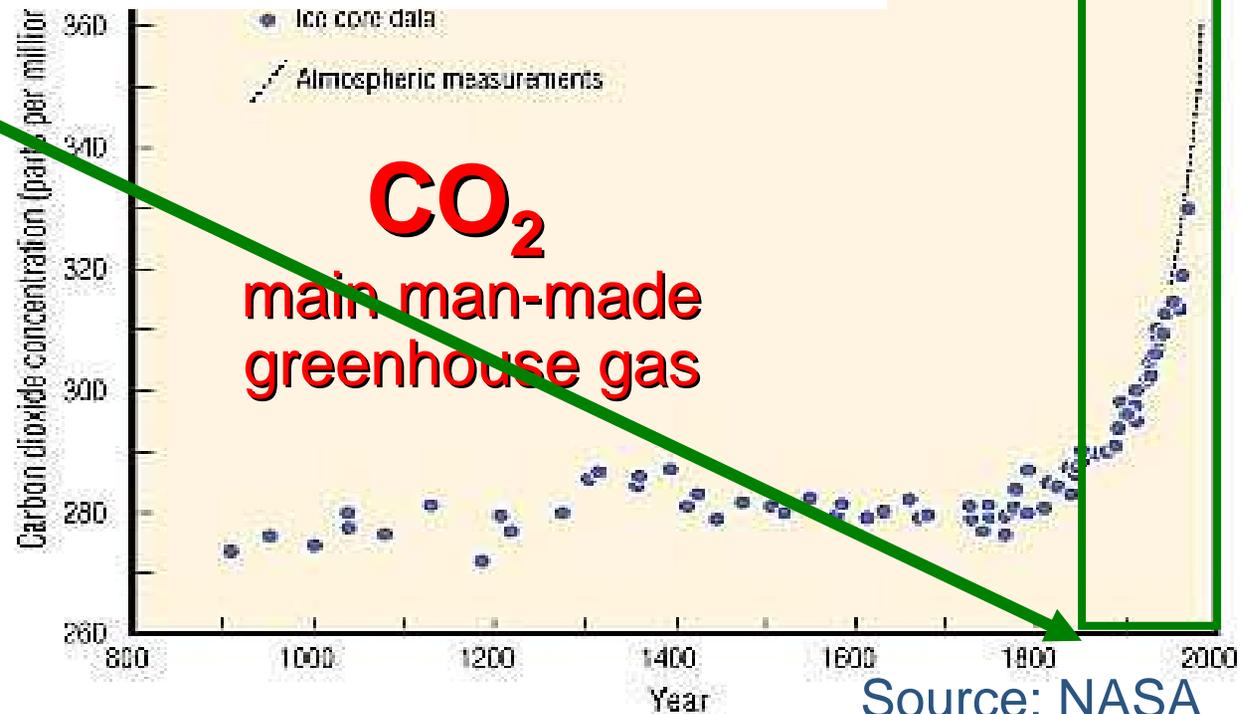
Milankowich Theory: Changes in Earth's orbital parameters cause ice-age cycles. Abrupt transitions?

Influence of Changes in Excentricity of Earth's Orbit on Earth's global Temperature





Is Global Warming Man-made?

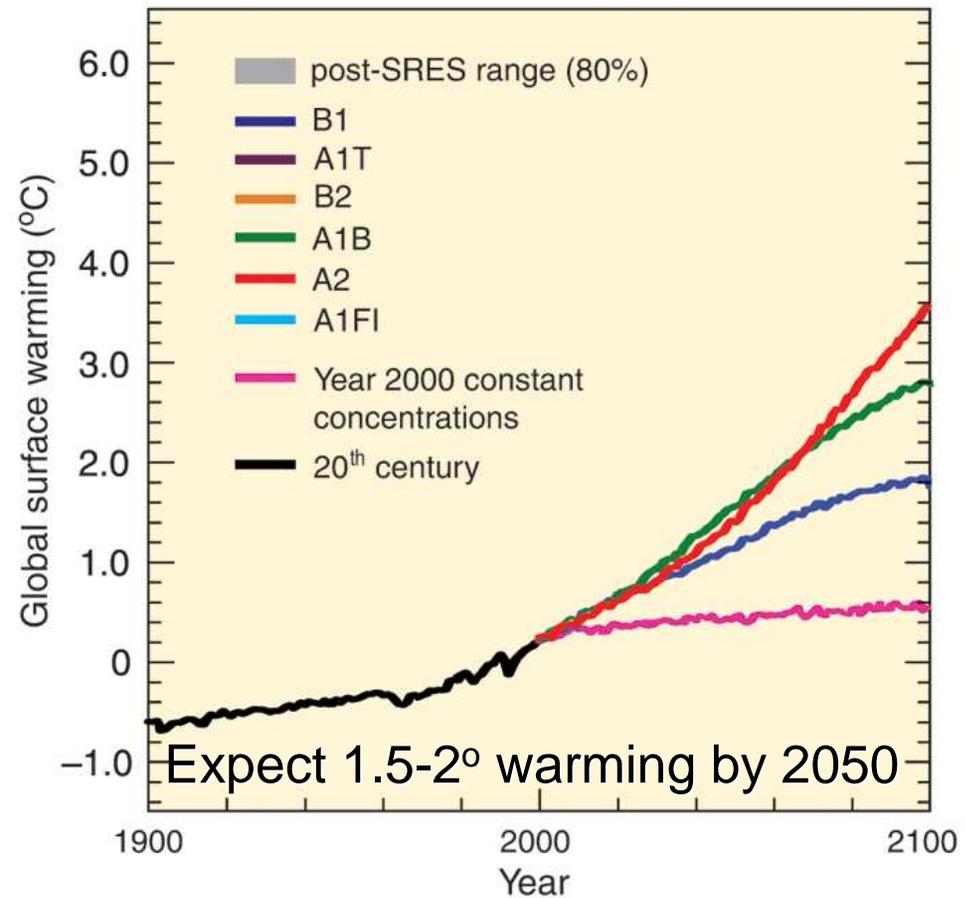
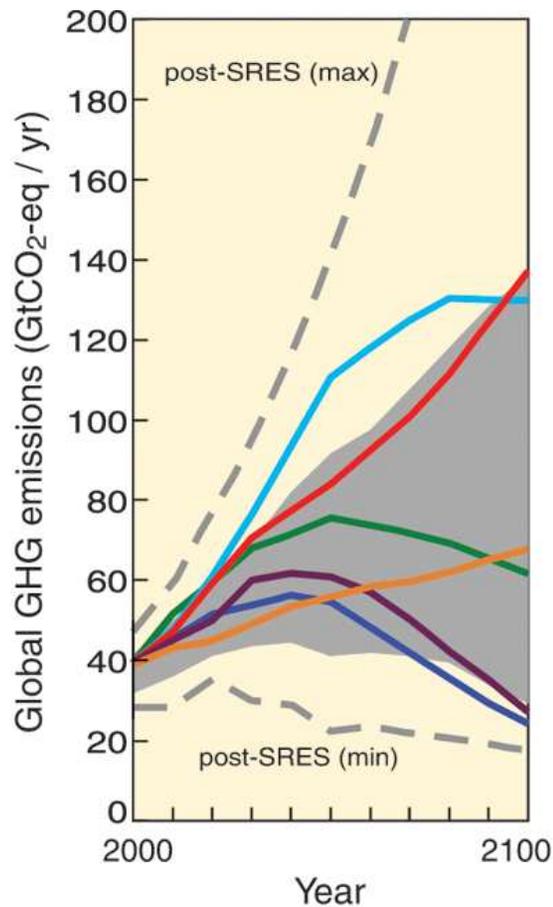


IPCC Predictions until 2100

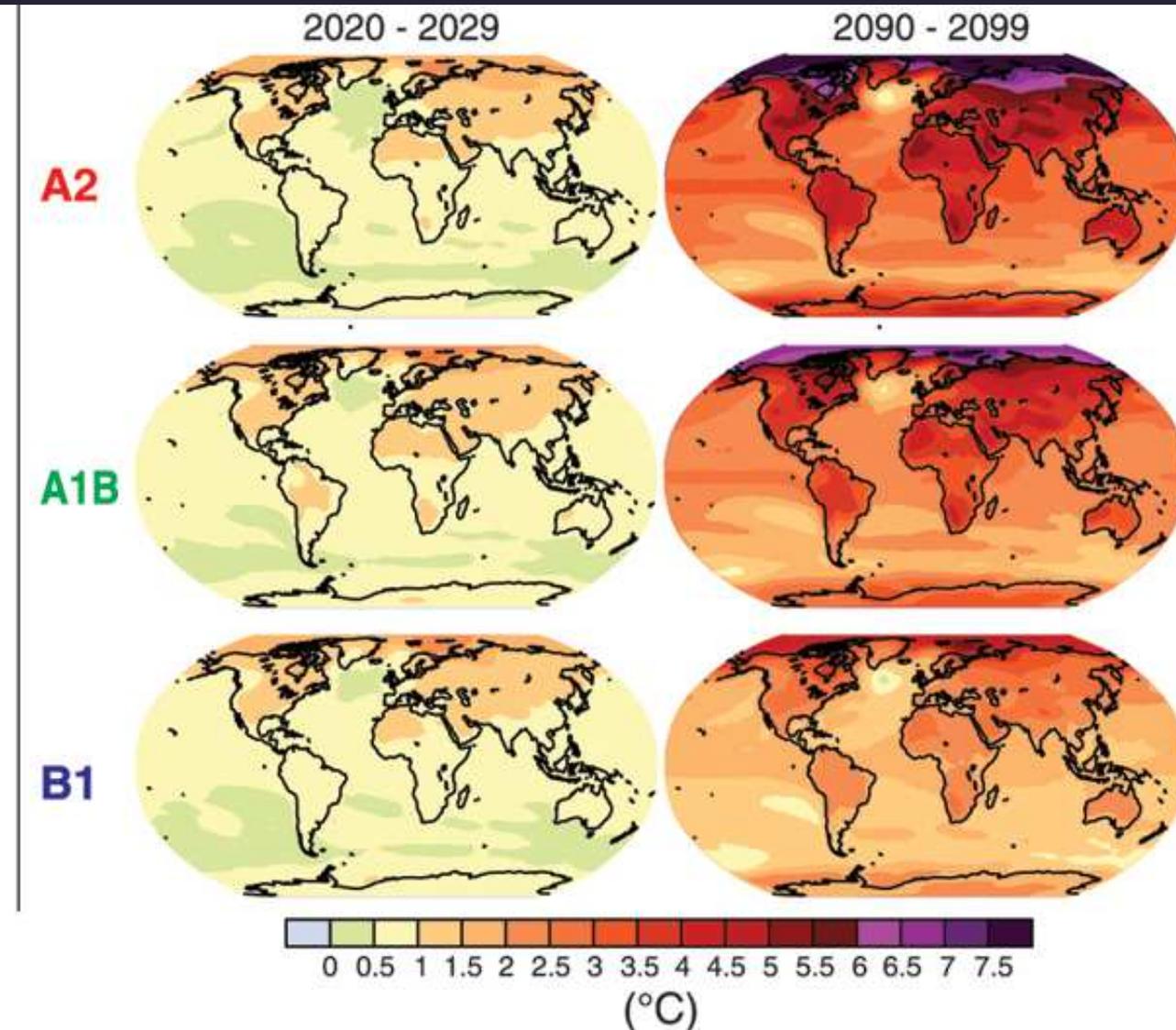
Scenarios for emission of Greenhouse Gases



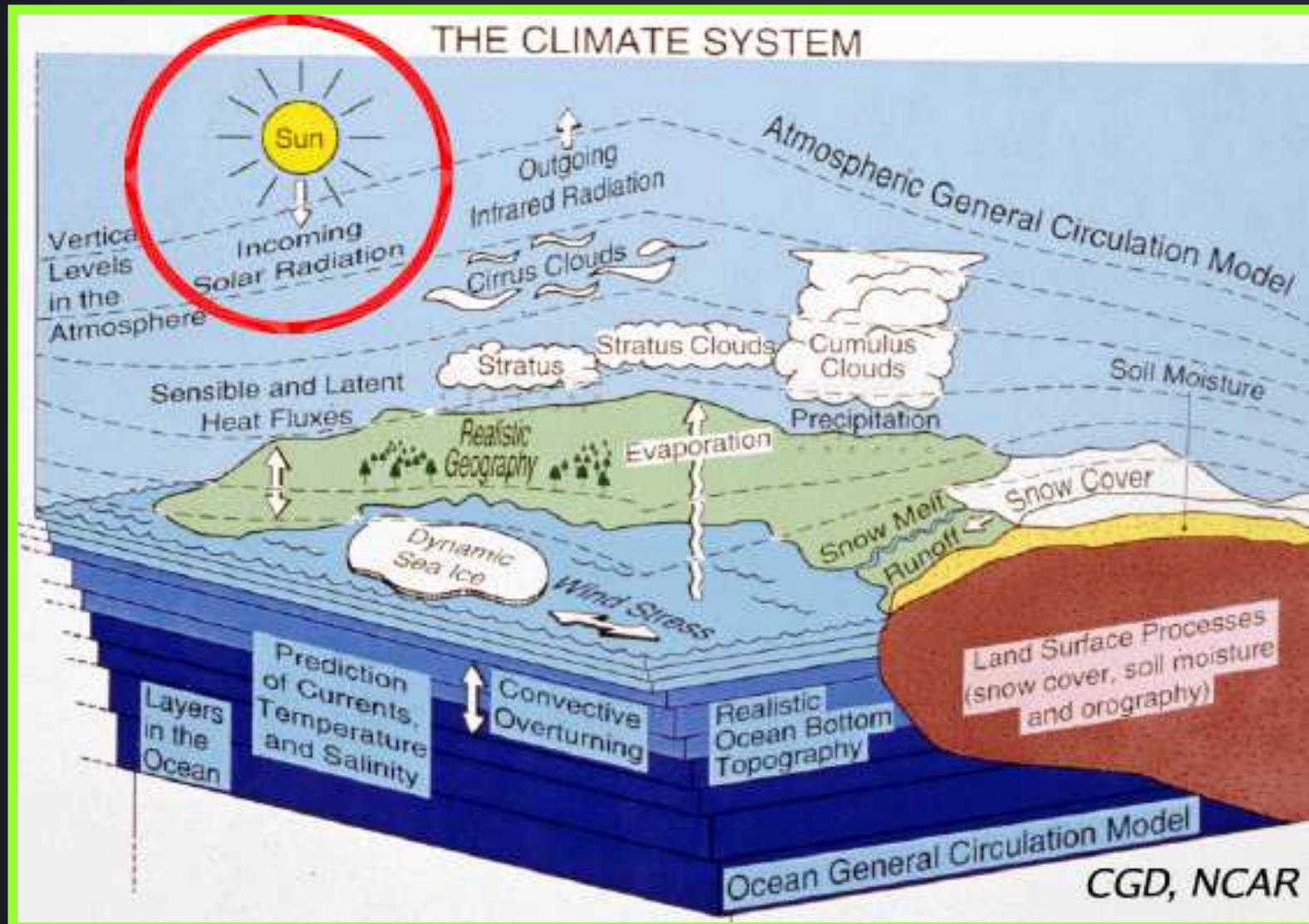
Predicted temperature over next 100 years



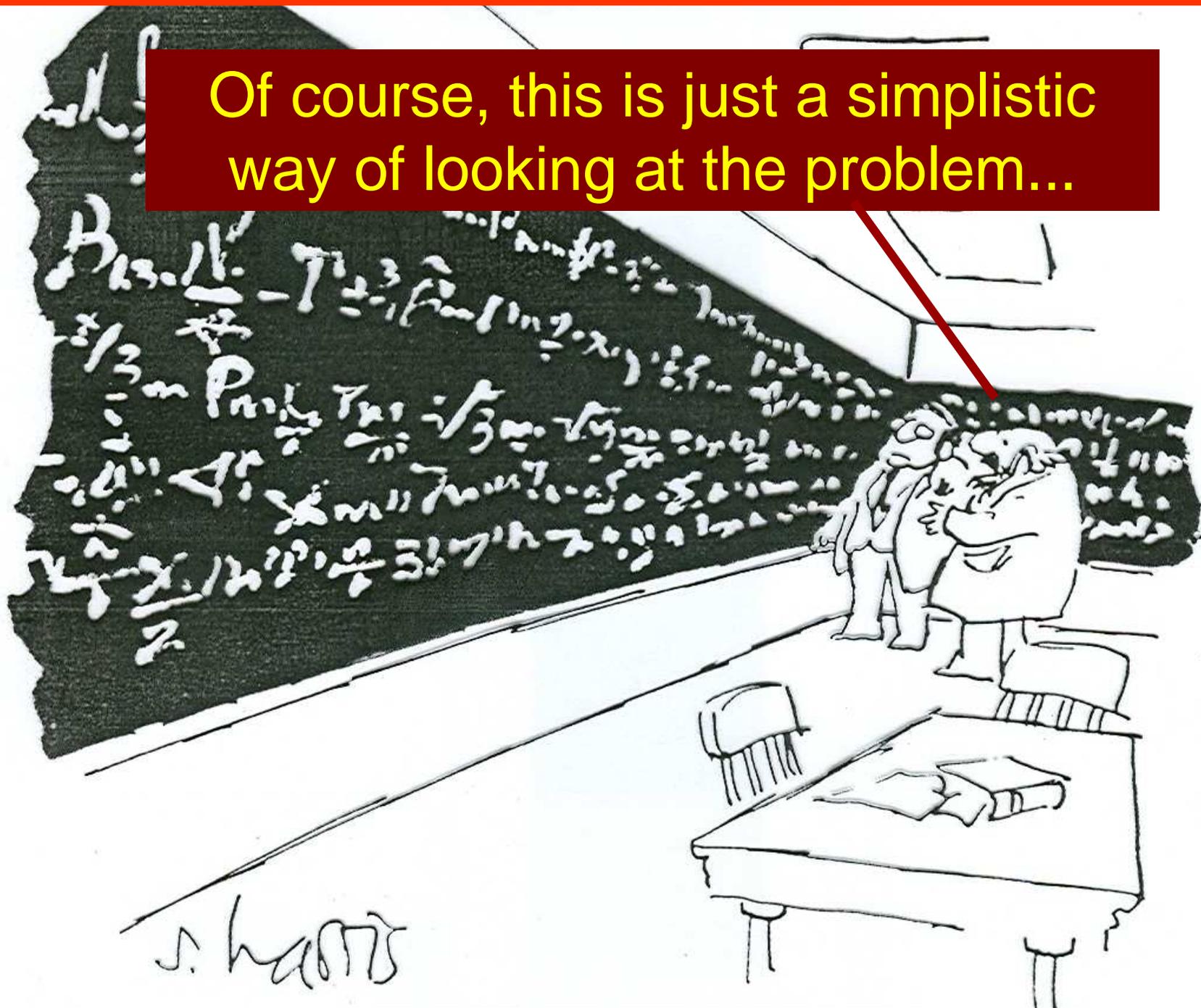
Warming is uneven over the globe



Is everything understood?

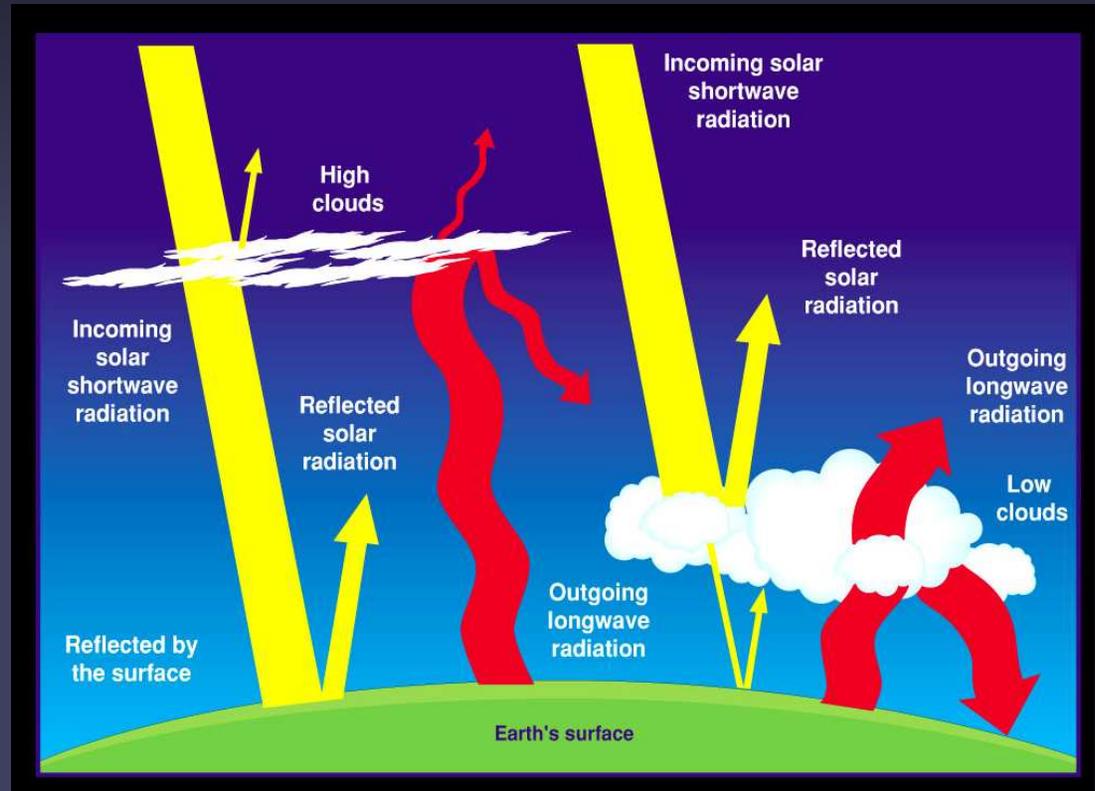


Of course, this is just a simplistic way of looking at the problem...



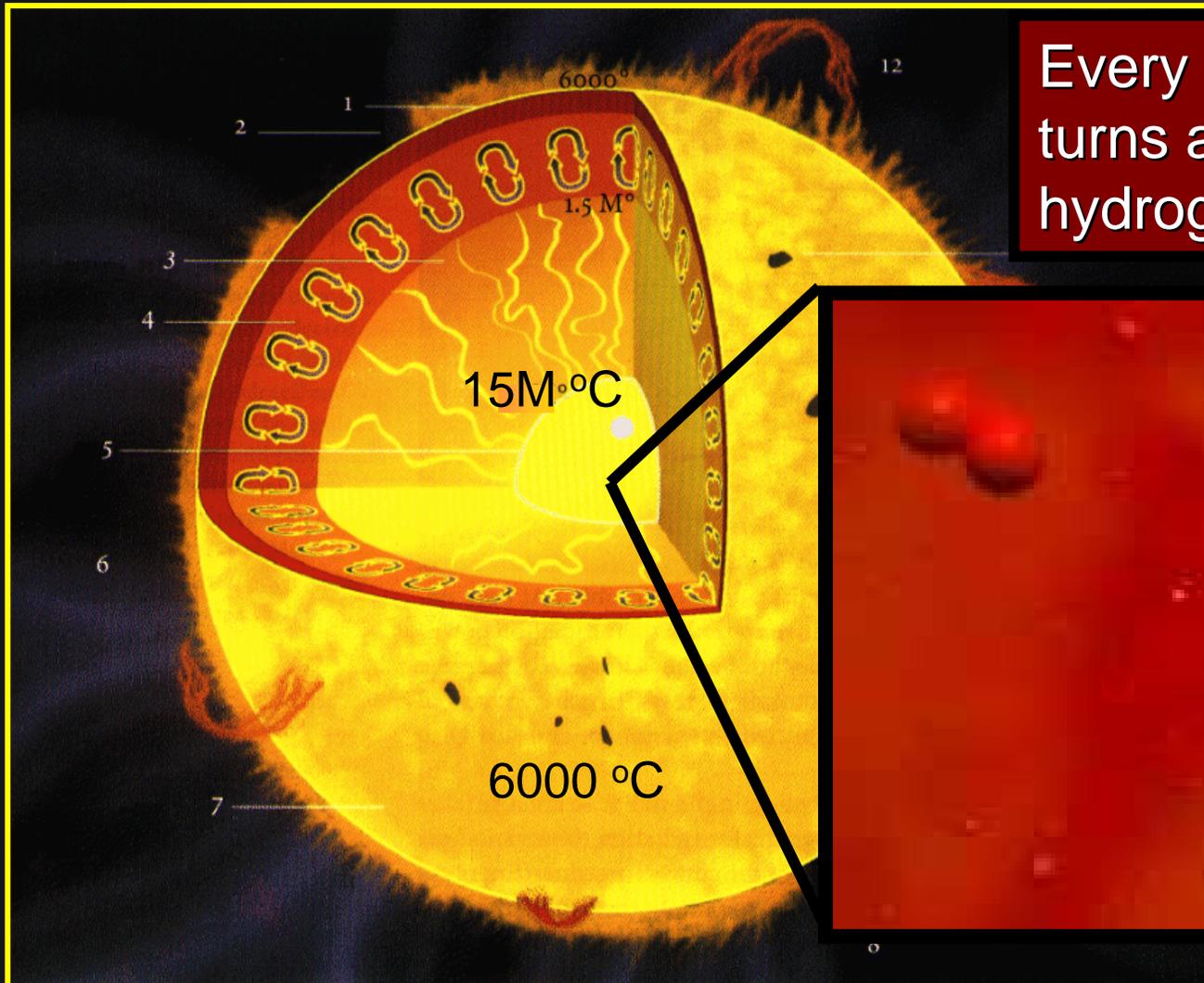
Could the Sun be to blame?

- The Sun delivers $1.36 \text{ kW} / \text{m}^2$. We get $\approx 1 \text{ kW} / \text{m}^2$ (at noon, if no clouds)
- In 20-30 min the Sun provides to Earth the yearly energy needs of Humanity



Without sunlight, no life (Our atmosphere would cool to below -200°C within weeks)

The Sun, a Star in the Prime of Life



Every second the Sun turns a billion tons of hydrogen into helium



The Sun in White Light

Recorded by
the MDI
instrument
on the
spacecraft
SOHO

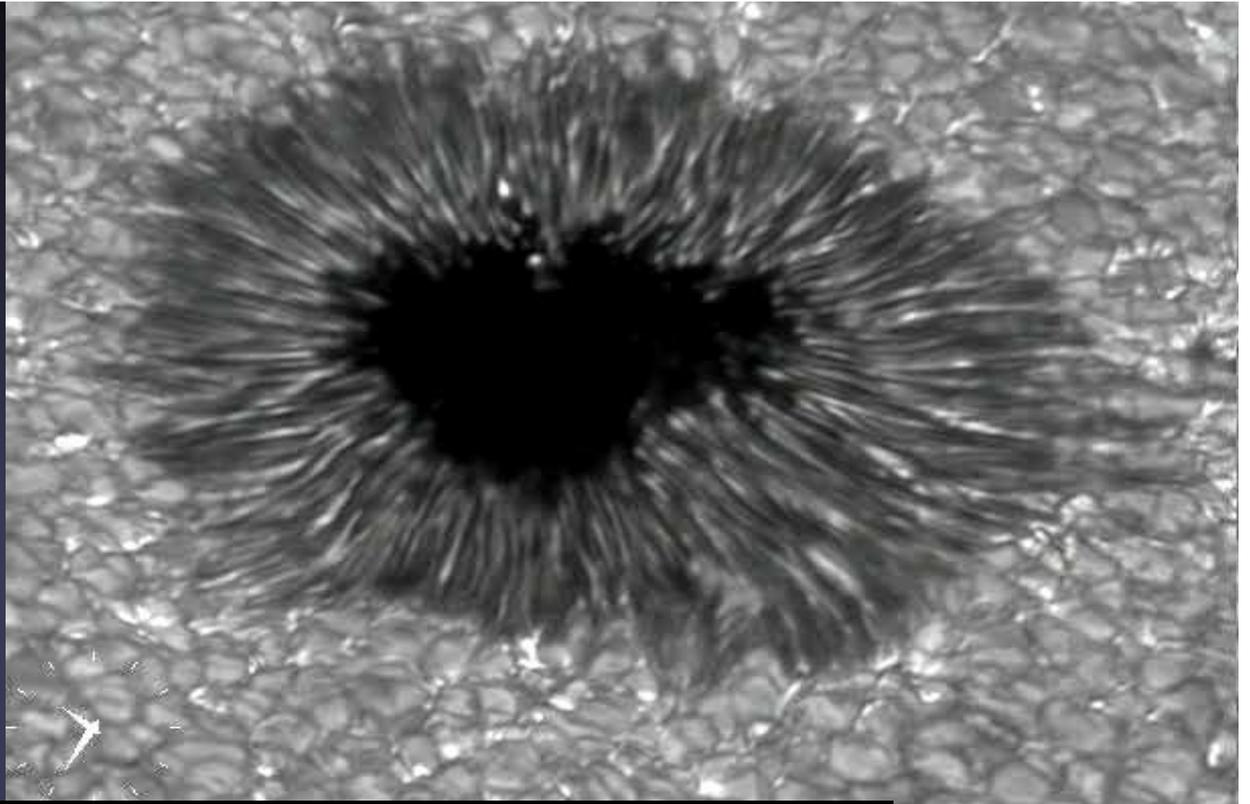


**Never look into the Sun with
unprotected eyes! Never ever
with a Telescope that doesn't
have a filter!**

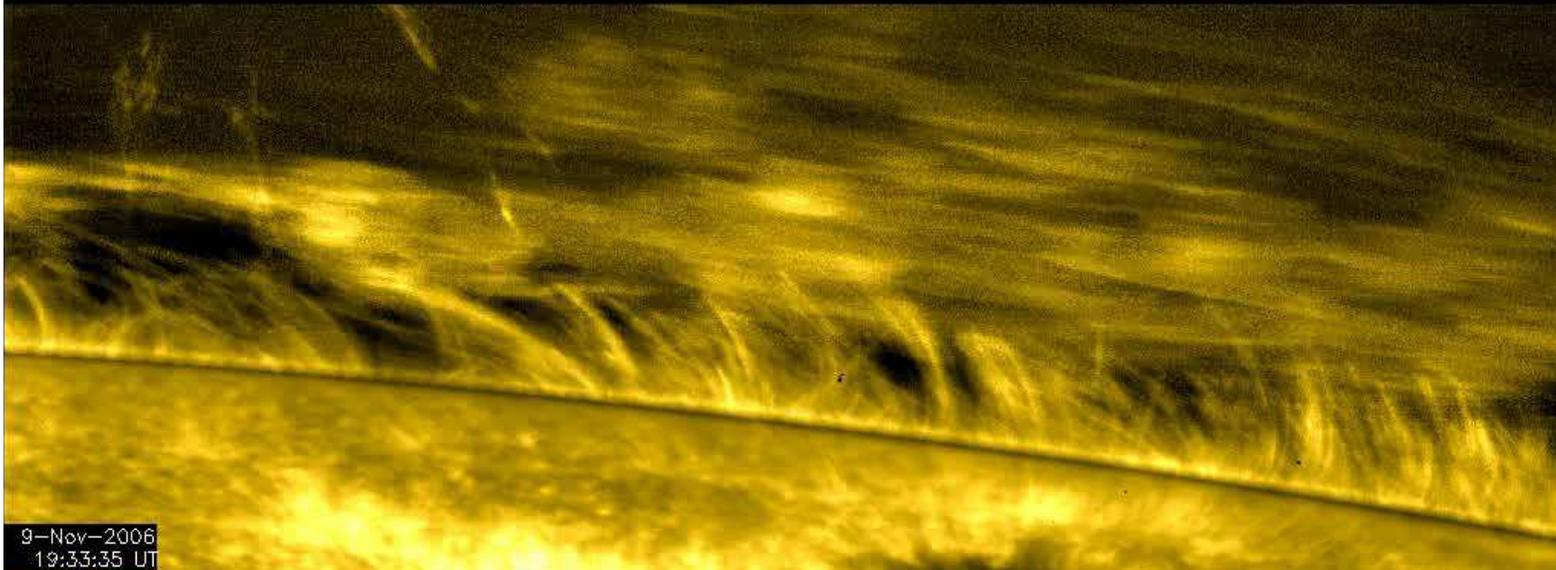
2003/10/07 14:24

The Dynamic Sun

Prominence



Sunspot



9-Nov-2006
19:33:35 UT

The Violent Sun

2002-Apr-21
00:43:09

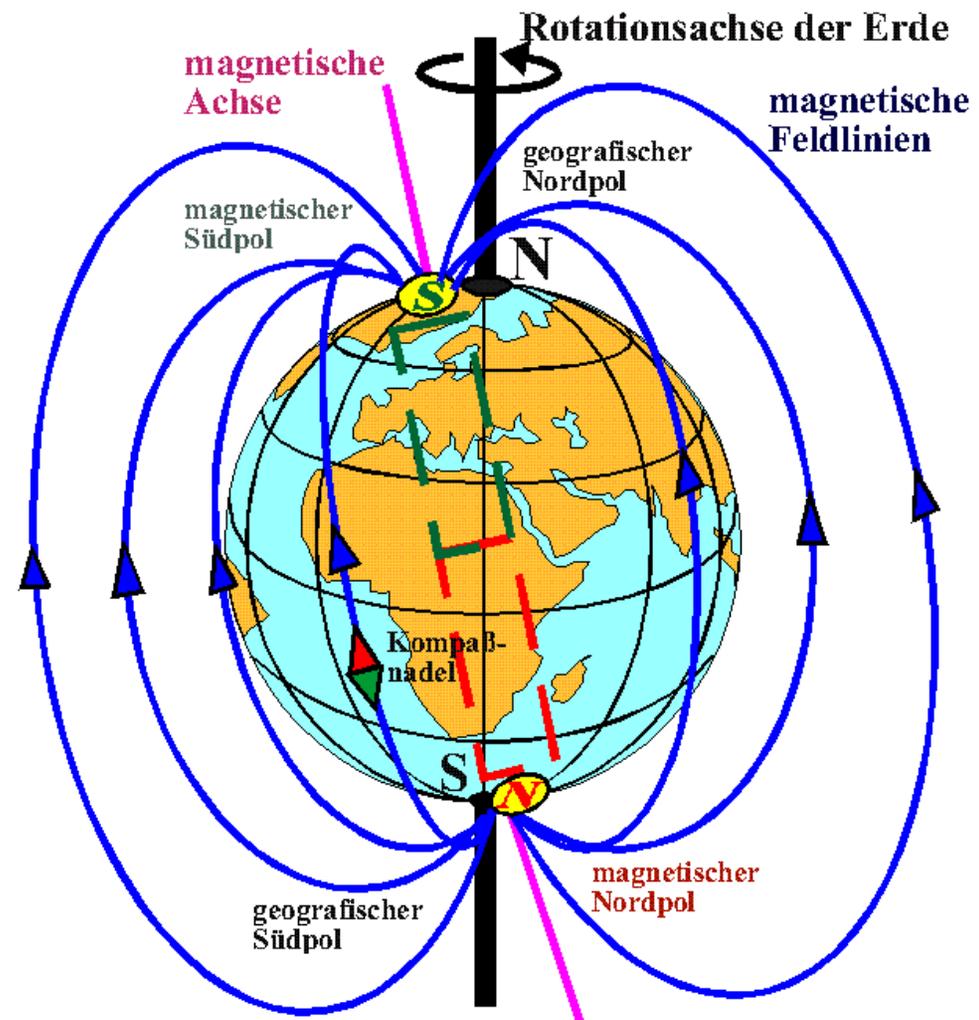
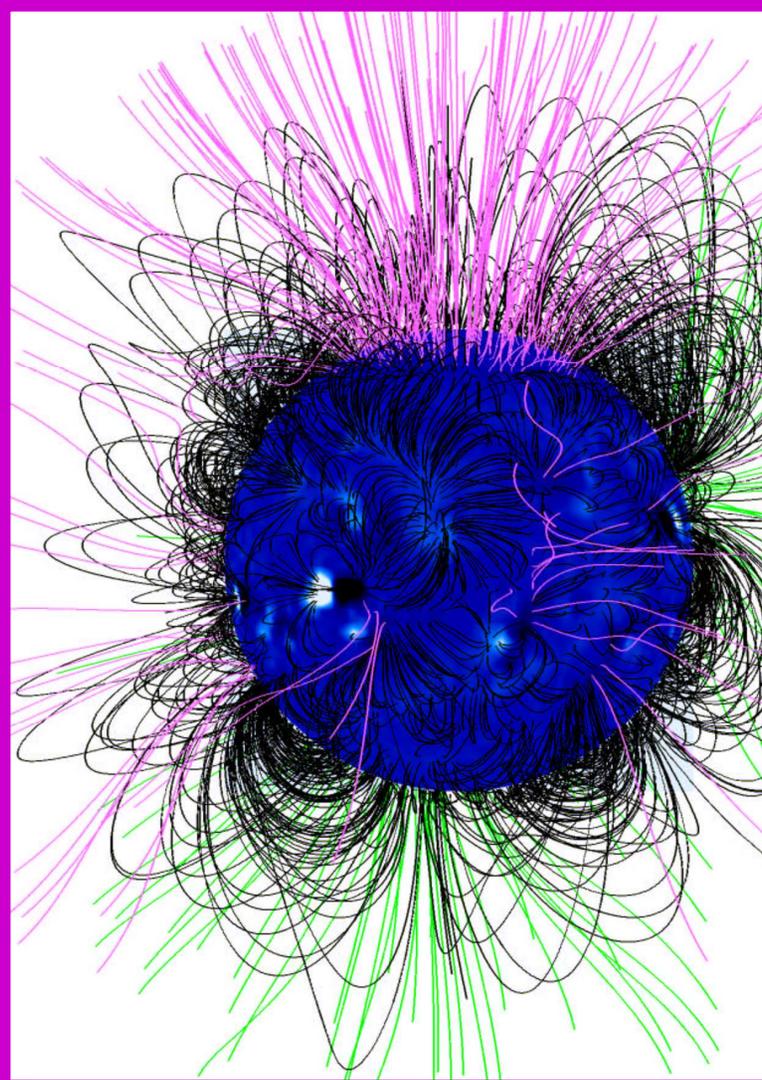
Flare

Solar wind
and coronal
mass ejections

2000/05/05 00:42



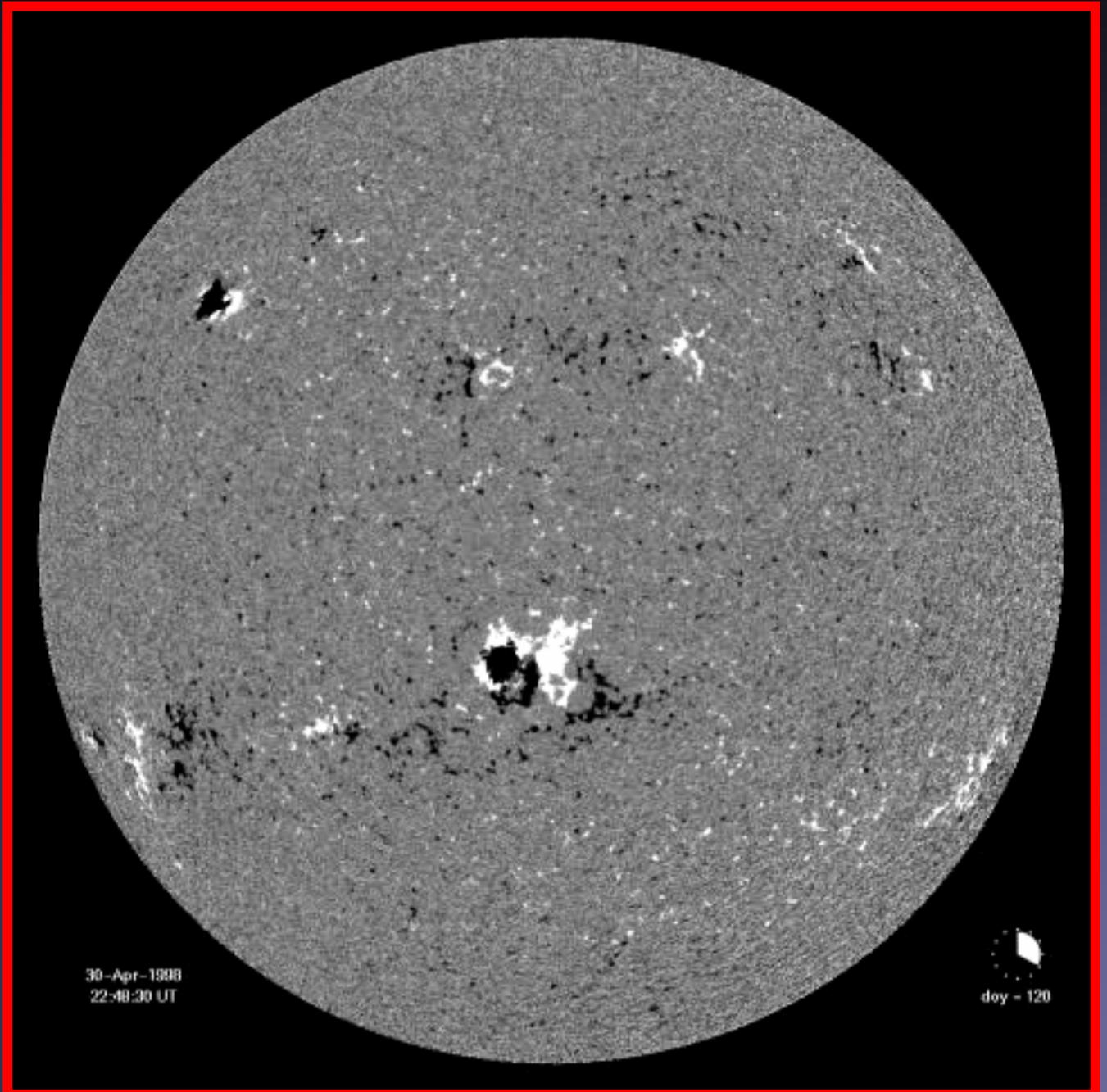
The dynamics and activity of the Sun are driven by its Magnetic Field



Evolution of the Sun's Magnetic Field

Sequence of
Magne-
grammes
over a Solar
rotation

MDI/SOHO

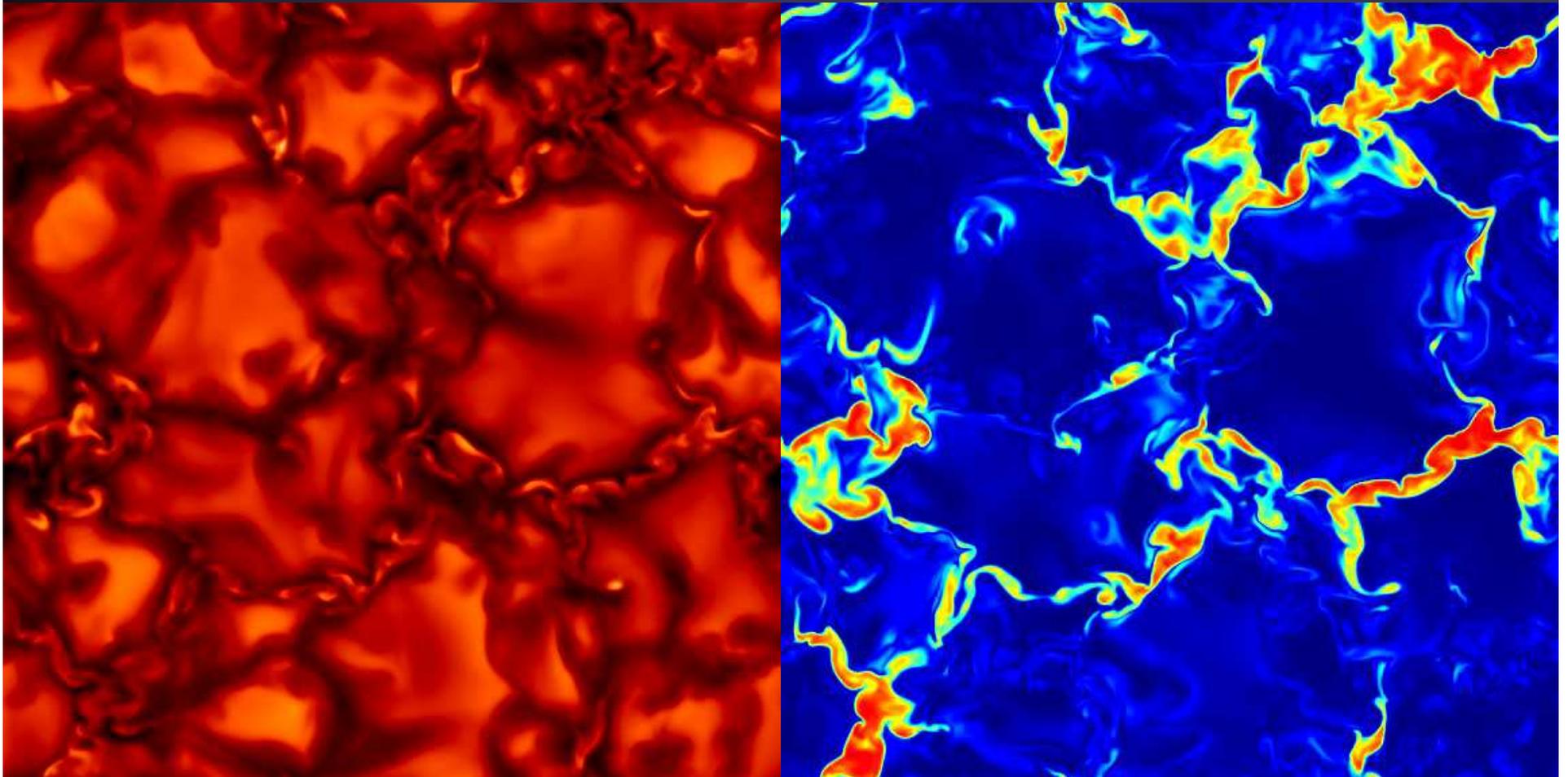


The Magnetic Field's Secret Dance

Simulations by *A. Vögler* (bringing the sunshine to computers)

Brightness

Magnetic field



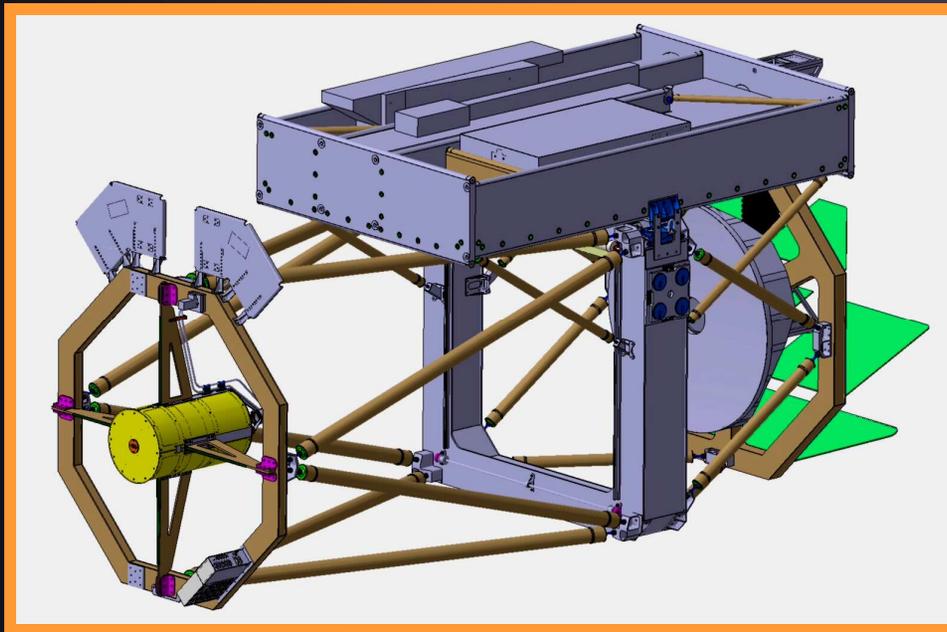


High Altitude Observatory



Sunrise

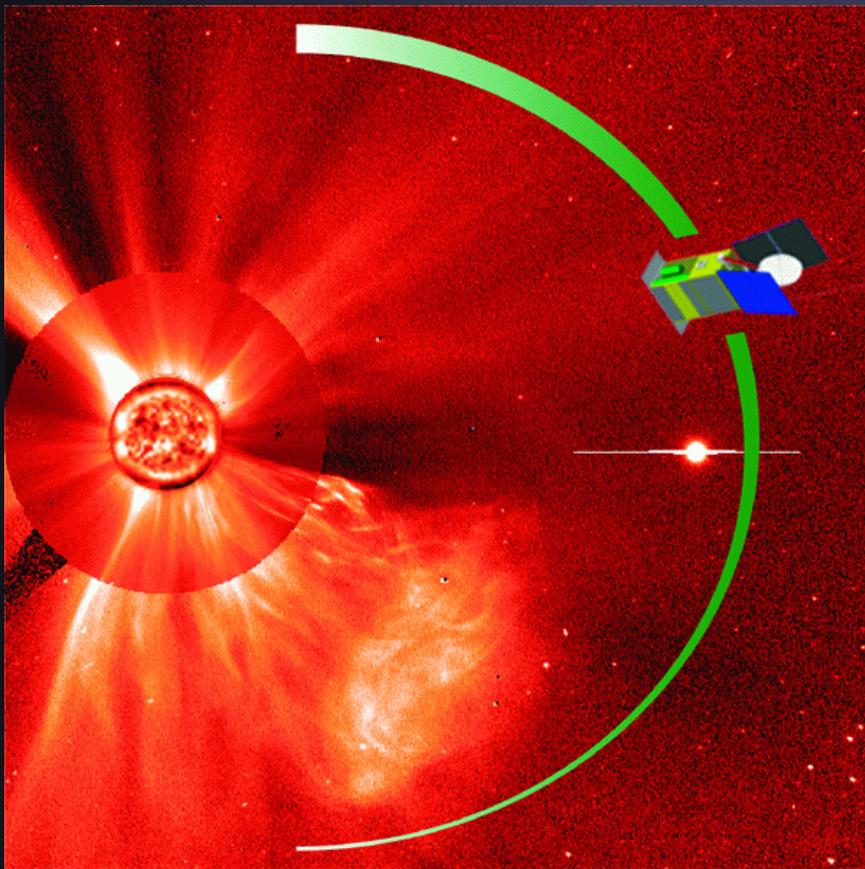
A mission aimed at resolving the structure and dynamics of the Sun's magnetic field



Balloon borne observatory with a 1-meter telescope aiming to observe magnetoconvection with a resolution of 35 km on the Sun. First science flight planned for 2009

Solar Orbiter

A high-resolution mission to the Sun and inner Heliosphere (launch 2015)



■ Solar Orbiter Firsts:

- Observe Sun from close up: 5x closer than Earth
- Provide the first images of the Sun's polar regions
- Co-rotate with Sun: disentangle spatial & temporal variation

■ Technical hurdles:

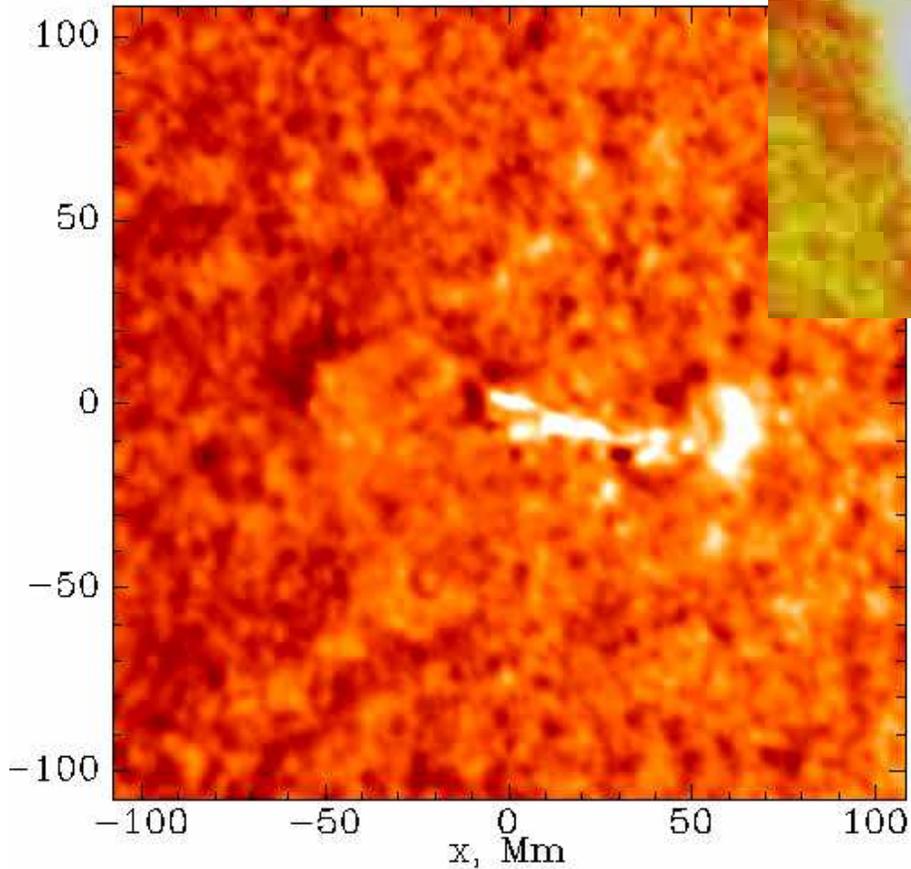
- Heat load (25 x higher)
- High flux of solar energetic particles

**The
Sun's
magnetic
field:
more
than just
skin
deep**



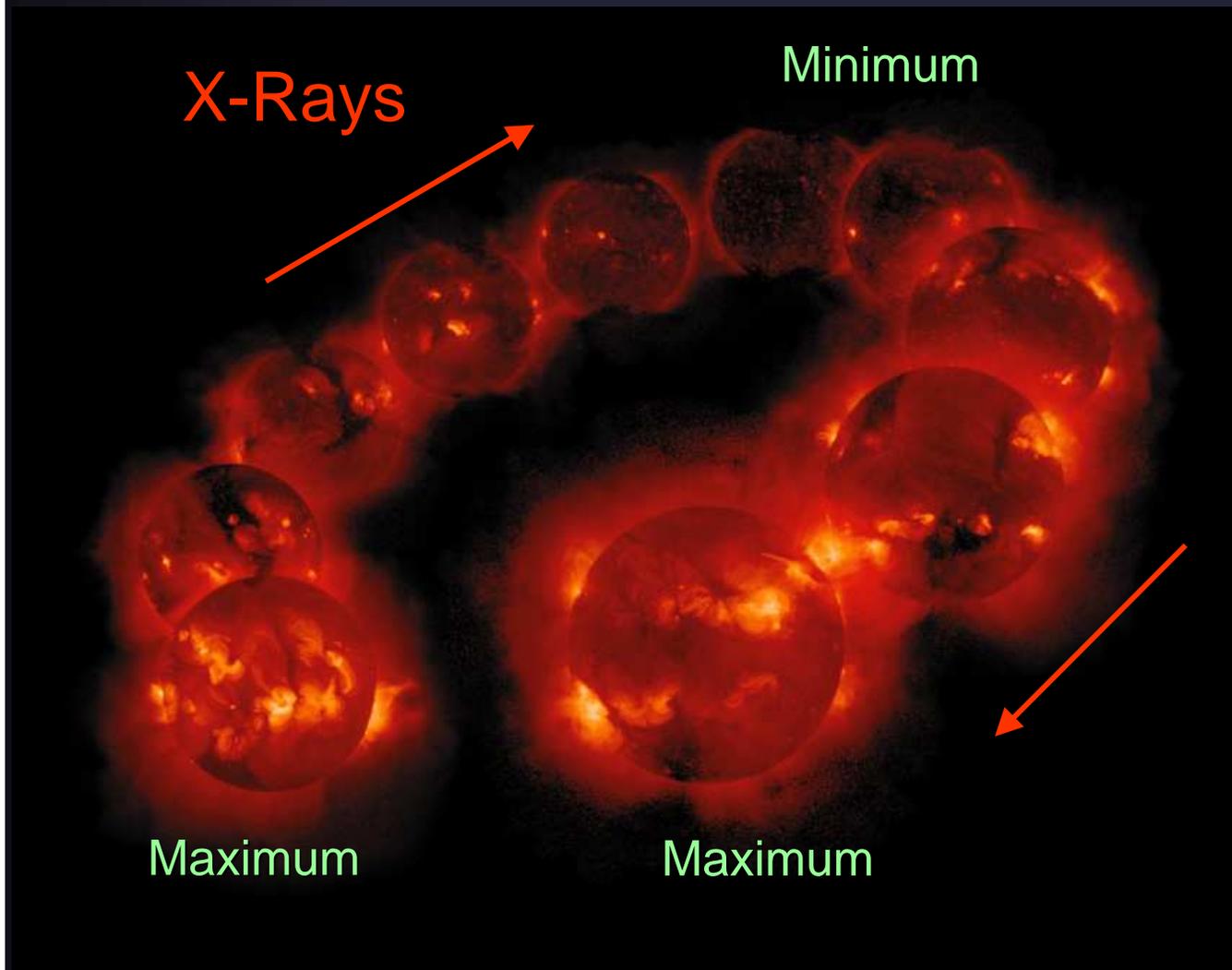
The magnetic field is formed in the Sun's interior by a dynamo process & emerges to the surface in the form of loop-like structures.

The magnetic field: more than just skin deep



The magnetic field is formed in the Sun's interior. Oscillations (Sun-quakes) allow us to glimpse inside (Helio-seismology)

Activity Cycle of the Sun

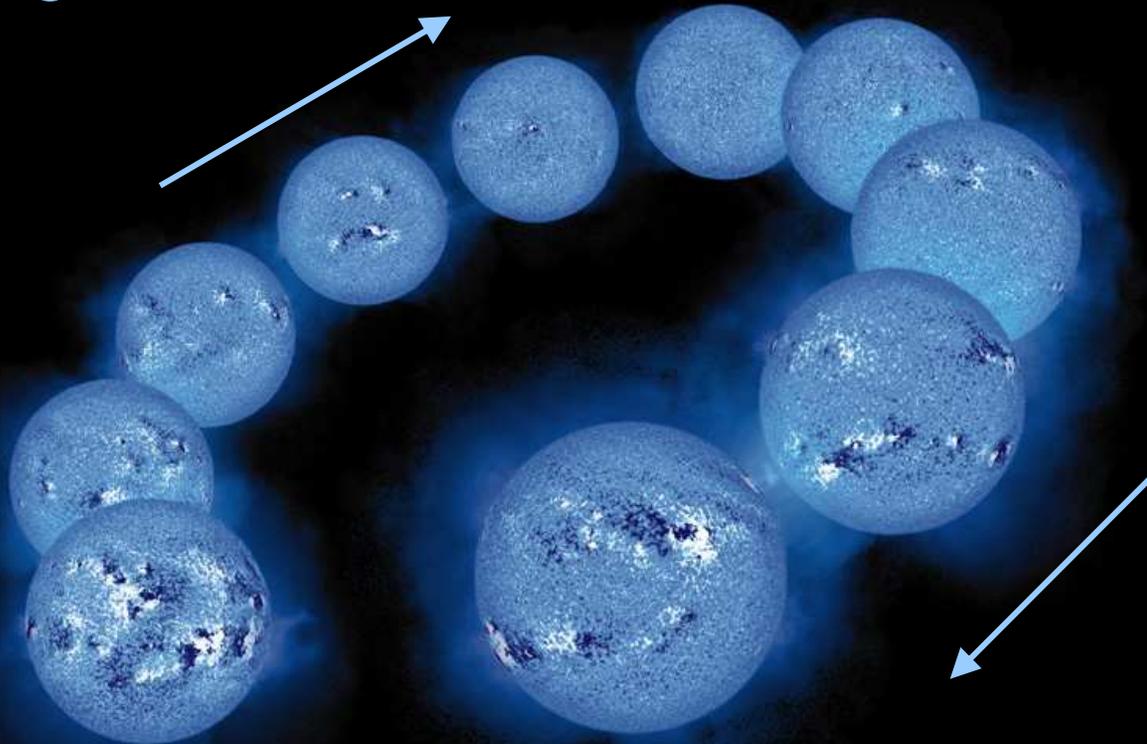


Energetic radiation from the Sun varies by a large amount over the solar cycle: by a factor of 2 in the EUV, by a factor of 100 in X-rays.

Activity Cycle of the Sun

Magnetic Flux

Minimum



Maximum

Maximum

The magnetic flux of the Sun also varies over the 11-year solar cycle.

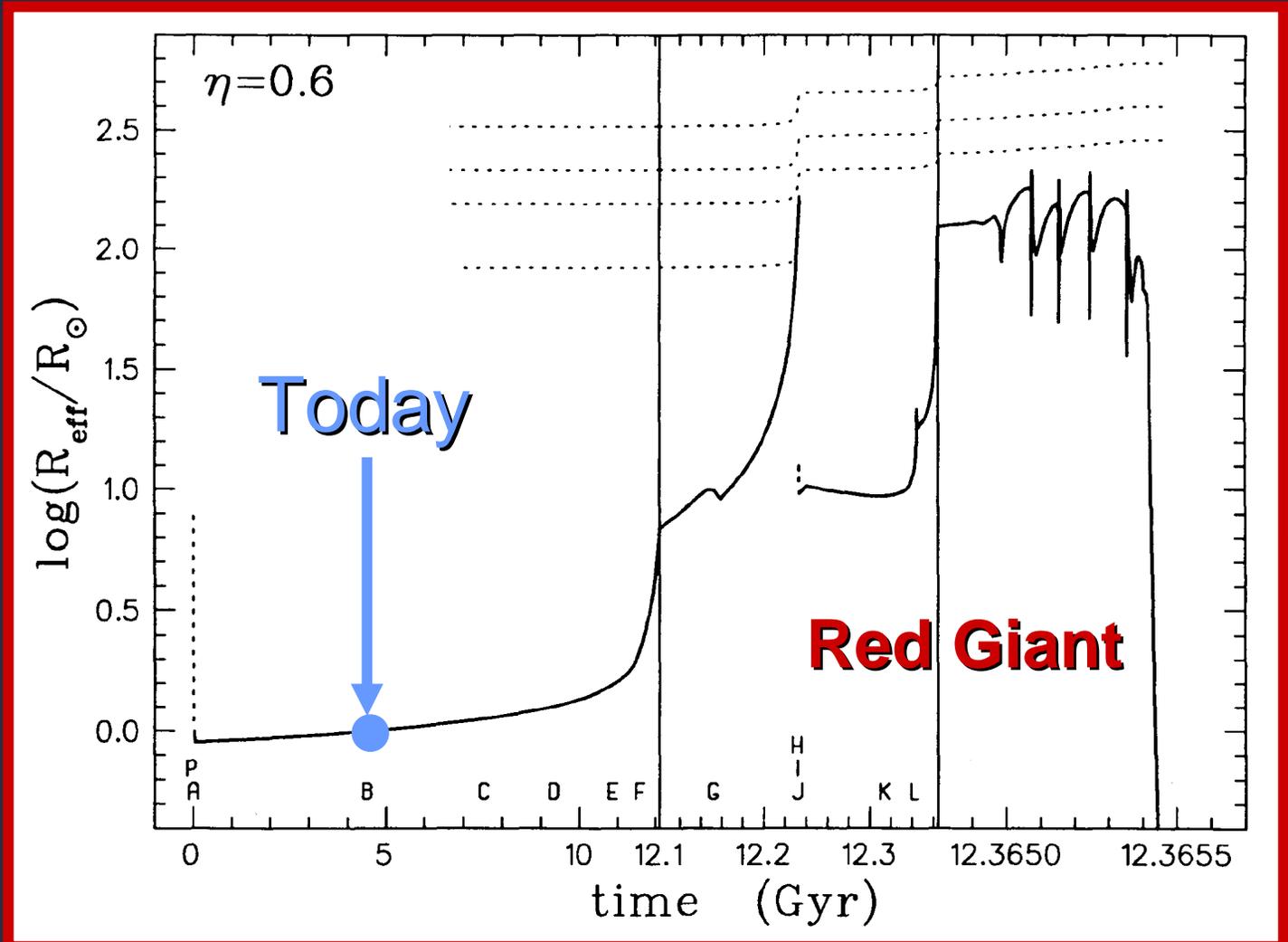
At the same time the number of sunspots and other indicators of solar activity also fluctuate.

Does the Sun Influence Our Atmosphere?

- **Yes**, but details depend on the **time scale**
 - **Millions to billions of years**: Sun evolves and changes the Earth in fundamental ways
 - **Minutes to days**: solar storms (flares and CMEs) produce storms in Earth's magnetosphere and upper atmosphere (space weather)
 - **Years to centuries**: Could changes in solar brightness (irradiance) influence global climate?

Will the Sun Swallow the Earth?

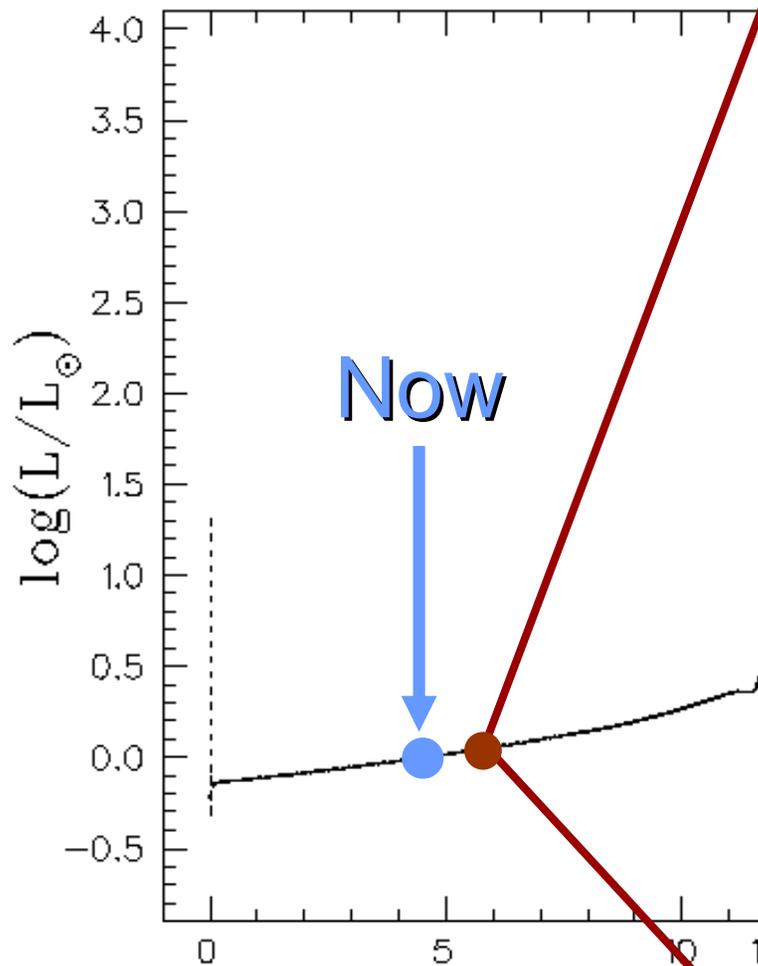
The Sun will become brighter & bigger & will start to swallow its children, finally reaching today's Earth orbit





Will the Earth really get away unharmed?

Evolution of Sun's Brightness



Sackmann et al. 1997



The Sun as the Driver of Space Weather



Damage to technical systems, etc. produced by the Sun could well run into billions of \$ per year



Sun's Influence on a Time Scale of Years ...

Scientist's shocking prediction:

Sun will burn out in 2 years!

... and we'll be turned into human ice cubes!

By THOMAS GREENE

Scientists used to say that our sun would provide heat and light for billions of years but new evidence indicates that old Sol is running out of

Looking for love?

It's easy to make someone fall in love with you — just look into their eyes!

That's the word from Clark University professor James Laird, who found in a study that people who make eye contact literally begin to fall in love.

"Mutual eye-to-eye contact did indeed increase feelings of attraction and excitement," the expert from Massachusetts said.

fuel — and will be stone cold within two years!

"I don't want to sound like an alarmist, but the sad fact is, we're dead," said

"When the sun does burn out everything on our planet will die. Earth will be nothing more than a dirty chunk of ice floating in the darkness of space."

Dr. Rieder's theory is based on a complex computer model

that estimates the rate at which the sun is consuming fuel and predicts when the last of it will be spent.

In the past such models indicated that the sun would burn for billions of years. But Dr. Rieder's model used several new mathematical formulas

Wacky book marks

Everything from bacon rind to money has been used as book markers in books returned to the public library in Gwynedd, Wales. Readers also marked their pages with banana skins and an old sock.

and factors that indicate it will burn out in dramatically less time — no later than December 1992.

Not all experts agree with Dr. Rieder. Dr. Franz Ehlen, the German astronomer, actually called the expert's predictions "insane."

Dr. Rieder countered: "I'm staking my reputation and career on these statements and am confident that what I am saying is true.

"If the world is going to end in 1992 — and it is — then all mankind should be warned. Some people might want to eat, drink and be merry. Others may want to get right with God."



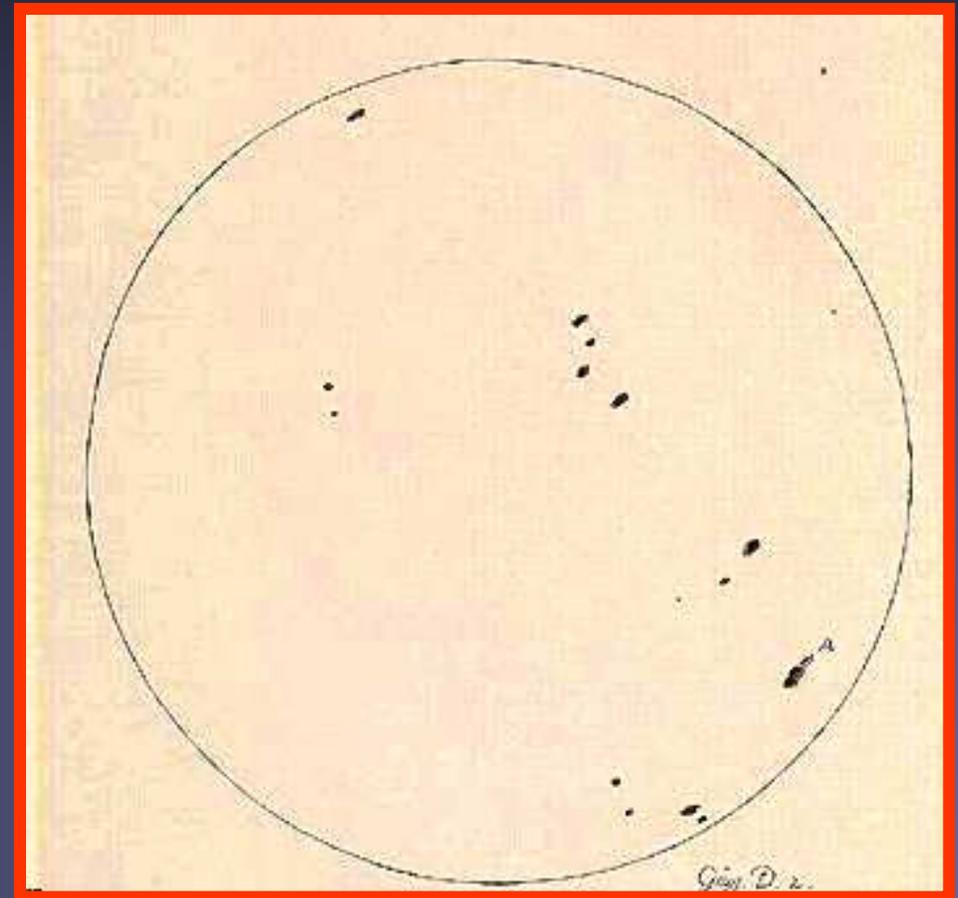
Beaned on c

Pretty teen Tyler met a gruesome death when she stuck her head out the window of a moving school bus and hit it on a telephone pole. The 13-year-old Yonkers seventh-grader died after the accident of head trauma.

National Enquirer 2006

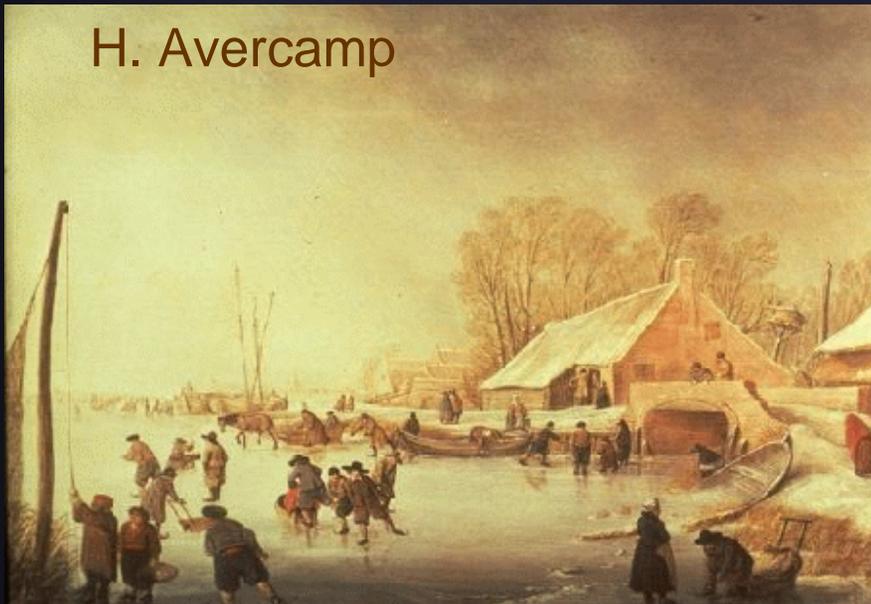
Sunspots: an an early scientific movie

- Galileo Galilei und Christoph Scheiner (aus Ingolstadt) beobachteten Sonnenflecken schon im Jahre 1610 mit dem damals neu erfundenen Teleskop.
- Ein Auslöser der grössten Umwälzung in der Geschichte der Naturwissenschaften: weg vom platonischen Ideal, hin zur Beobachtung und zum Experiment.



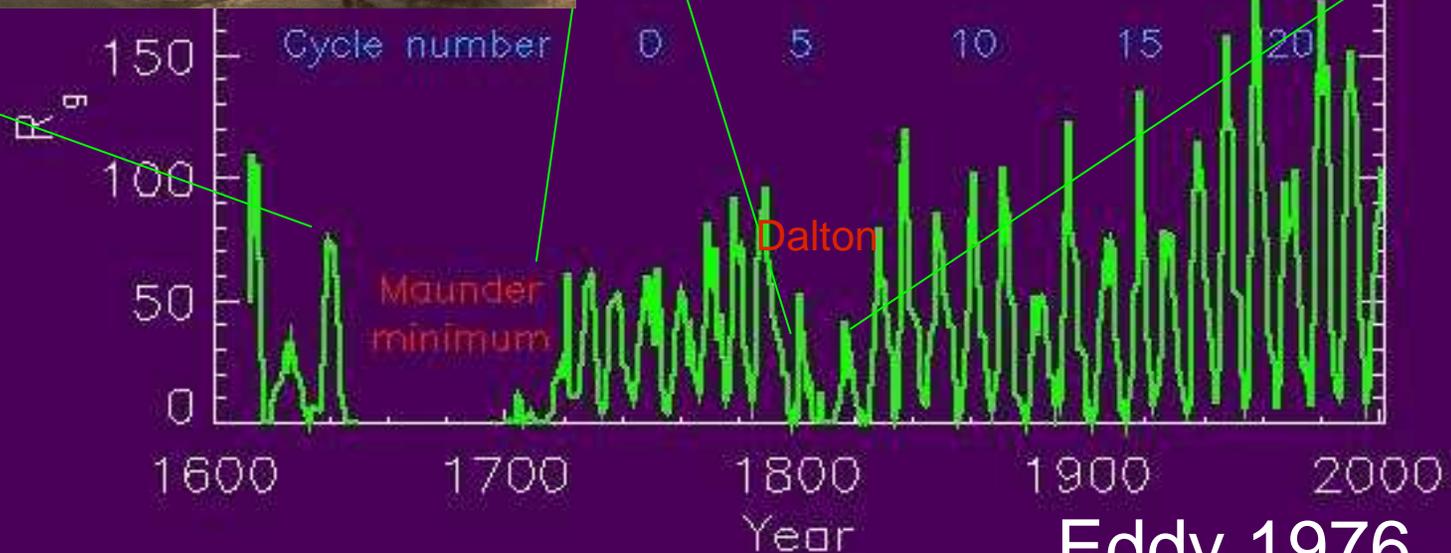
Galileos Aufzeichnungen

Maunder Minimum & Little Ice Age



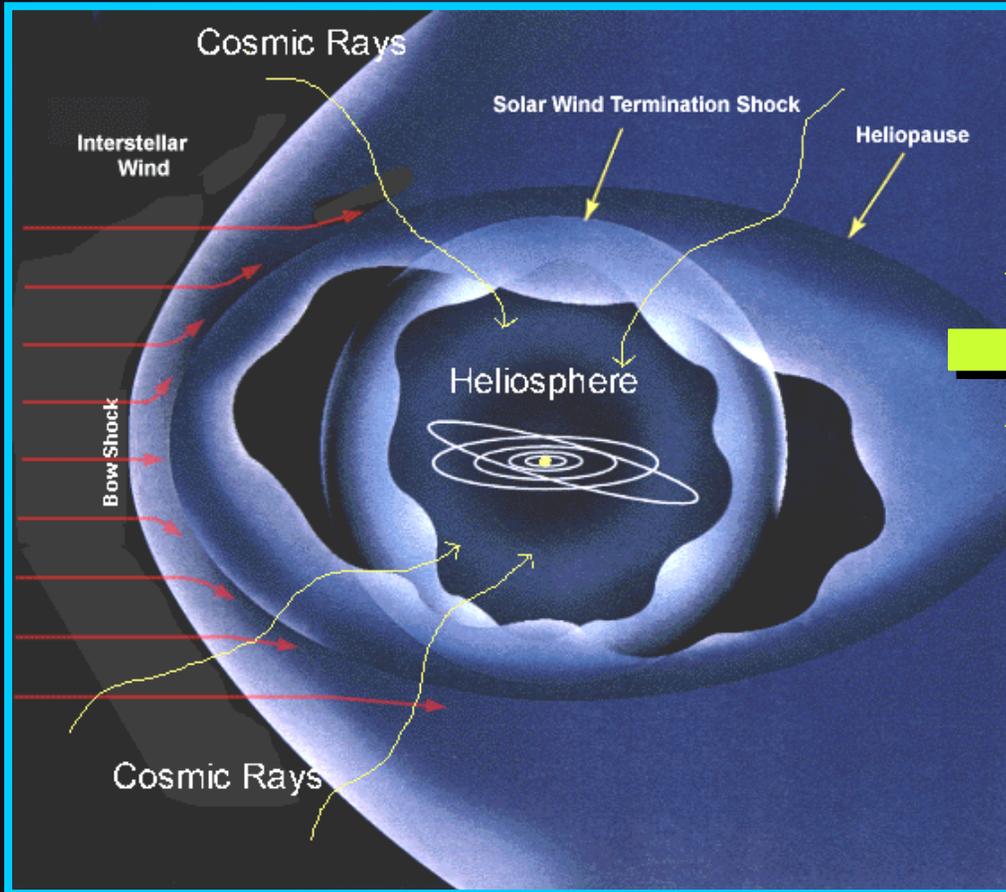
The Maunder Minimum coincided with coldest part of the Little Ice Age:
Is there a connection?

Coldest decade in England since the Little Ice Age; 1813/1814 – last Christmas Fair on the Thames

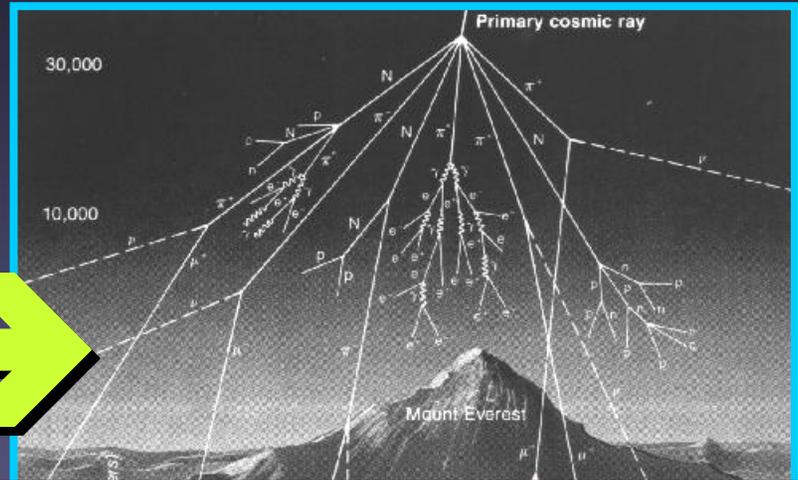


Eddy 1976

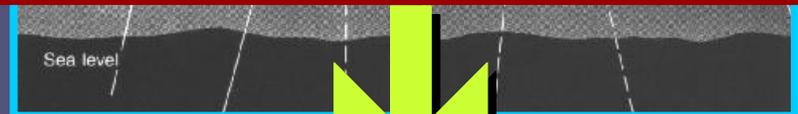
Cosmic Rays, the Sun & Tree Rings



Flux of cosmic rays is changed by solar activity



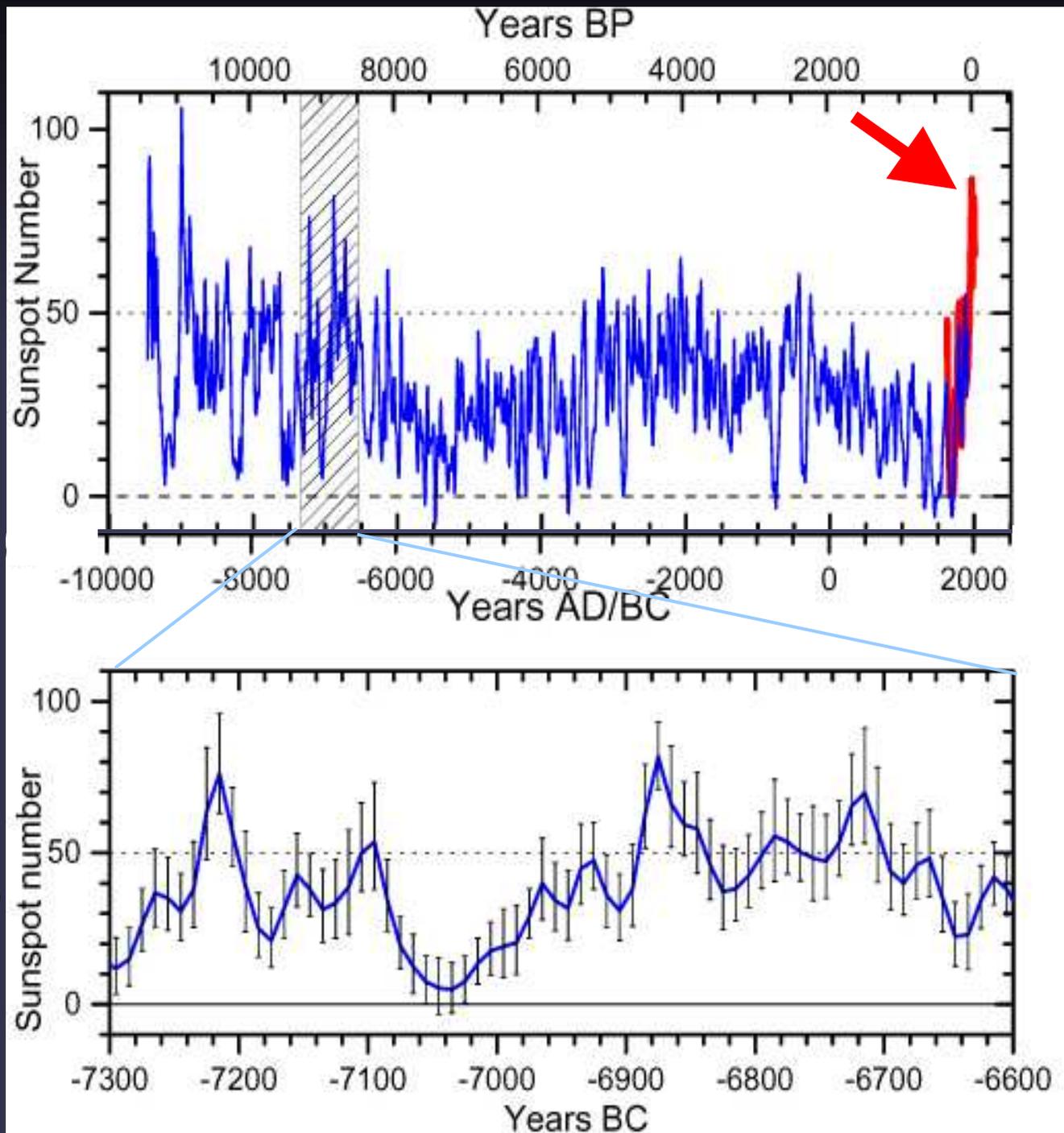
Production of isotopes, such as ^{14}C (used for radiocarbon dating)



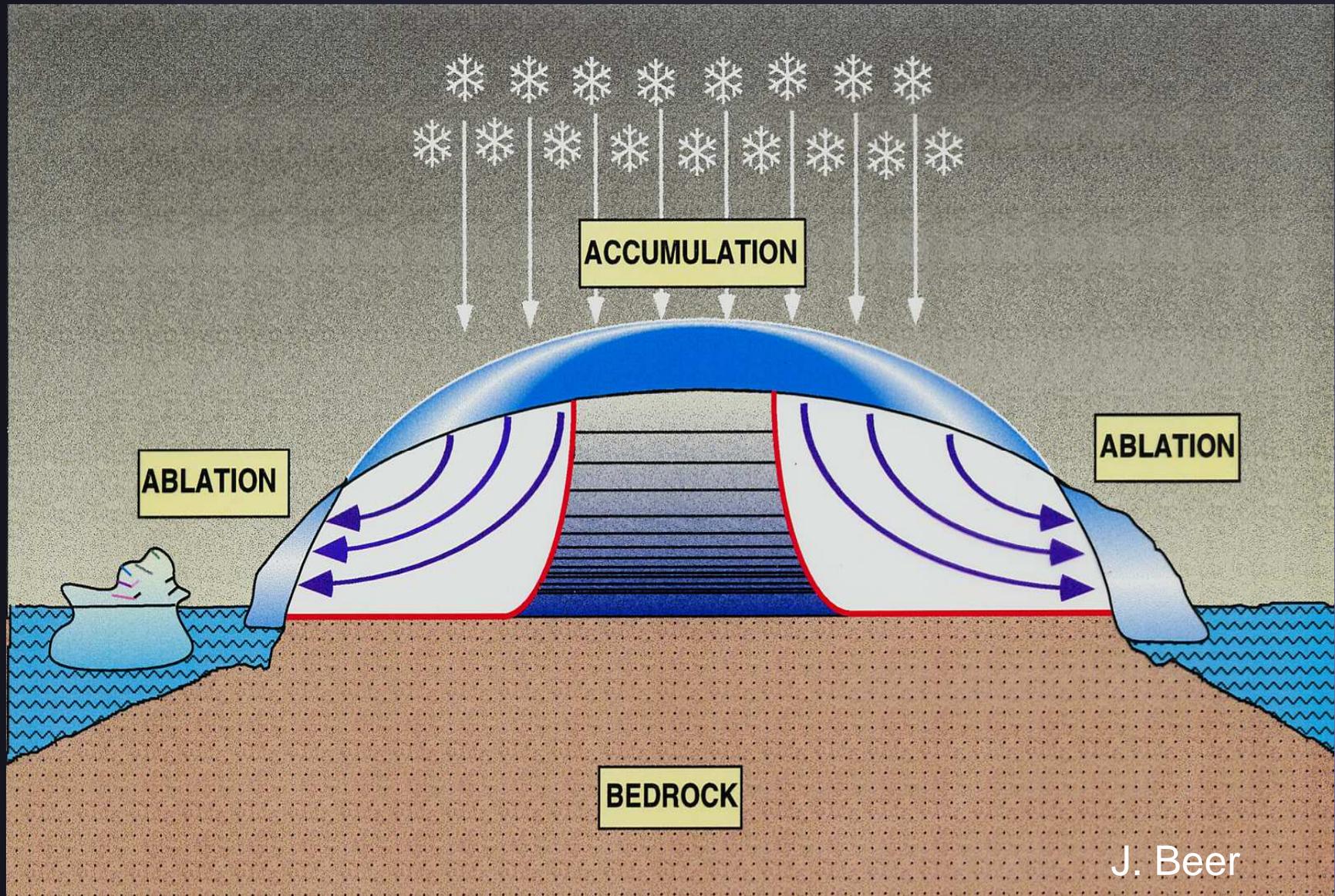
How did the Sun Behave since last Ice Age?

Number of Sunspots over last 11400 years reconstructed from ^{14}C in tree rings → Sun is very active **today** compared to last **11000 years**

Solanki et al. 2004
Nature



The Life Story of Greenland Ice



J. Beer

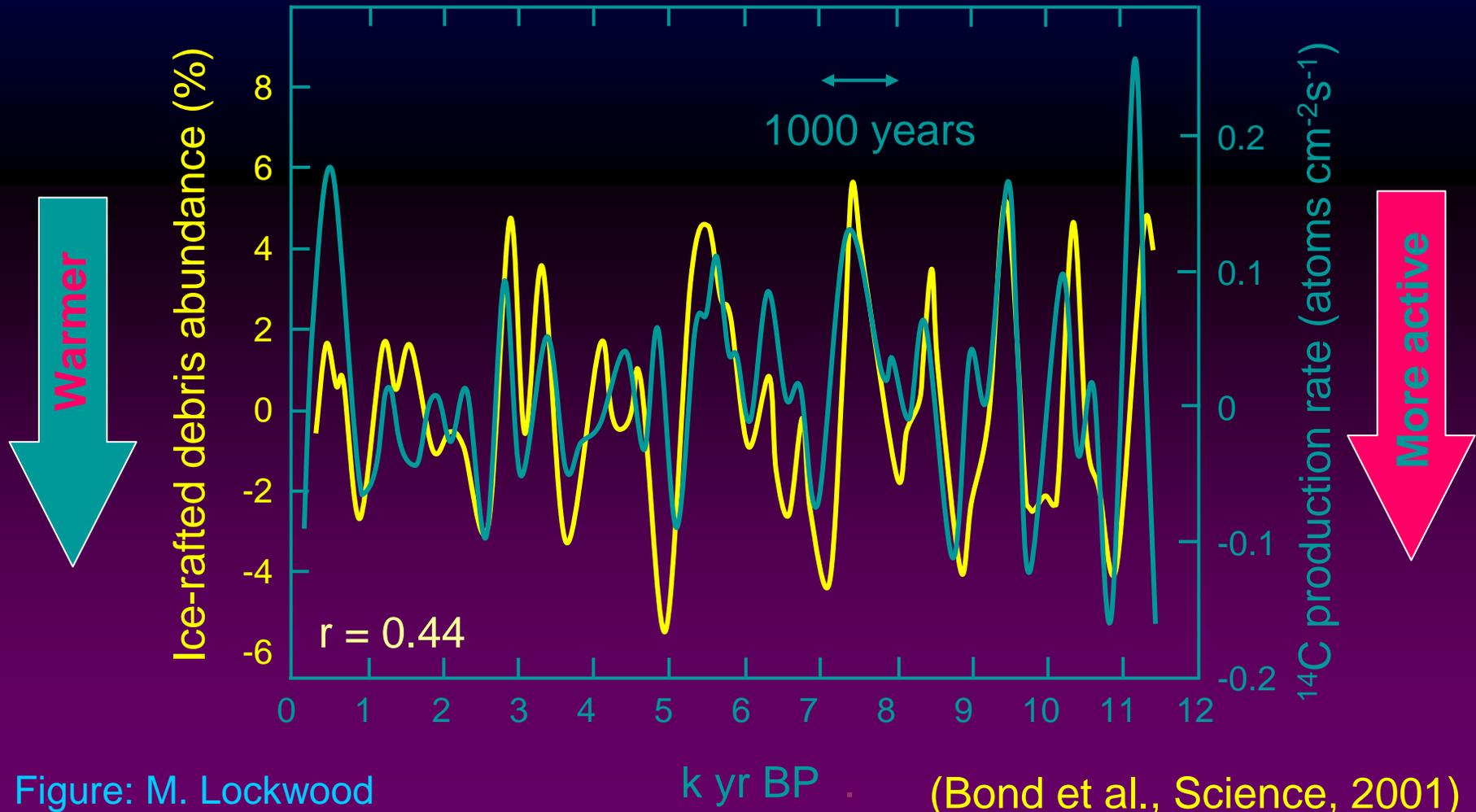
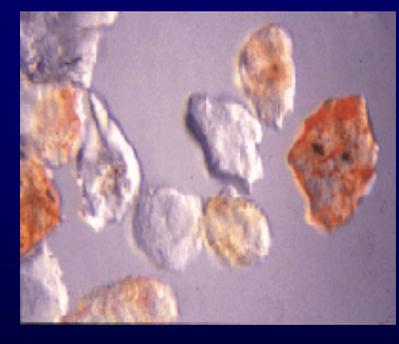
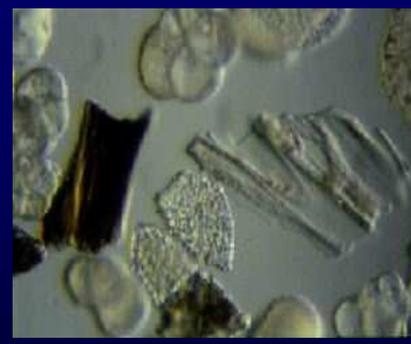
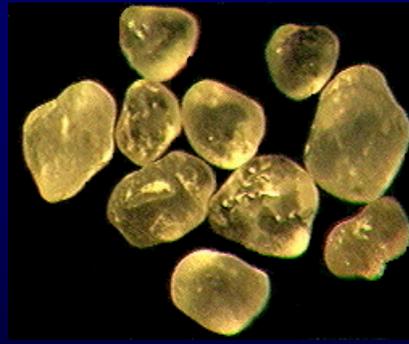
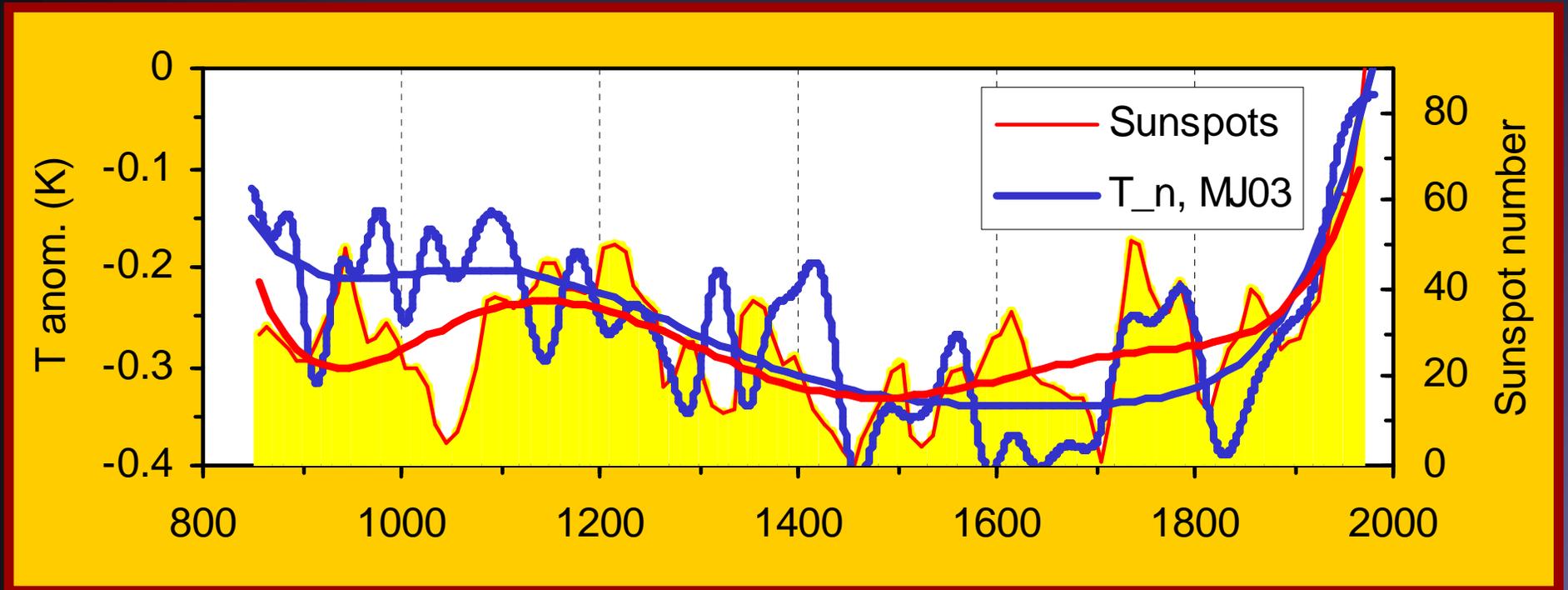


Figure: M. Lockwood

k yr BP

(Bond et al., Science, 2001)

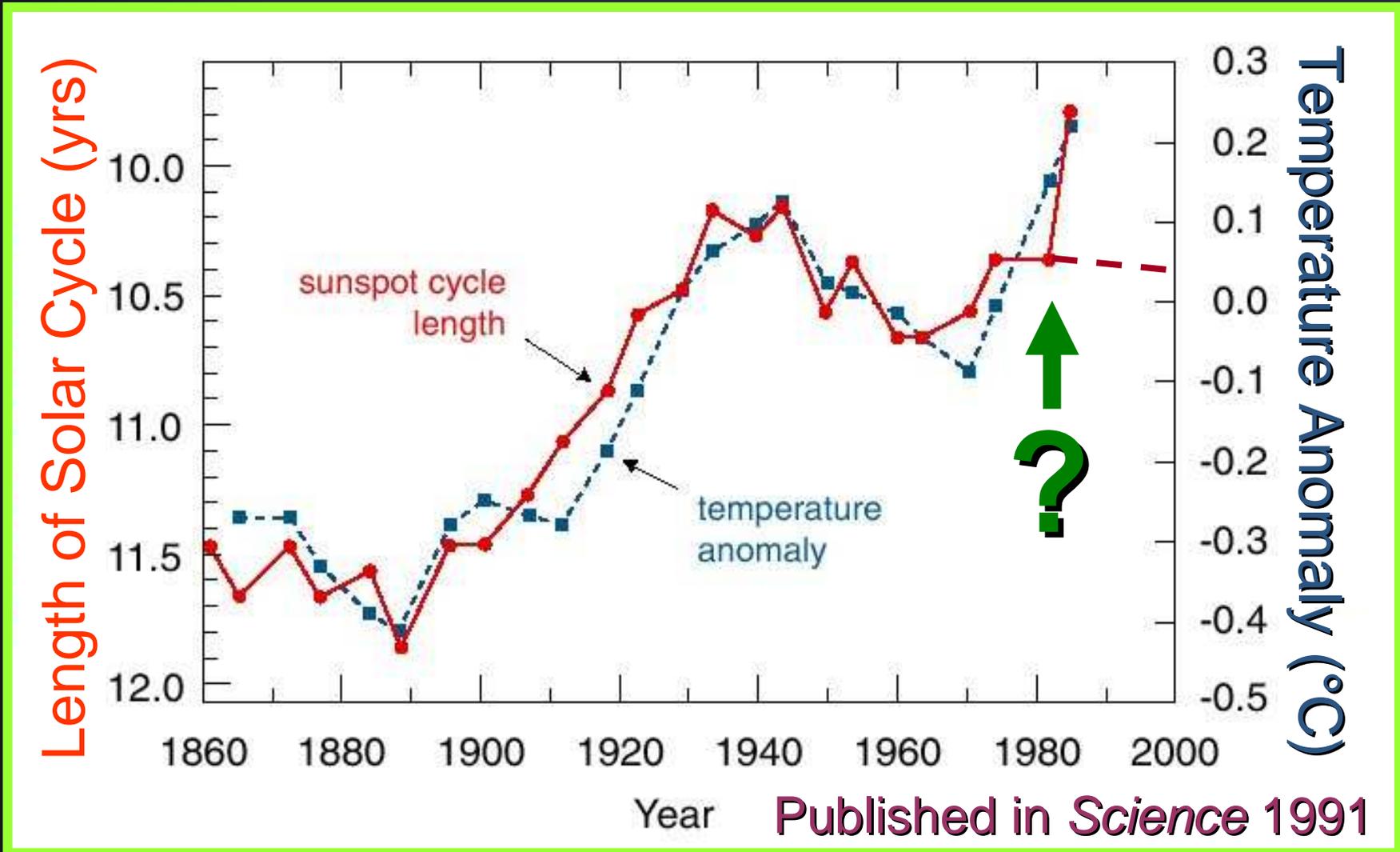
Comparison Between Sunspot Number and Climate



Climate data (hockey stick curve) from Mann & Jones 2003
Period after 1970 has been removed

Usoskin et al. 2003 Phys. Rev. Lett., 2005 JGR

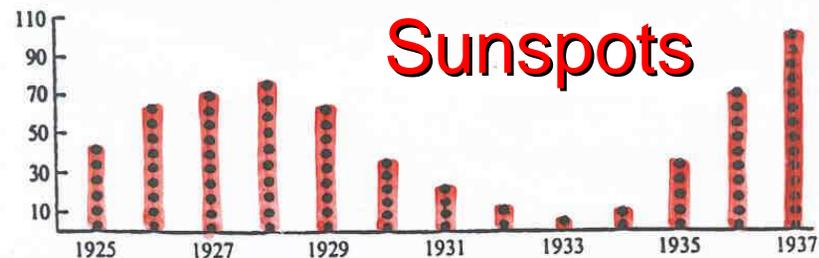
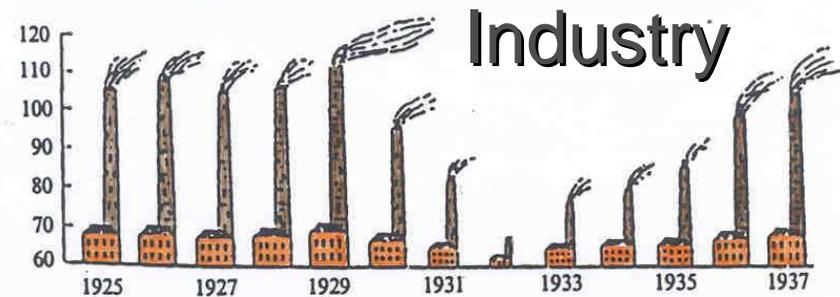
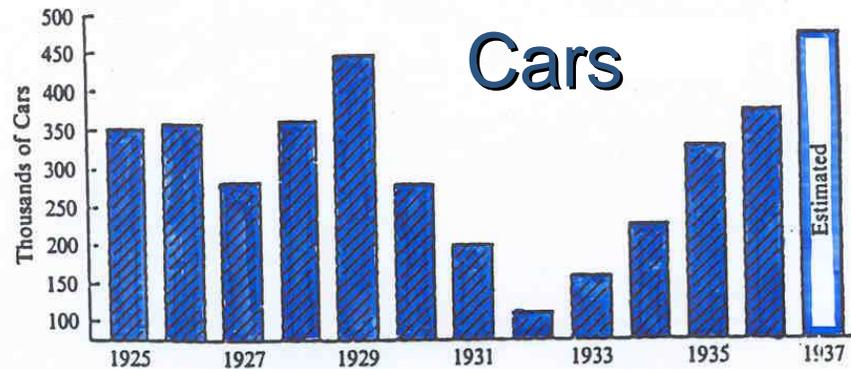
Solar Cycle Length & Global Temperature



Chance correlations between solar and climate parameters?

A further example of correlations:

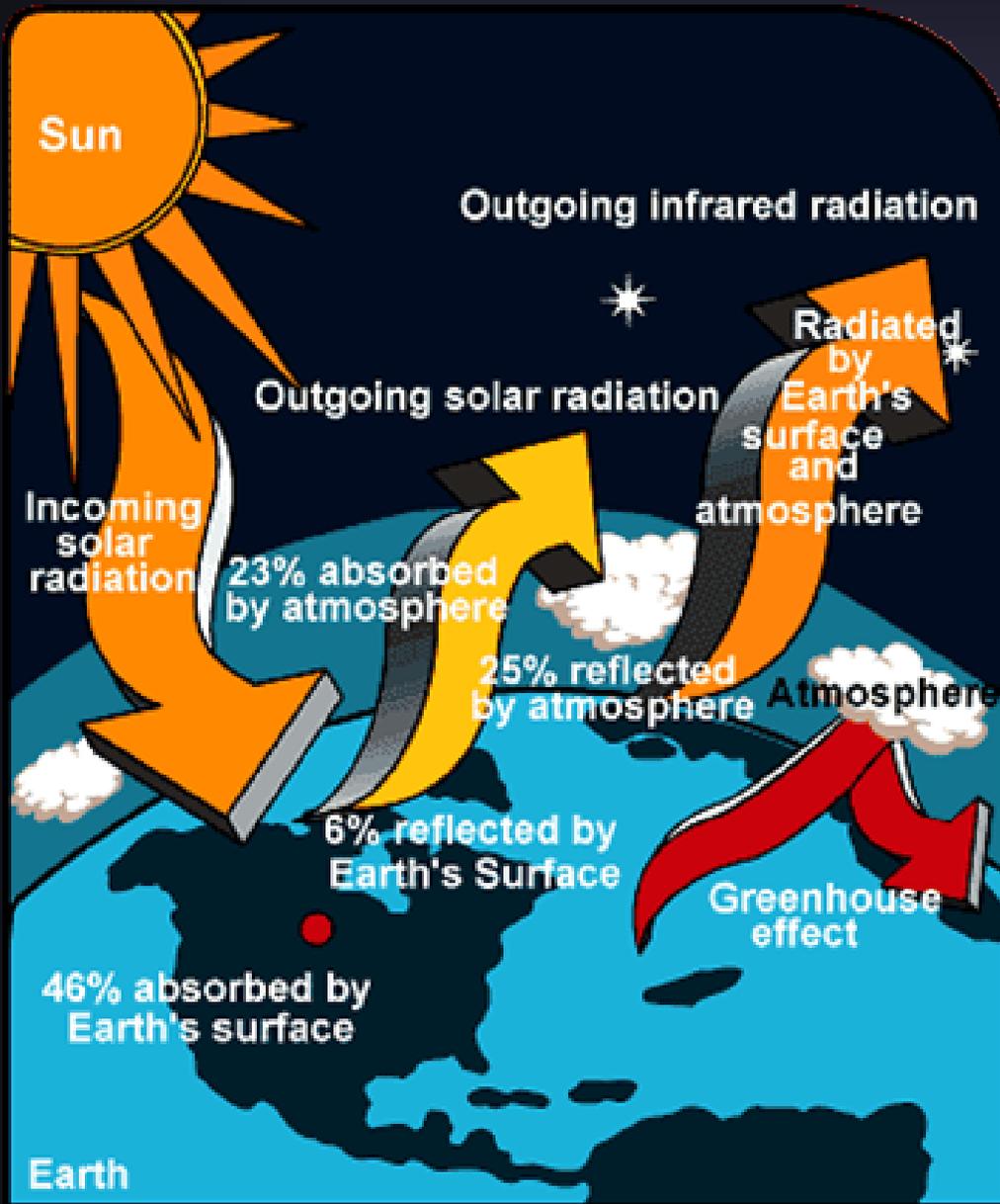
(from the archive of the Swiss National Bank)



Paths by Which Sun may Affect Climate

- **Variations of total irradiance:** change in total energy input to Earth's atmosphere
- **Variations of UV irradiance:** influence on atmospheric chemistry (e.g. stratospheric ozone production and depletion)
- **Modulation of cosmic rays:** has been proposed to affect cloud cover

Sun-Climate: Possible Mechanisms



**Total
Solar
Irradiance
Variations**



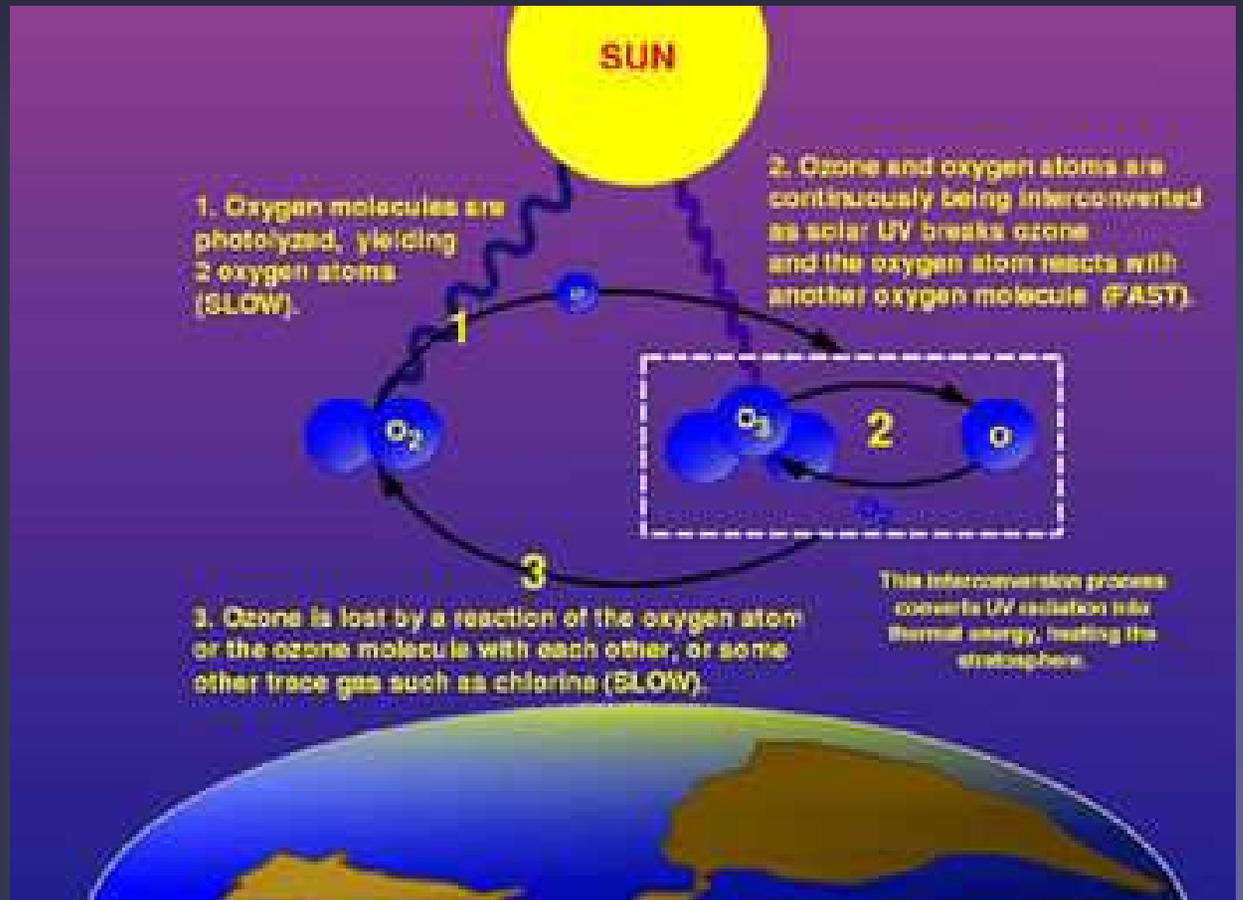
*Energy input to the
Earth's atmosphere*

Sun-Climate: Possible Mechanisms

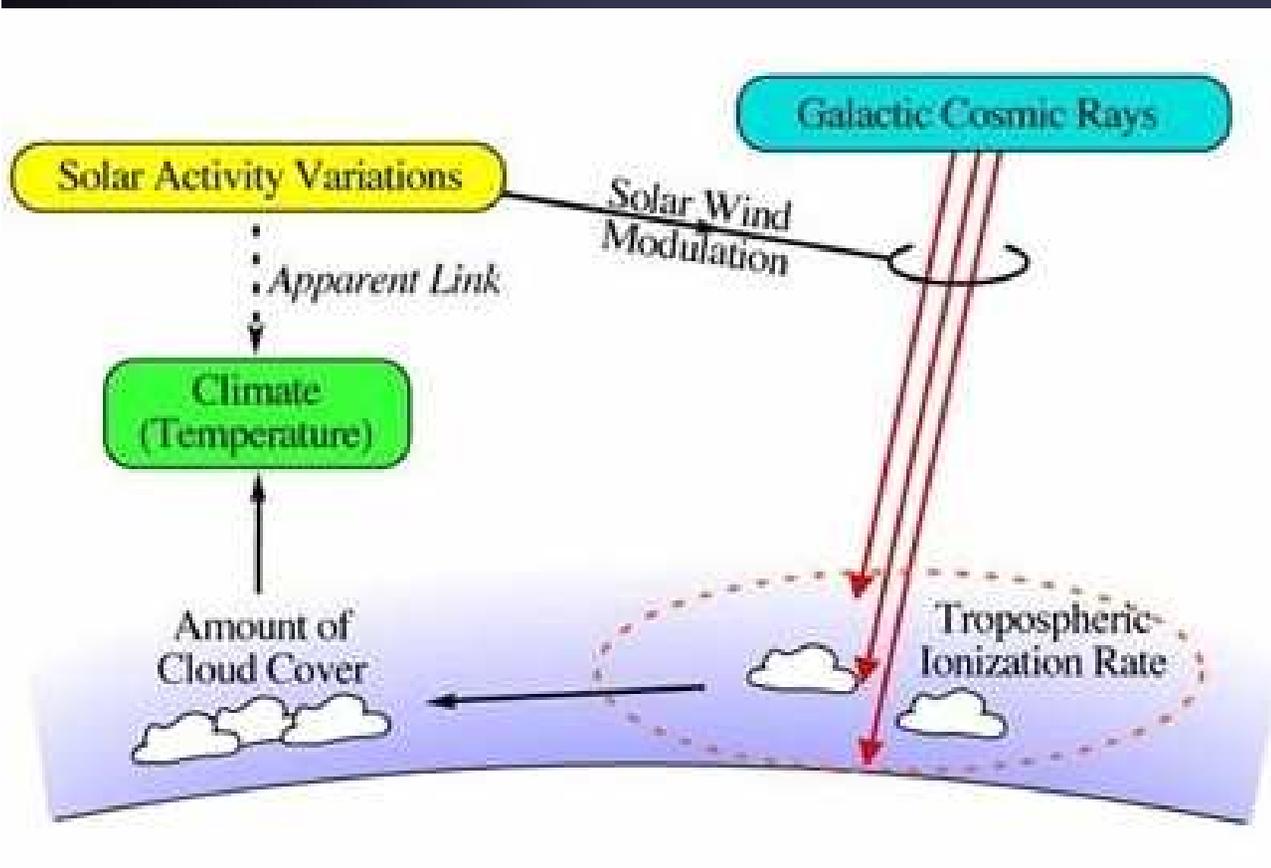
**UV
Irradiance
Variations**



*Changes in
stratospheric
chemistry*



Sun-Climate: Possible Mechanisms

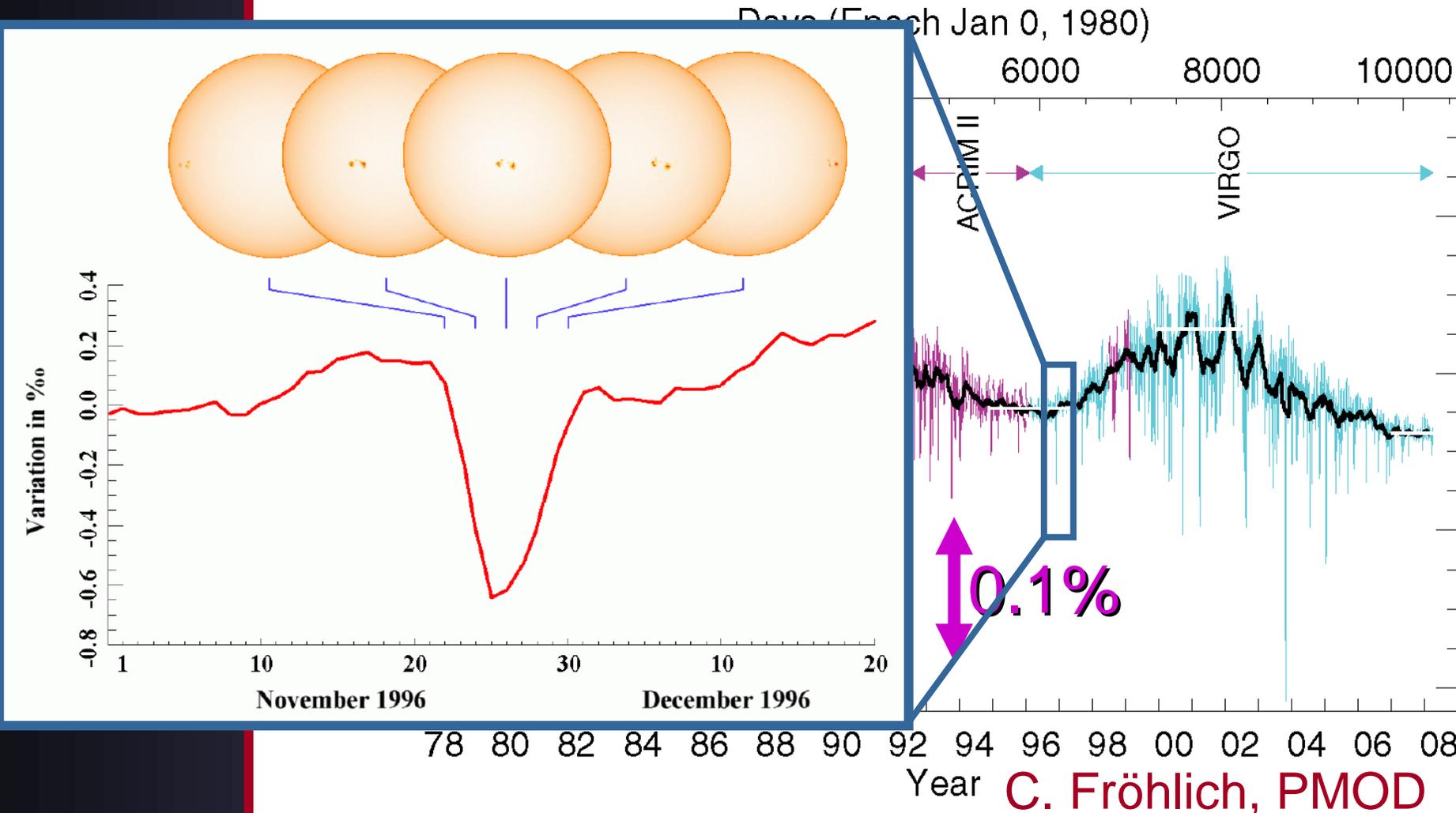


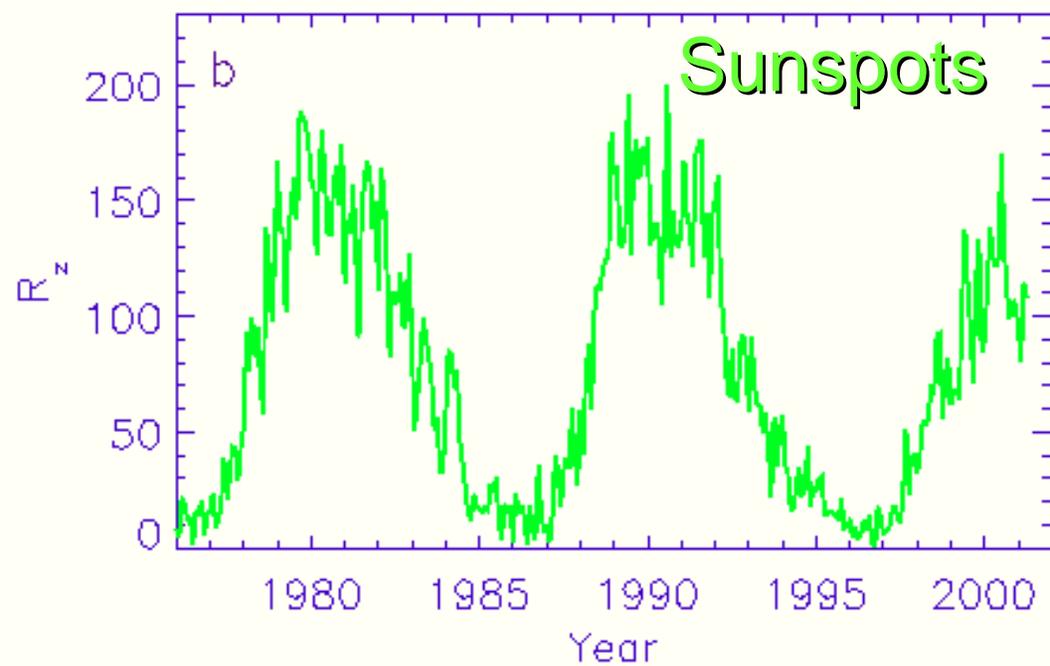
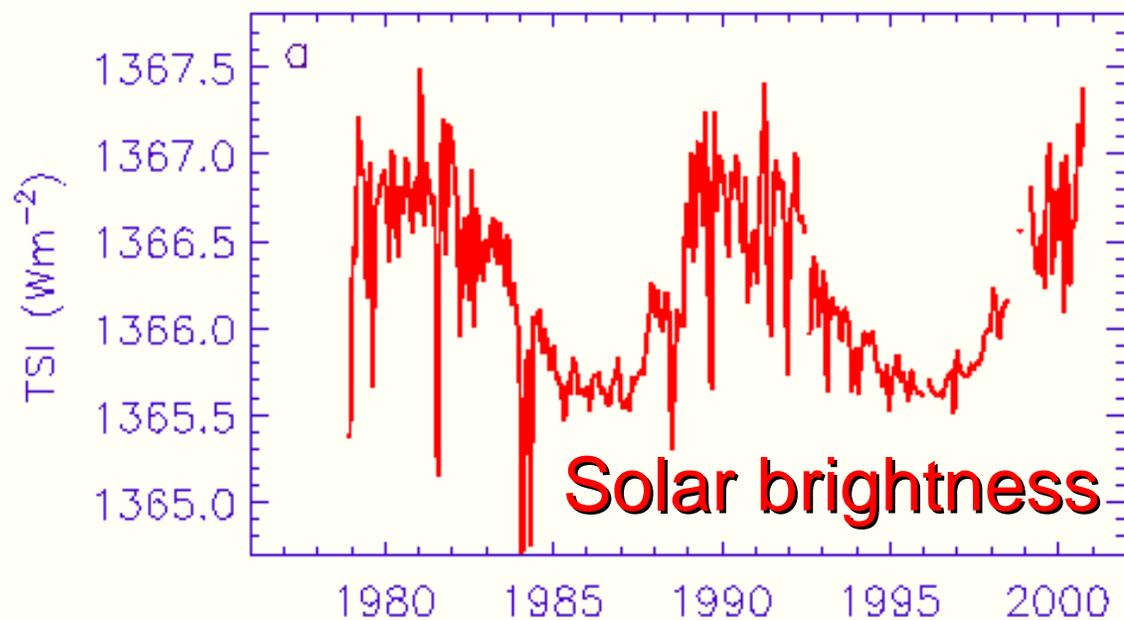
**Modulation of
cosmic rays
flux**



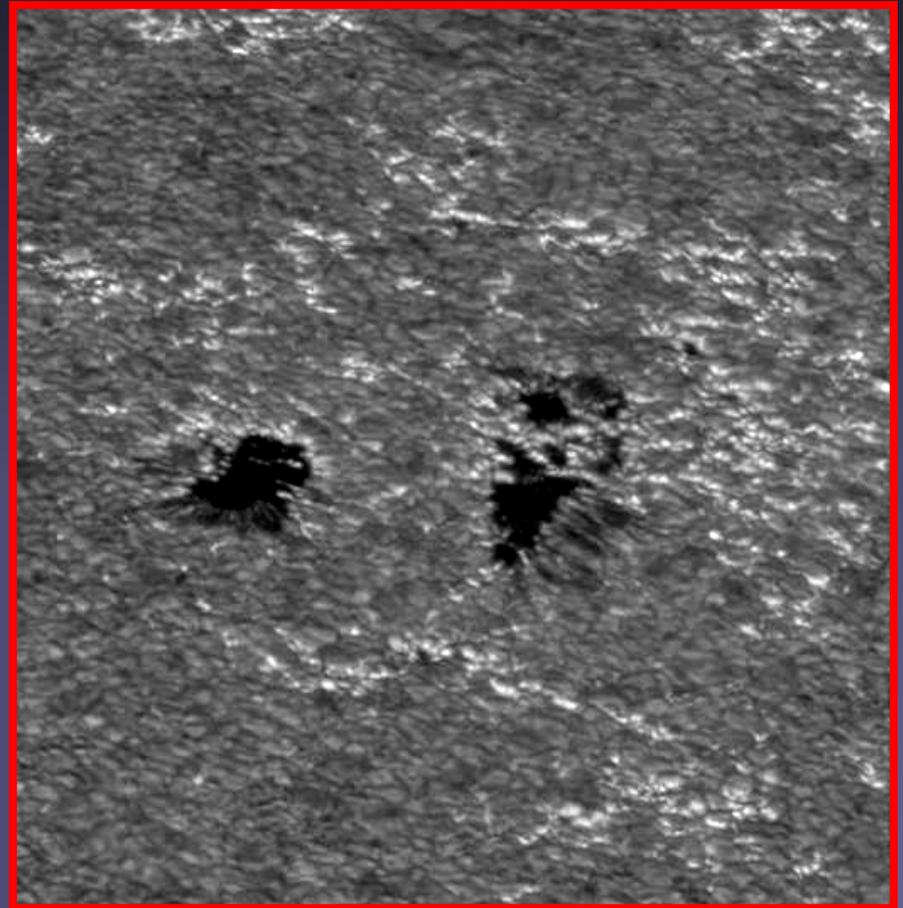
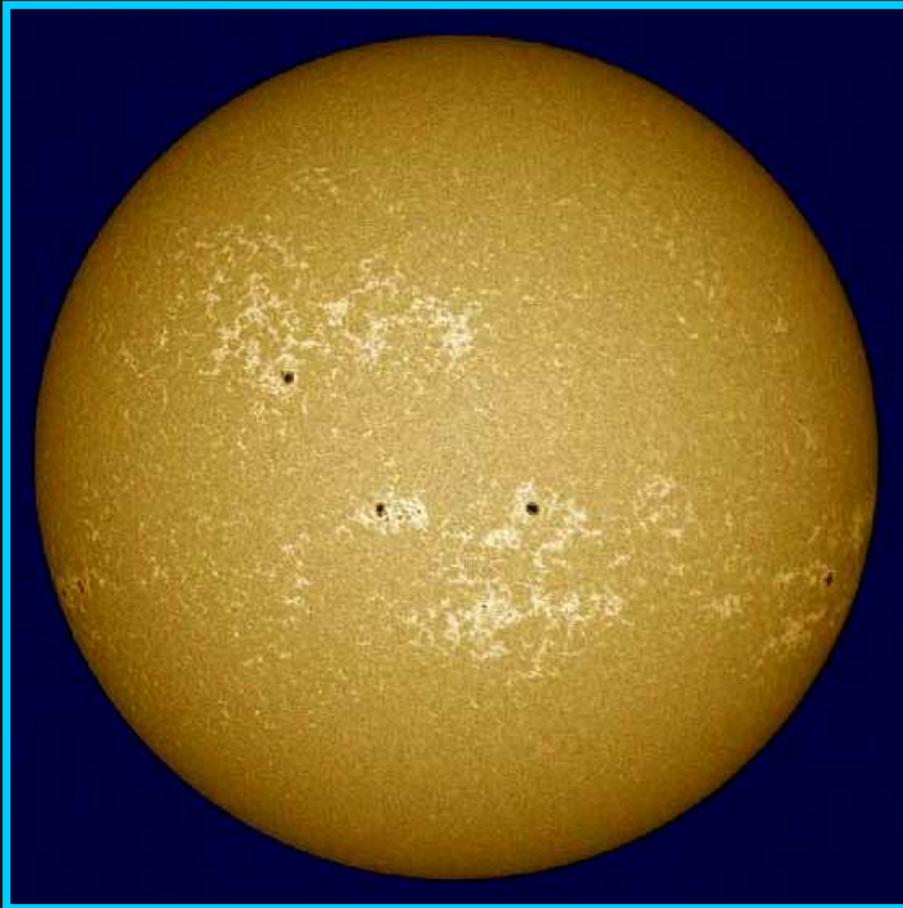
**Changes in
cloud cover**

Measured total irradiance



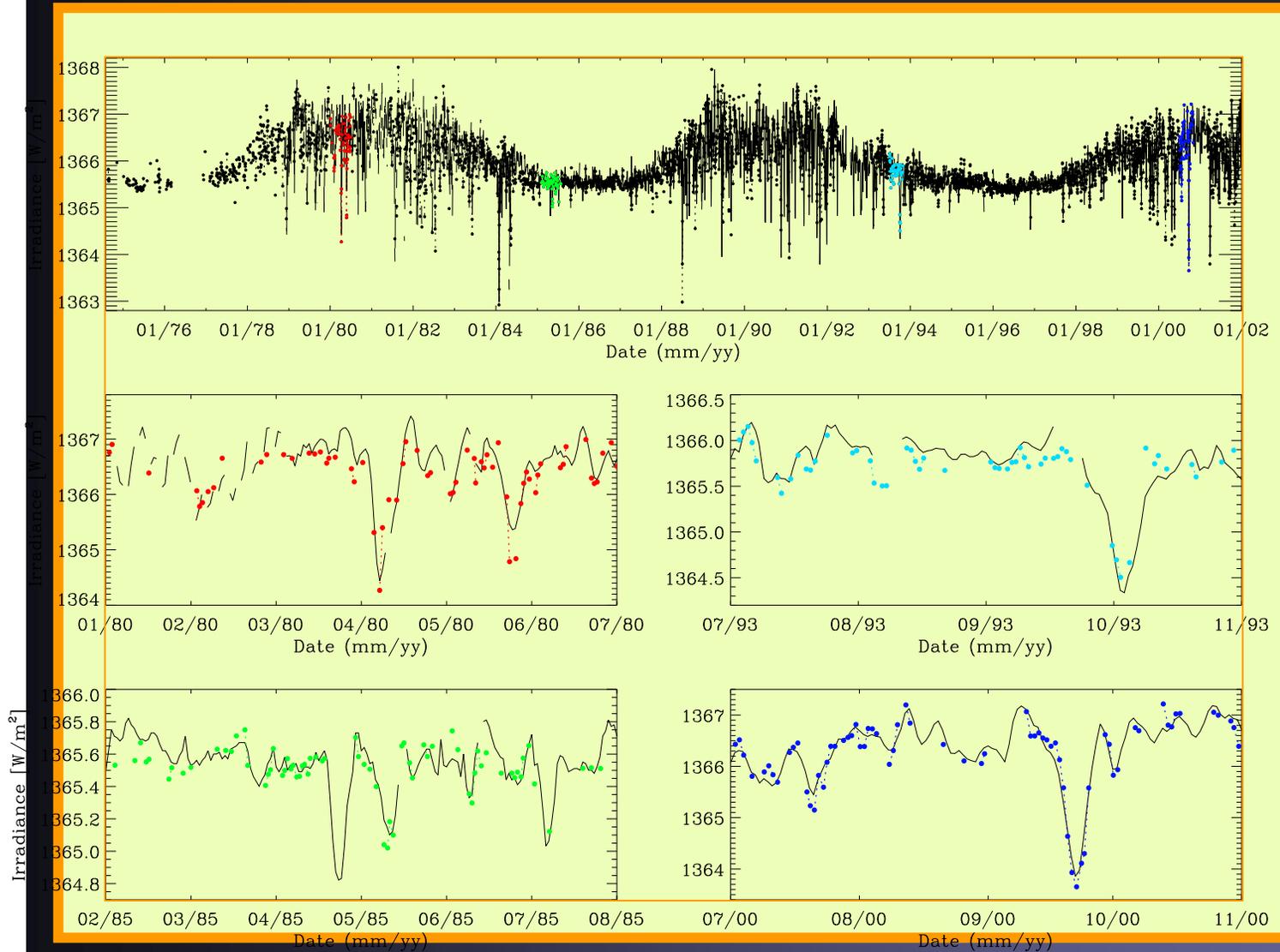


Faculae



Area covered by faculae increases faster from Min. to Max. of solar activity than by sunspots

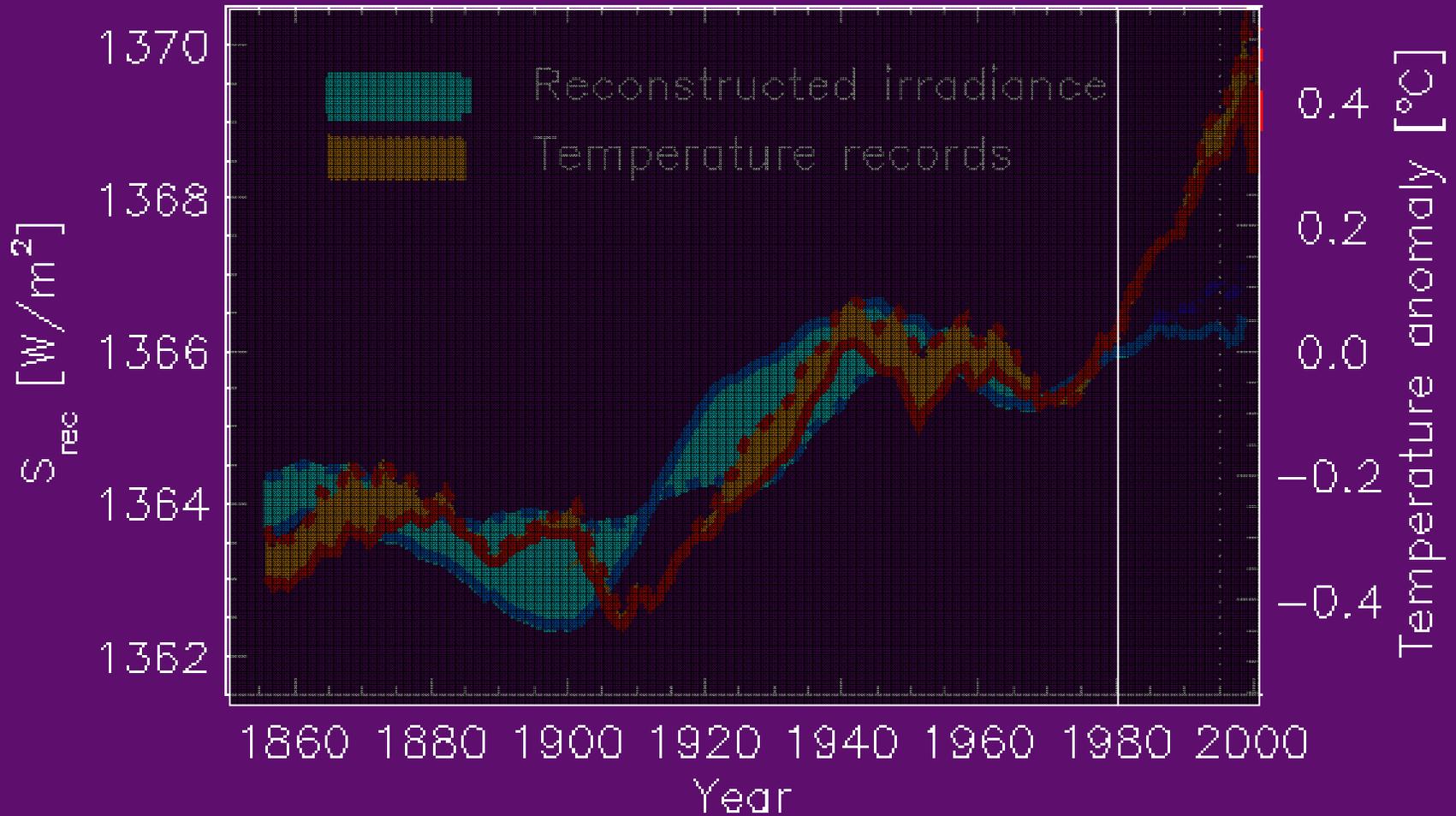
Magnetic Field & Brightness Changes



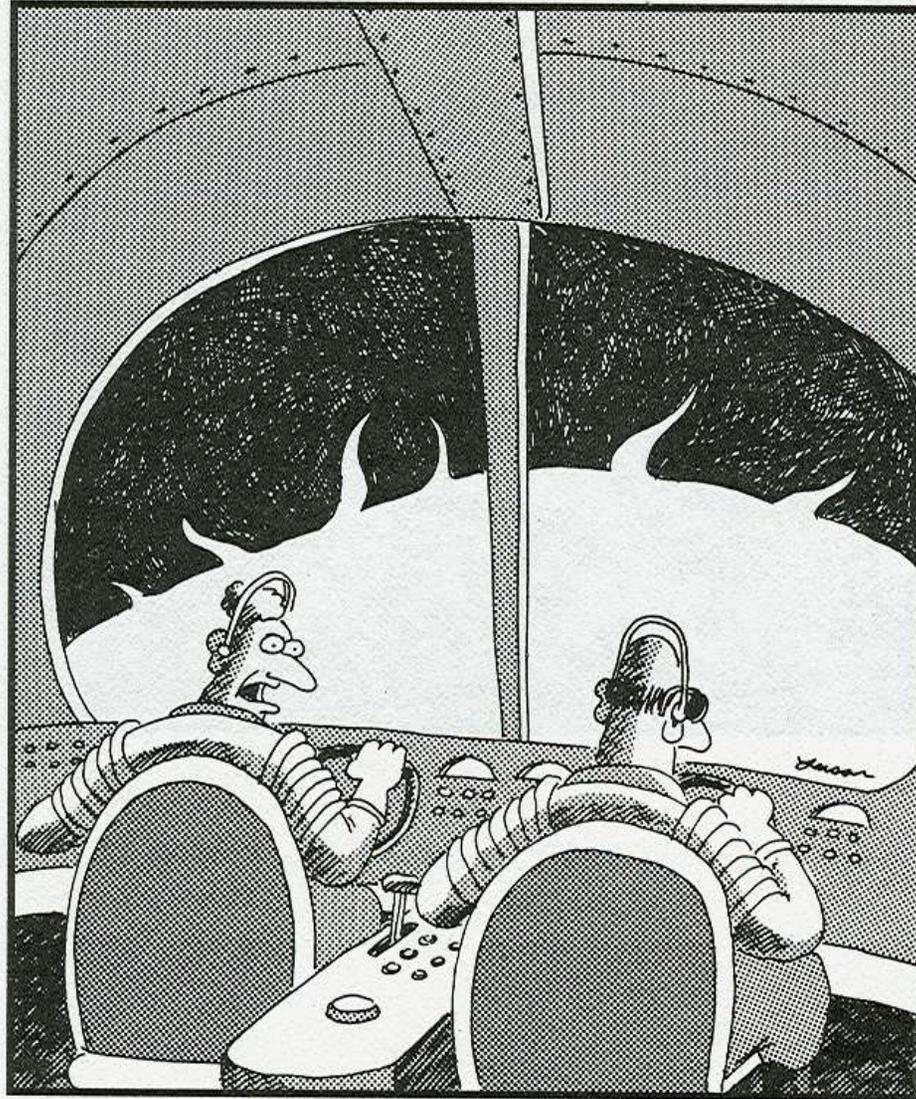
Model:
based on
assumption
that
brightness
changes are
caused by
magnetic
field at solar
surface

Obs.: by
various
Instruments

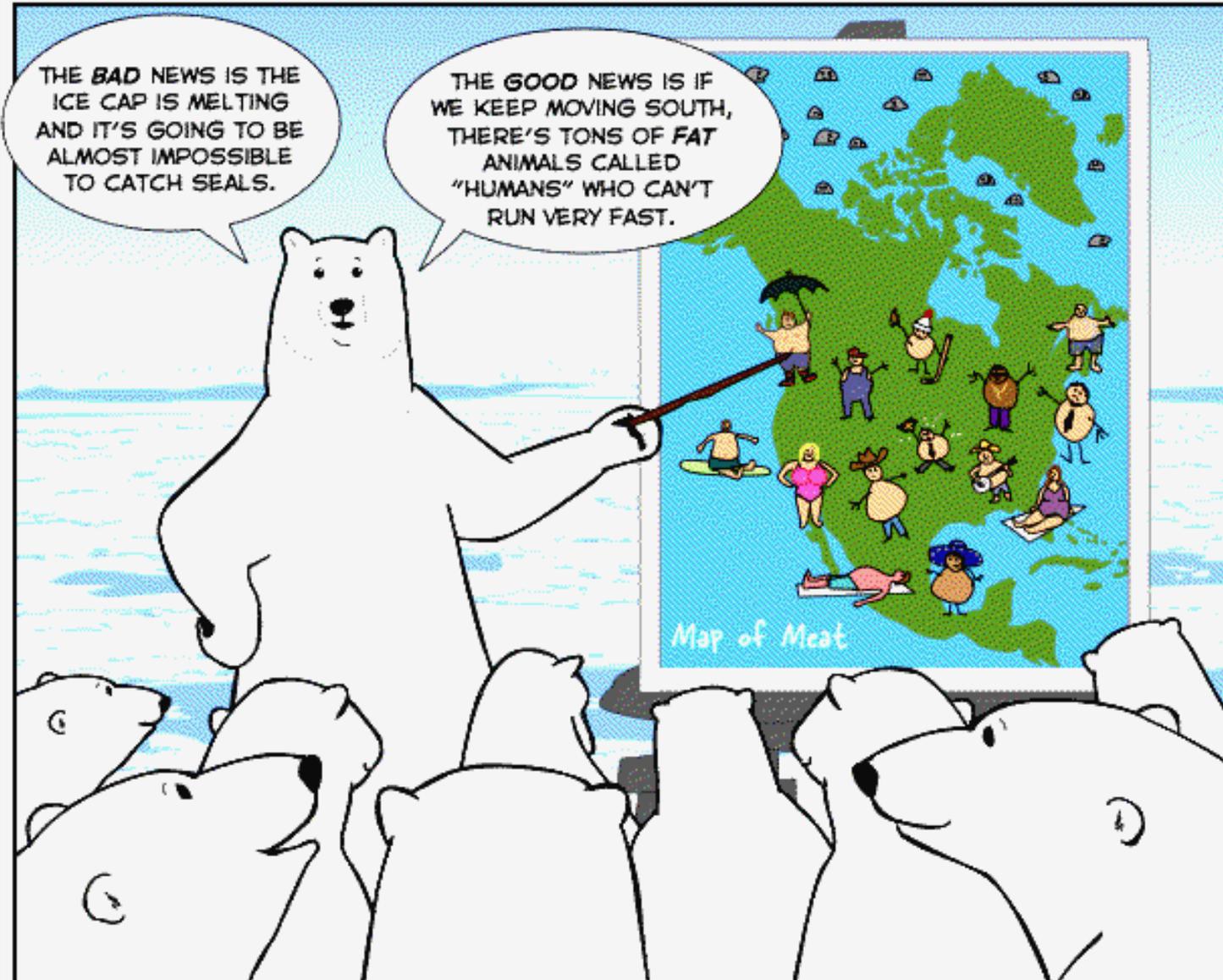
Solar Brightness and Climate



Solanki & Krivova 2003 JGR



“It’s no good, Dawson! We’re being sucked in by the sun’s gravitational field and there’s nothing we can do! ... And let me add those are my sunglasses you’re wearing!”



**We have started a gigantic experiment
with the only home we have, the Earth**

**... and we are dangerously close to
letting it get out of control**



Thank you for your attention!









Sunspots

Umbra

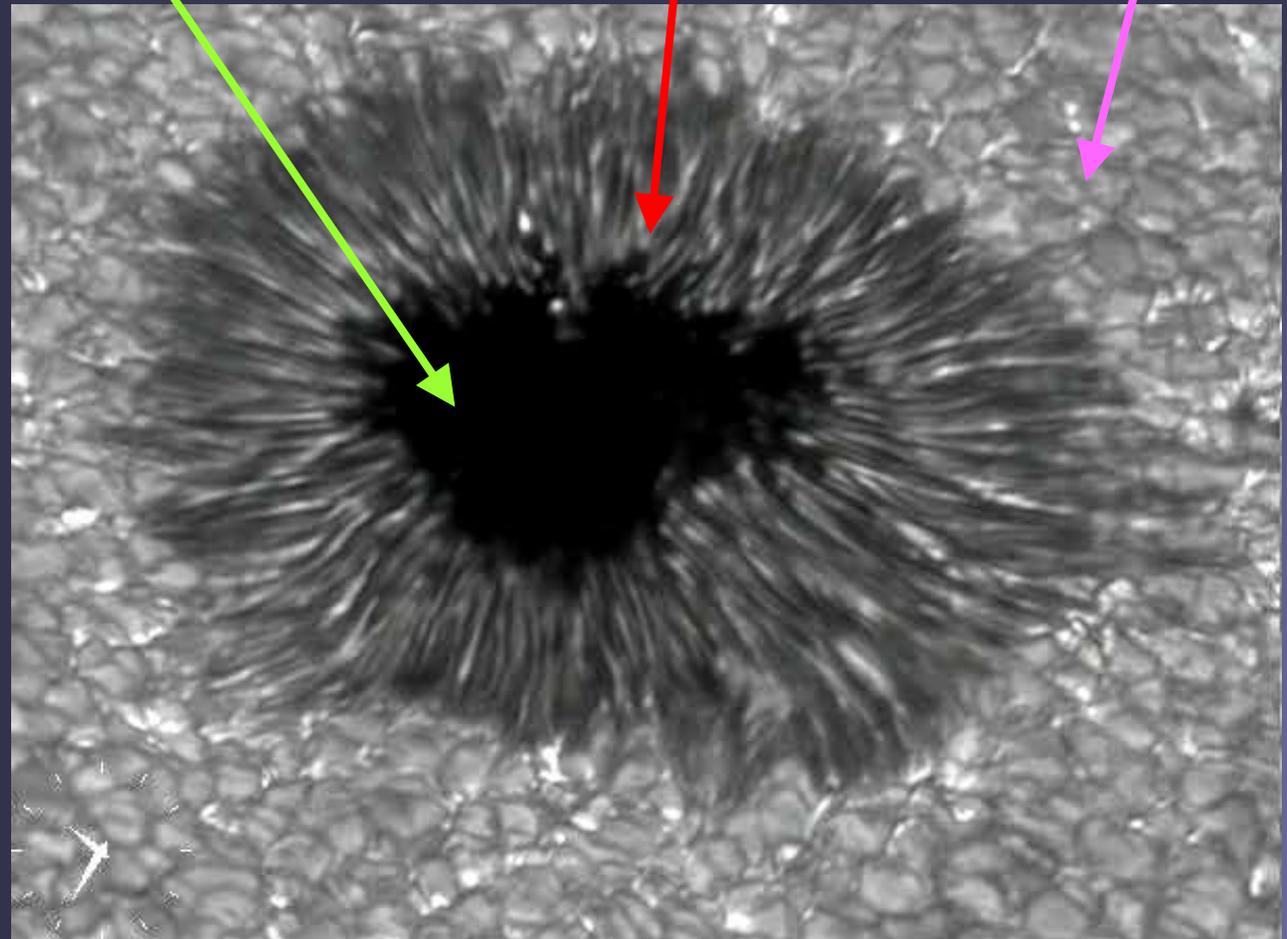
Penumbra

Granule

Umbra:
Temp = 4000°

Penumbra:
Temp = 5200°

Granules:
Temp = 5500°



Faculae & the Network



Gas at 8000° (Ca II K)

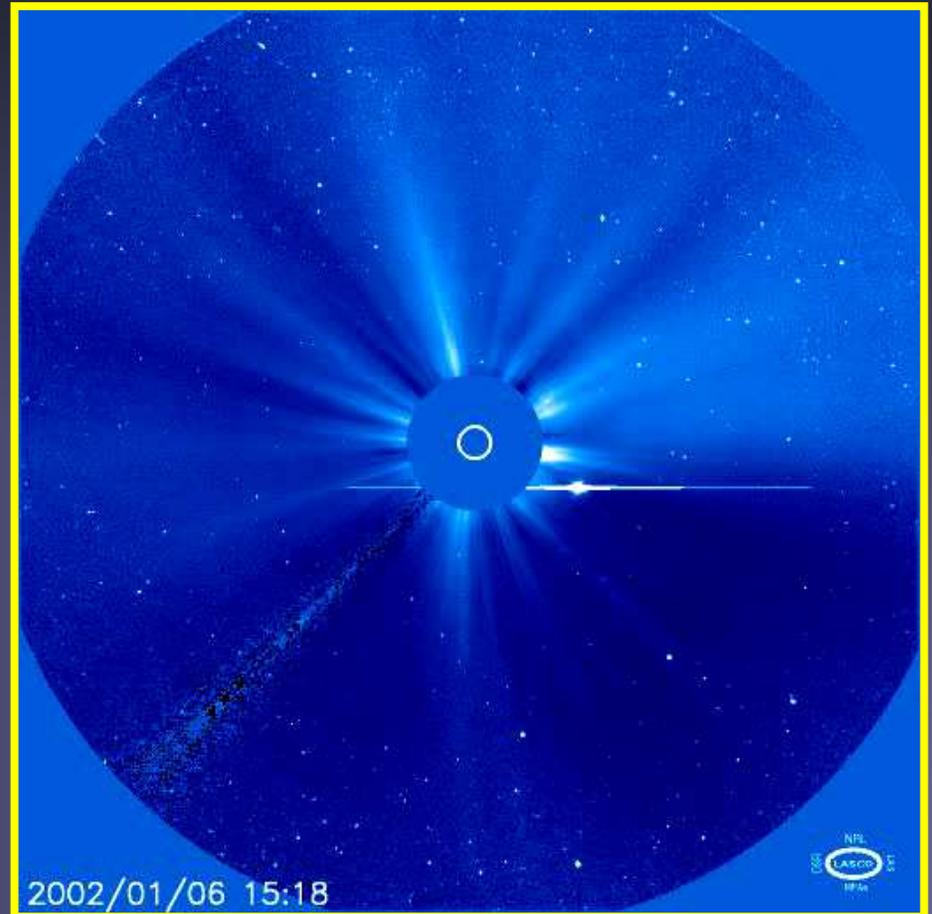


Gas at $50\,000^{\circ}$ (EIT He II)

The Hot and Dynamic Corona



2002/05/31 09:48
Corona during an Eclipse
EUV Corona: Plasma at
>1 Mio °C (EIT 195 Å)



2002/01/06 15:18
Artificial eclipse
(LASCO C3 / SOHO, MPS)

A Flare Near the Solar Limb

Gas at
1 Million
degrees
(Corona)

Movie
covers 4
hours

