Cosmo-Climatology

Cosmic rays, Clouds, and Climate

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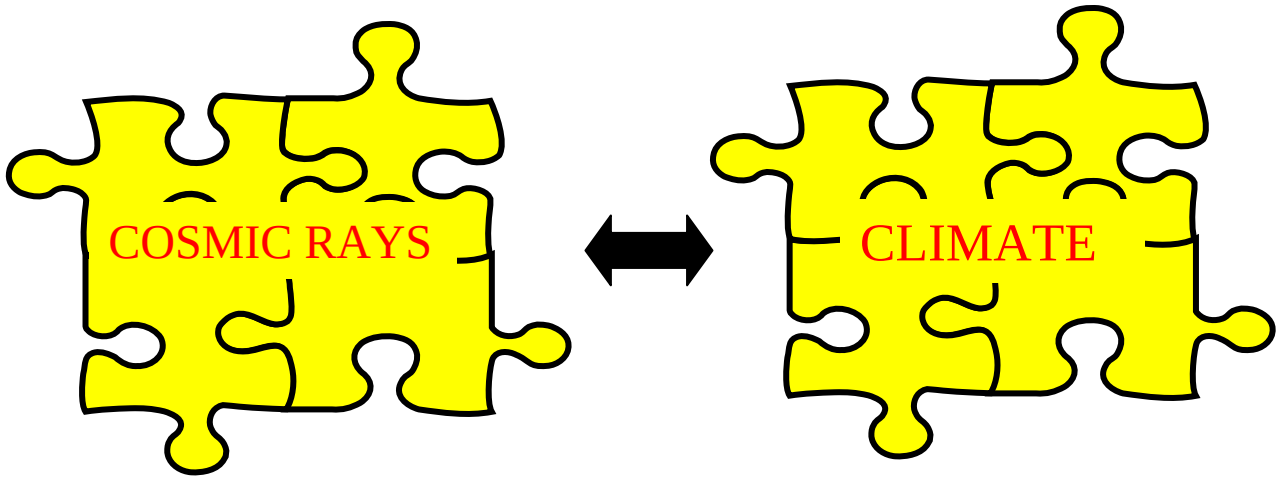
Space- DTU

Cosmoclimatology

- Cosmic rays and climate
  - Definitions
  - Motivation
  - Empirical evidence
- Experimental efforts and results
- Does is work in the real atmosphere
- Implication on long time scales.
  - Phanerozoic climate variations (550 myr)
  - Climate variations over the age of the Earth (4.6 Gyr)

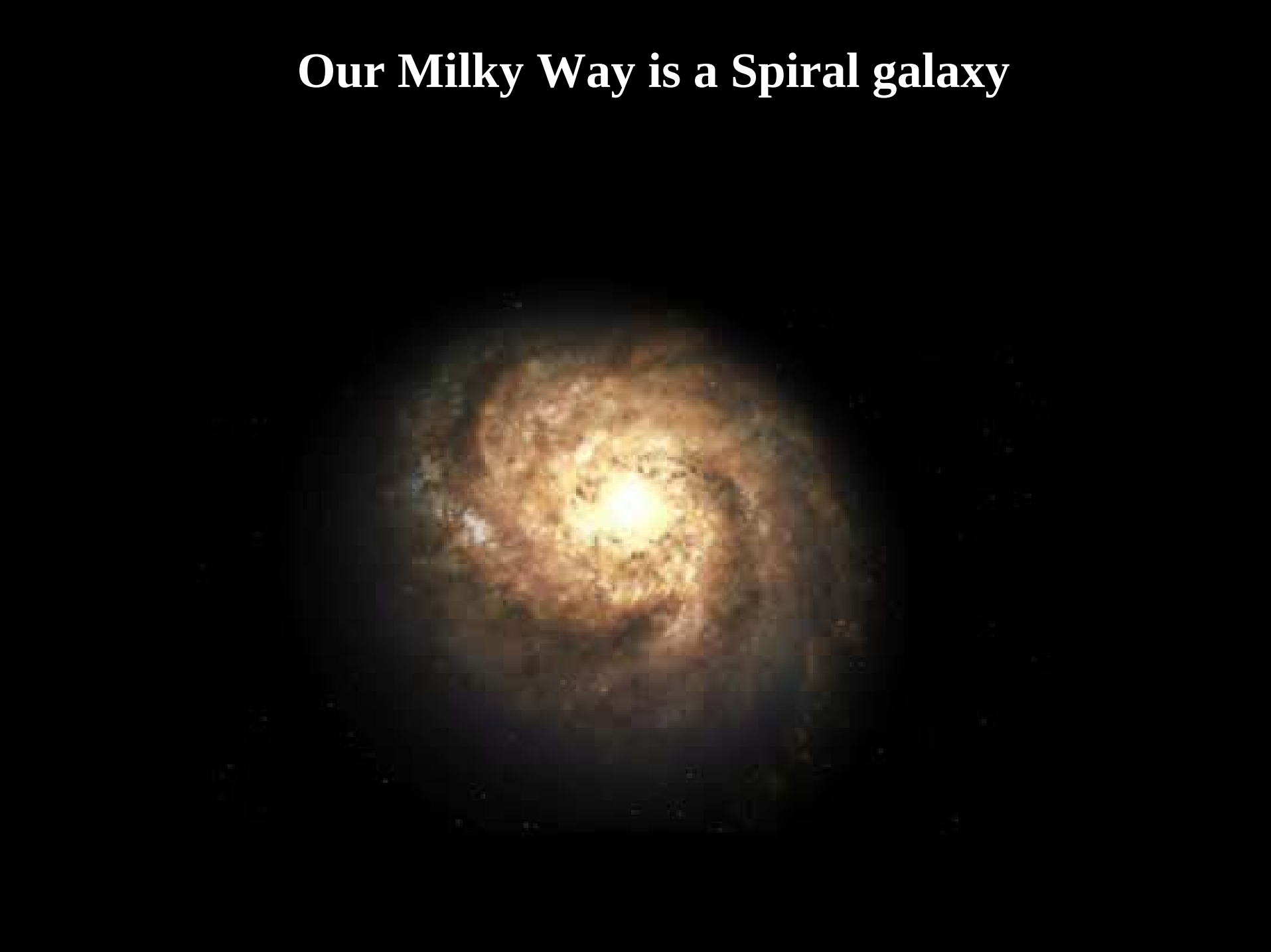
Cosmic Rays and Climate



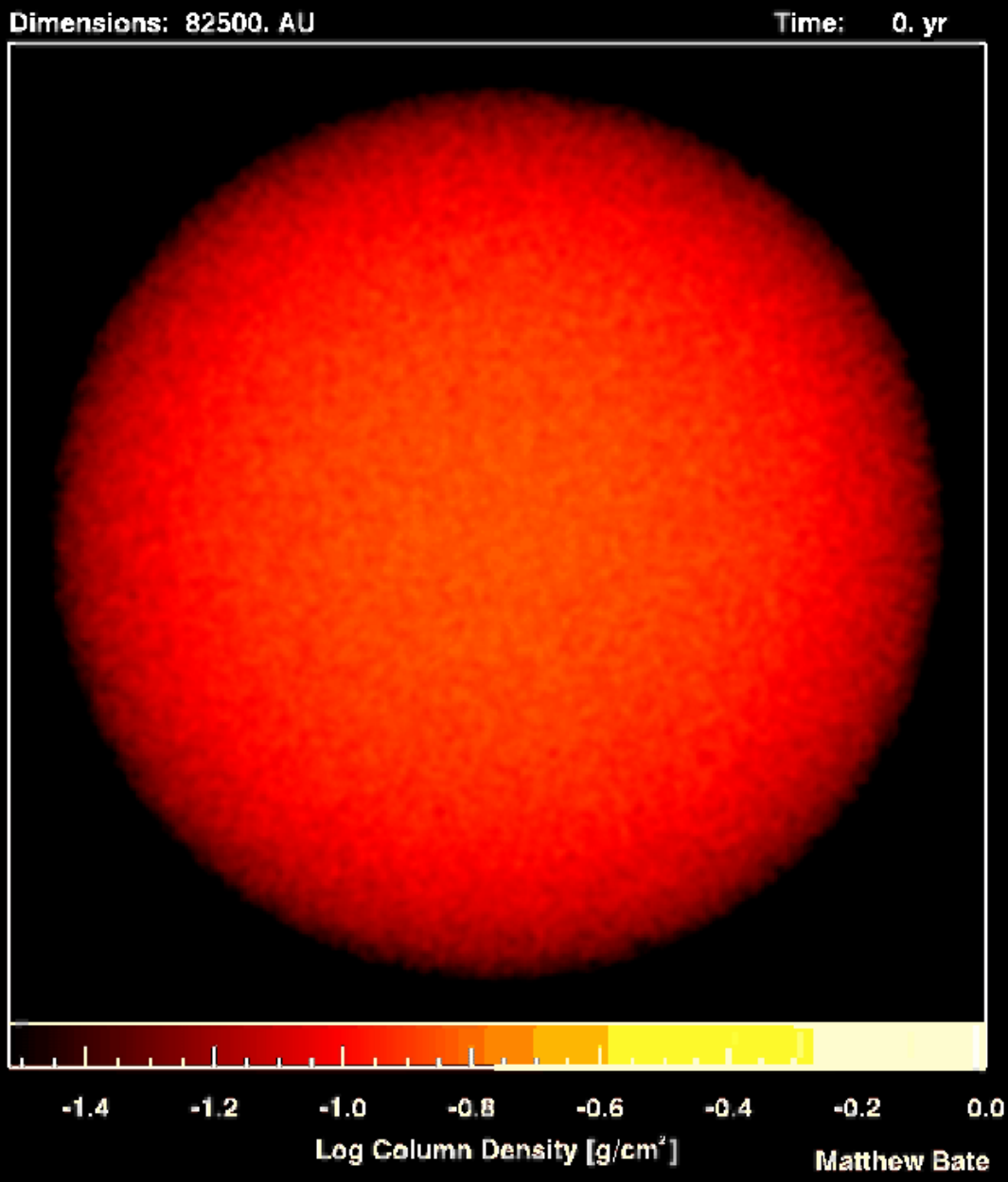
Variations in Cosmic Ray Flux Affects Earths Climate,
and Cause Variations in Climate.

Examples with
Solar Modulated Cosmic rays

Our Milky Way is a Spiral galaxy



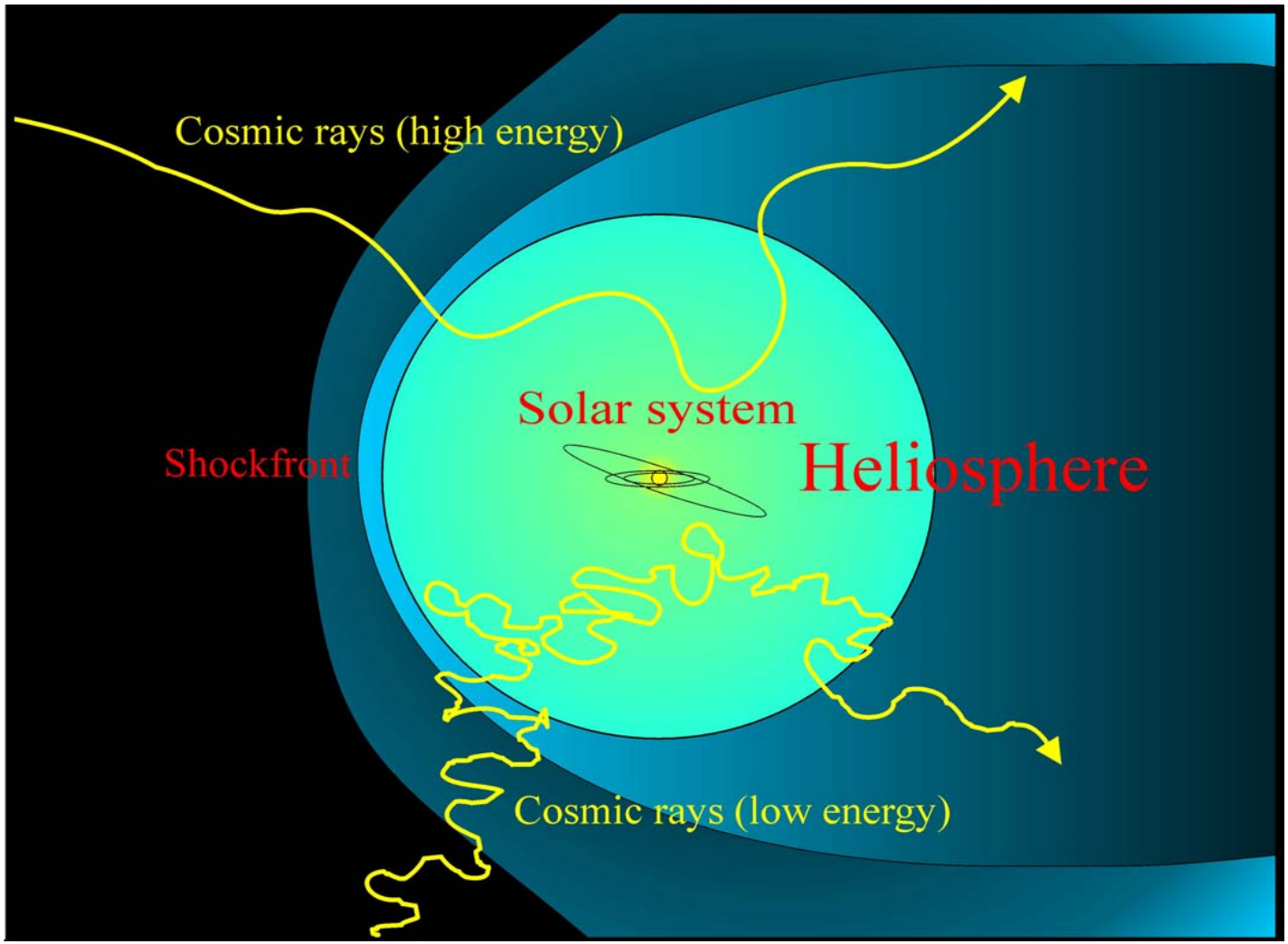
Star formation from a cloud of gas of hydrogen



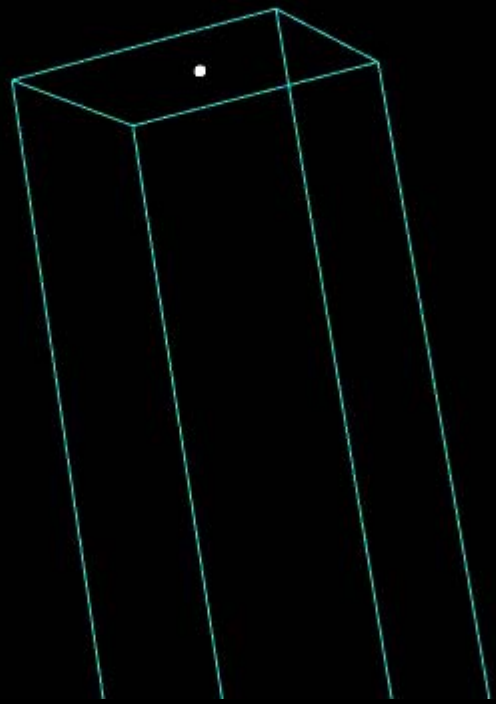
Super Nova explosions happens for heavy stars (> $8M_{sun}$)

What are Cosmic Rays?

Heliosphere, Cosmic Rays and Solar Activity

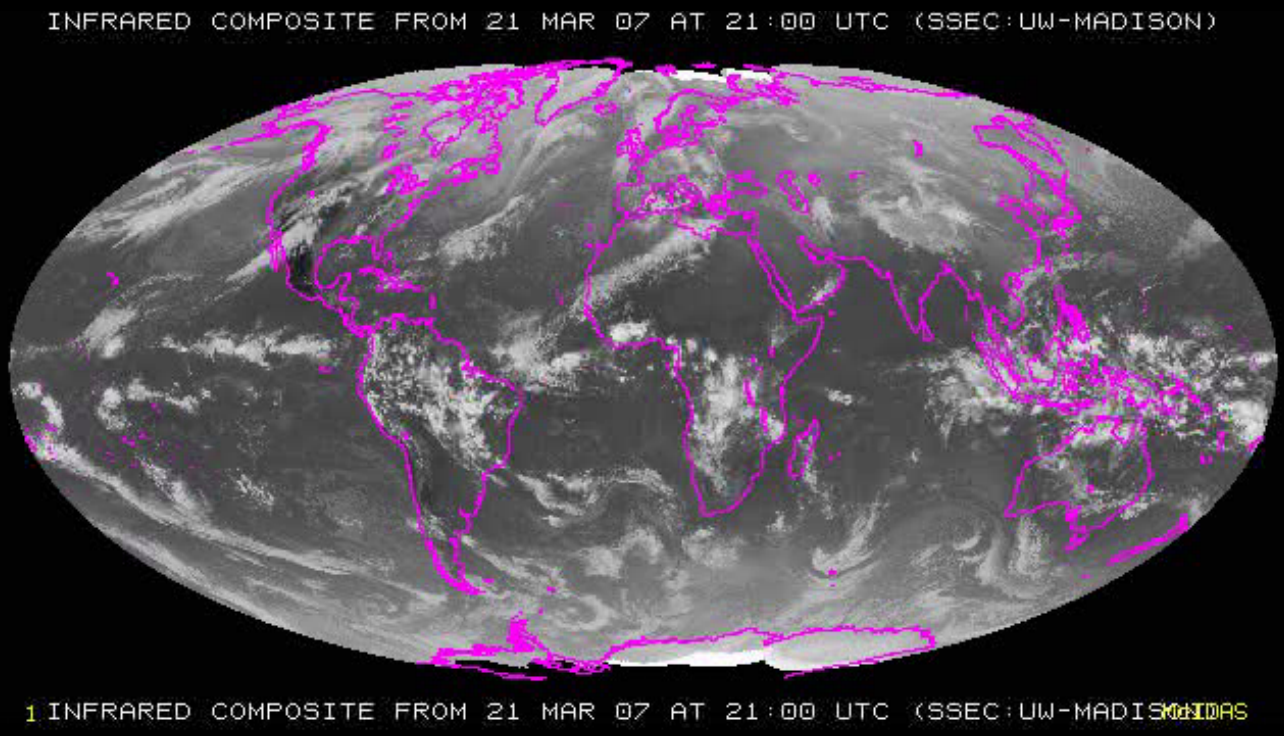


Cosmic ray shower (Movie)



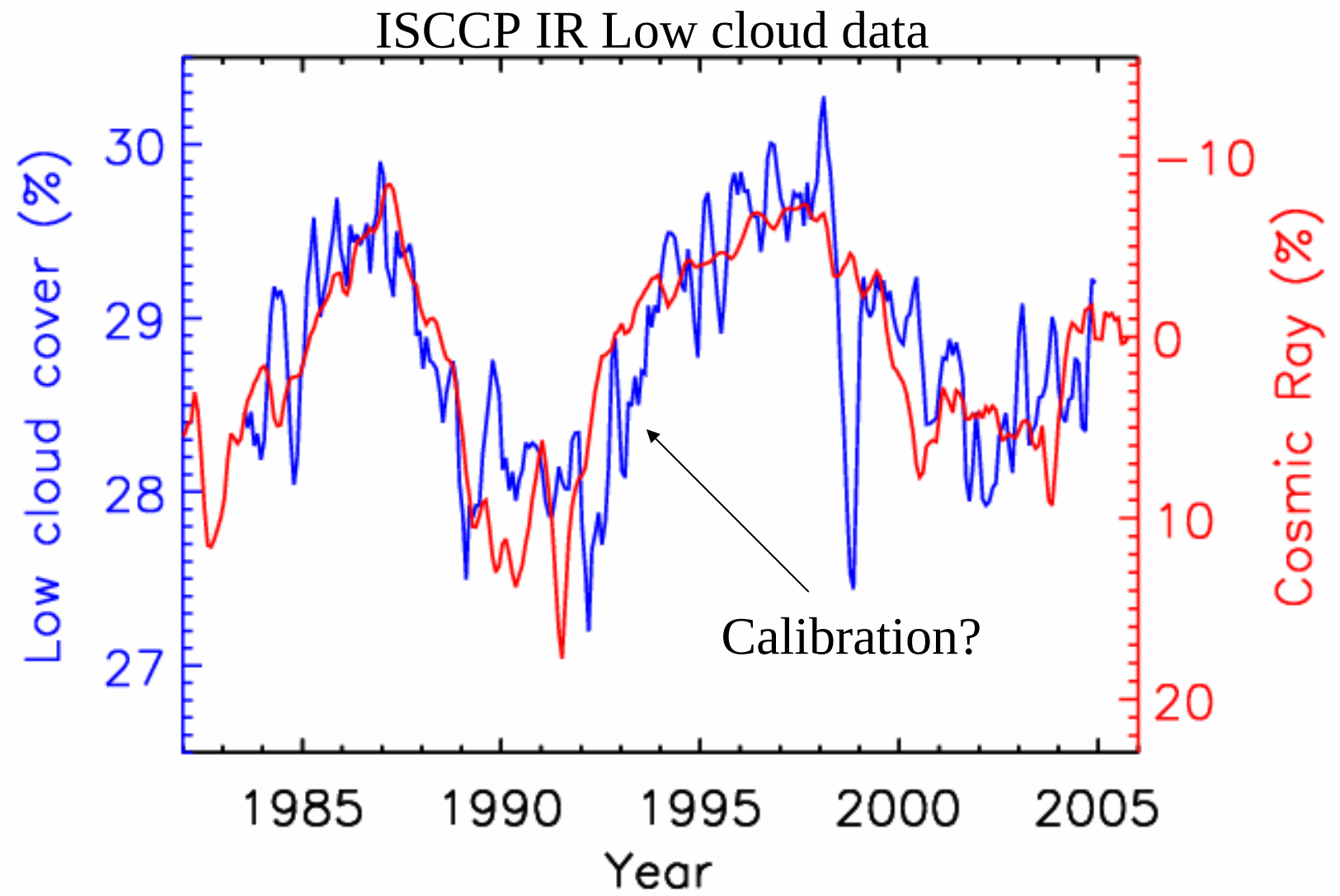
About 70 muons/s /m^2 at the Earths surface
In 24 hours about 12 million muons goes through a human body

How can STARS influence Climate?



Net effect of clouds is to cool the Earth by about 30 W/m^2

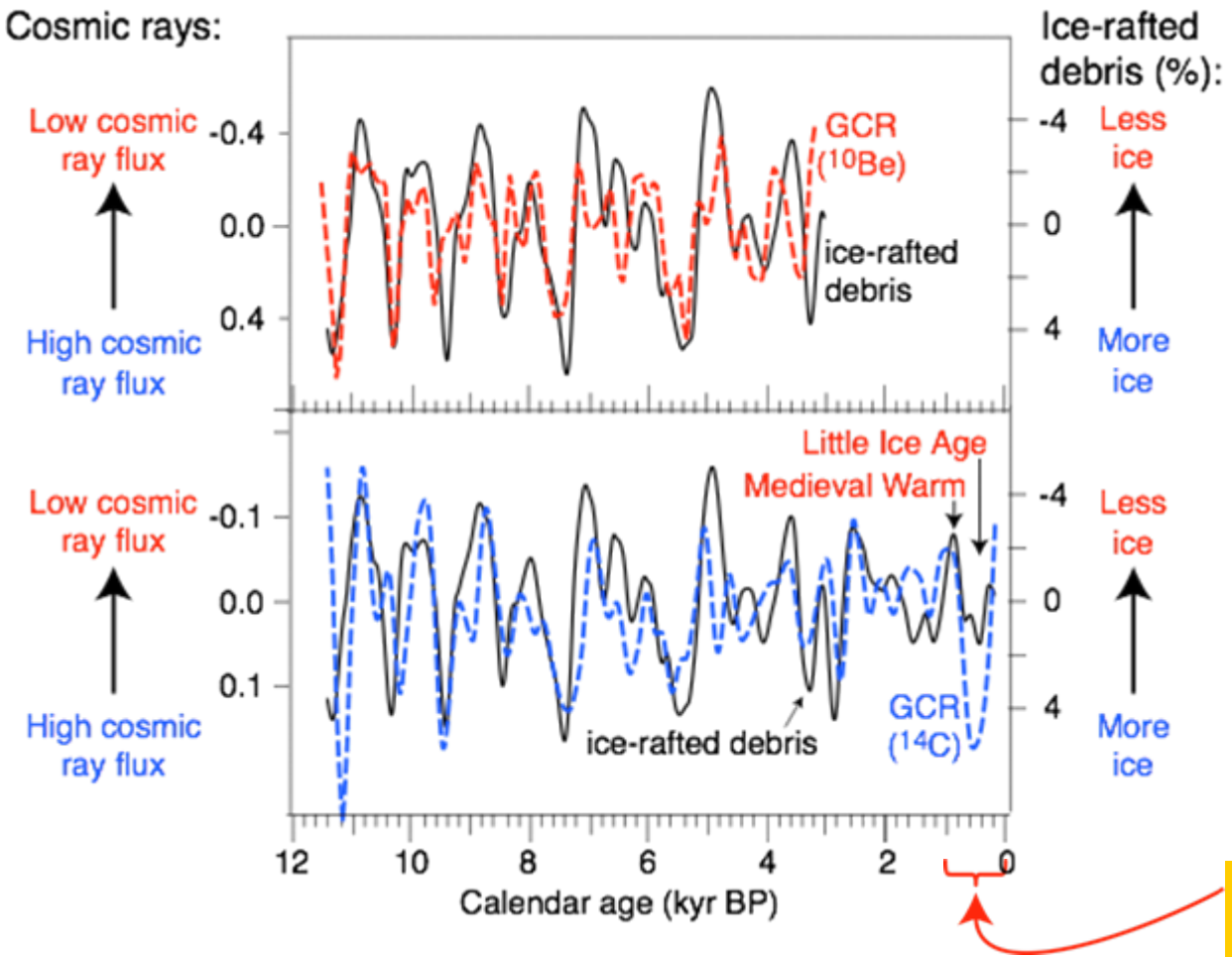
Link between Low Cloud Cover and Galactic Cosmic Rays?

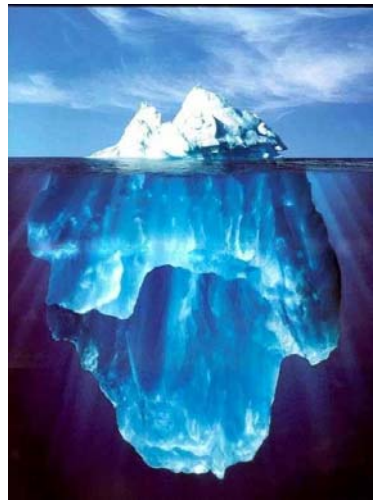


Svensmark & Friis-Christensen, JASTP 1997, Svensmark, PRL 1998, Marsh & Svensmark, PRL, 2000. (update 2005)

Cosmic rays and climate over the last 10.000 years

Bond et al, Science 294, 2001





According to icecores CO_2 levels has been constant ~280 ppm

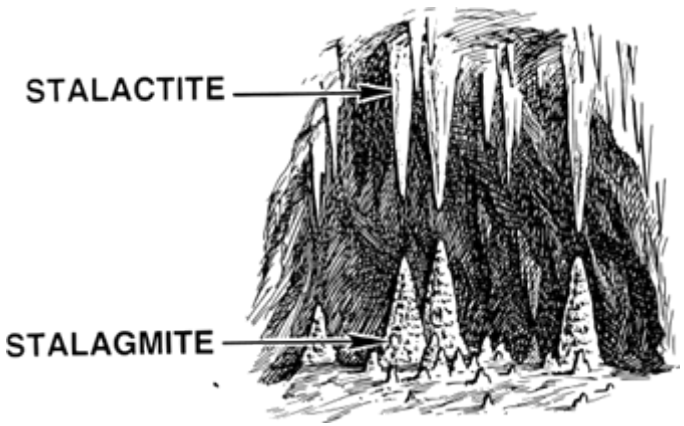
Last 1000 years
Little Ice Age

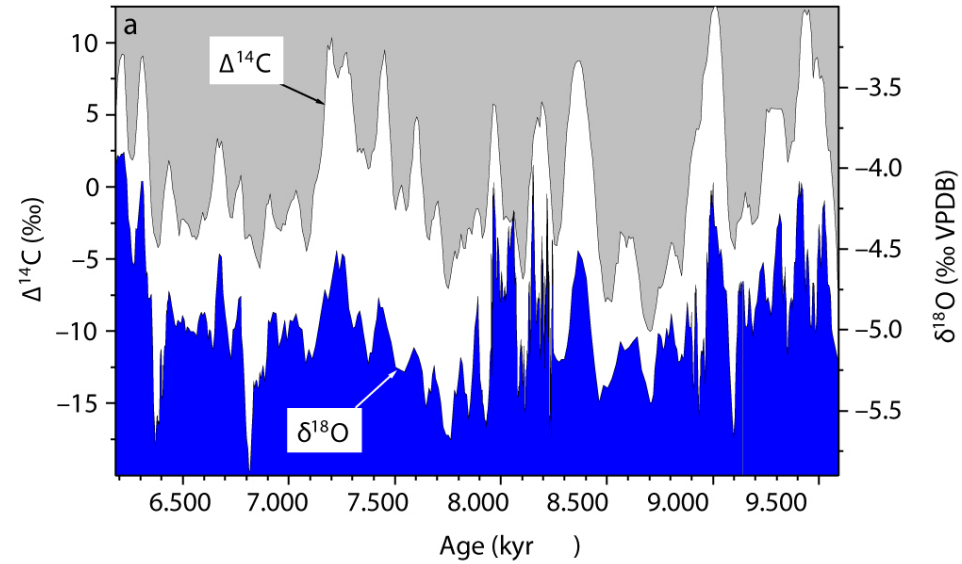
- Little Ice Age is merely the most recent of a dozen such events during the last 10.000 years

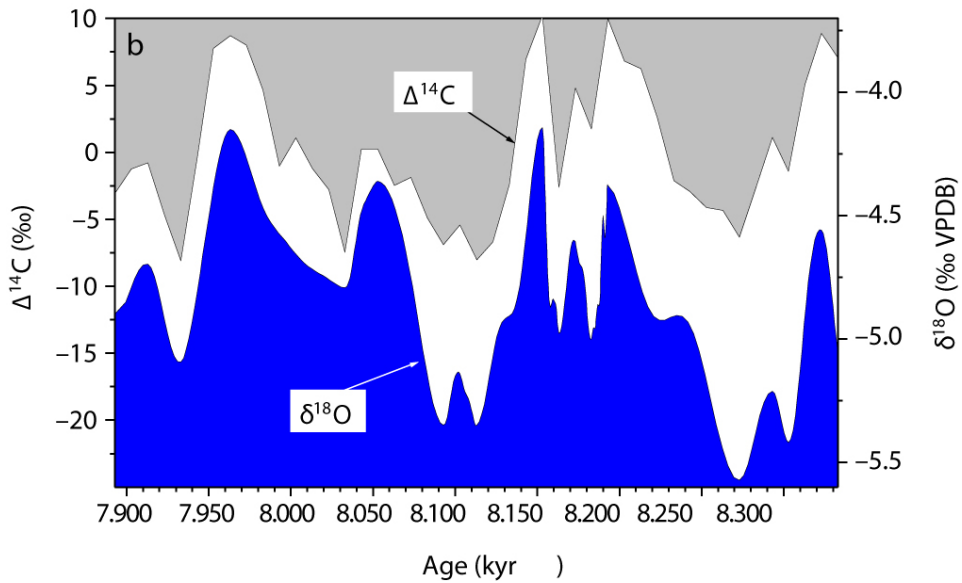
Adapted from Kirkby

Strong coherence between solar variability and the monsoon in Oman between 9 and 6 kyr ago

The formation of stalagmites in northern Oman has recorded past northward shifts of the intertropical convergence zone3, whose northward migration stops near the southern shoreline of Arabia in the present climate

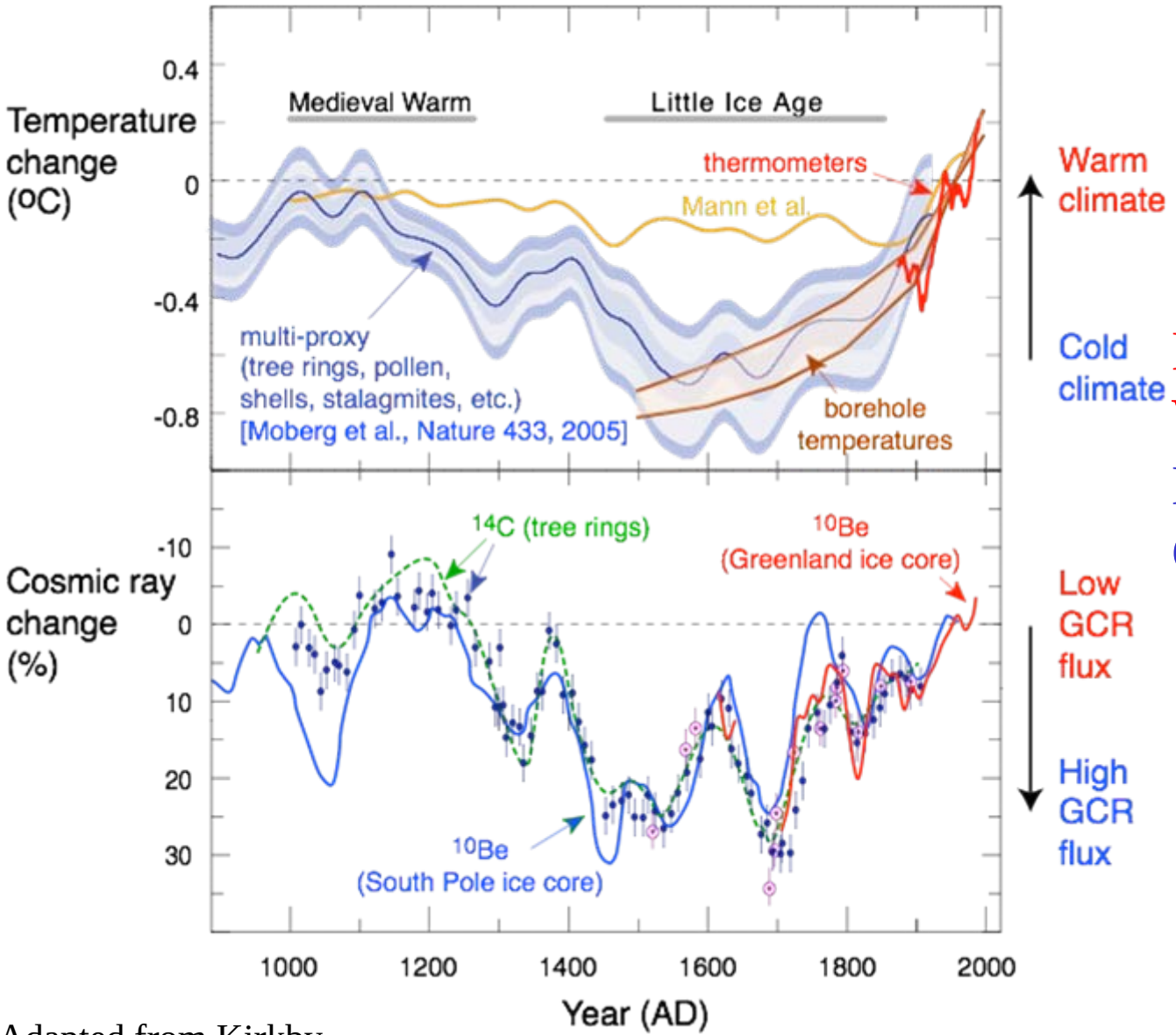






U. Neff et al., Nature 411, 290 - 293 (2001)

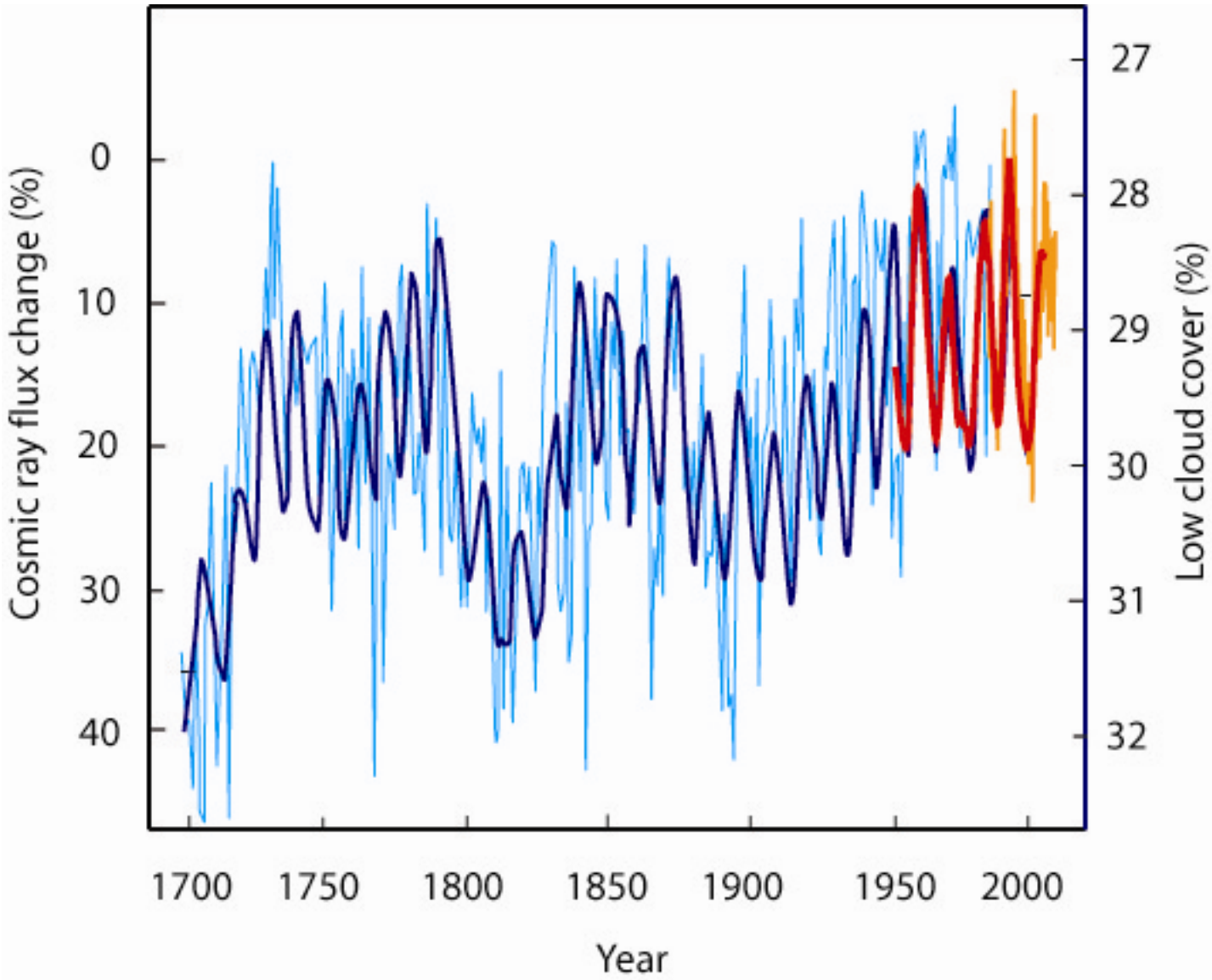
Cosmic rays and climate over the last millennium



Low Cosmic ray flux
Warmer Climate
High Cosmic ray flux
Colder Climate

Adapted from Kirkby

Change in Cosmic ray flux through 300 years

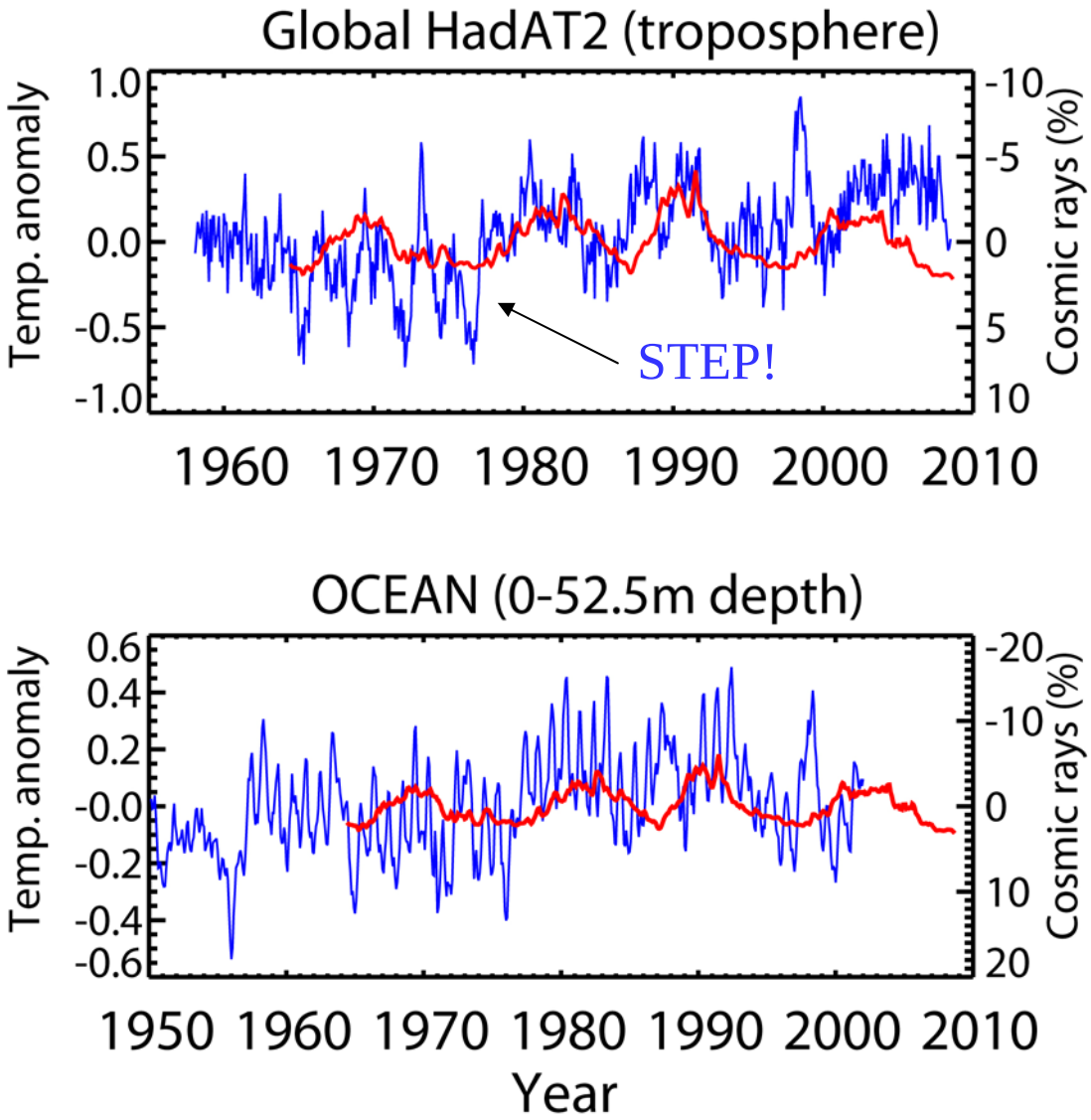


Clouds must respond to the changing COSMIC RAY FLUX

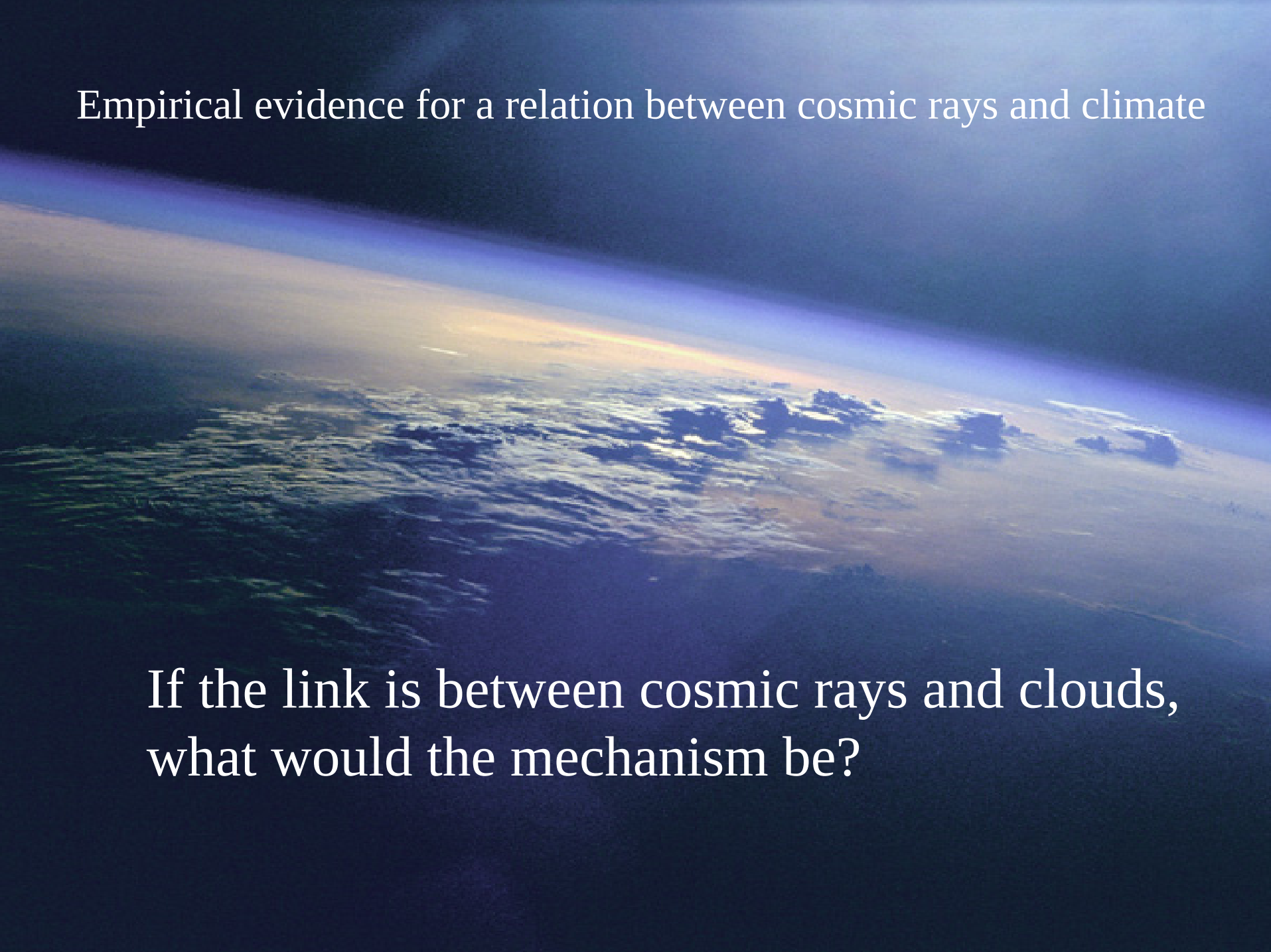
There is evidence from boreholes suggesting that clouds have been forcing the Earth over the last 6000 years.

Cosmic Rays and 1960 -2008 tropospheric temperatures

Average temperature between 0-10 km



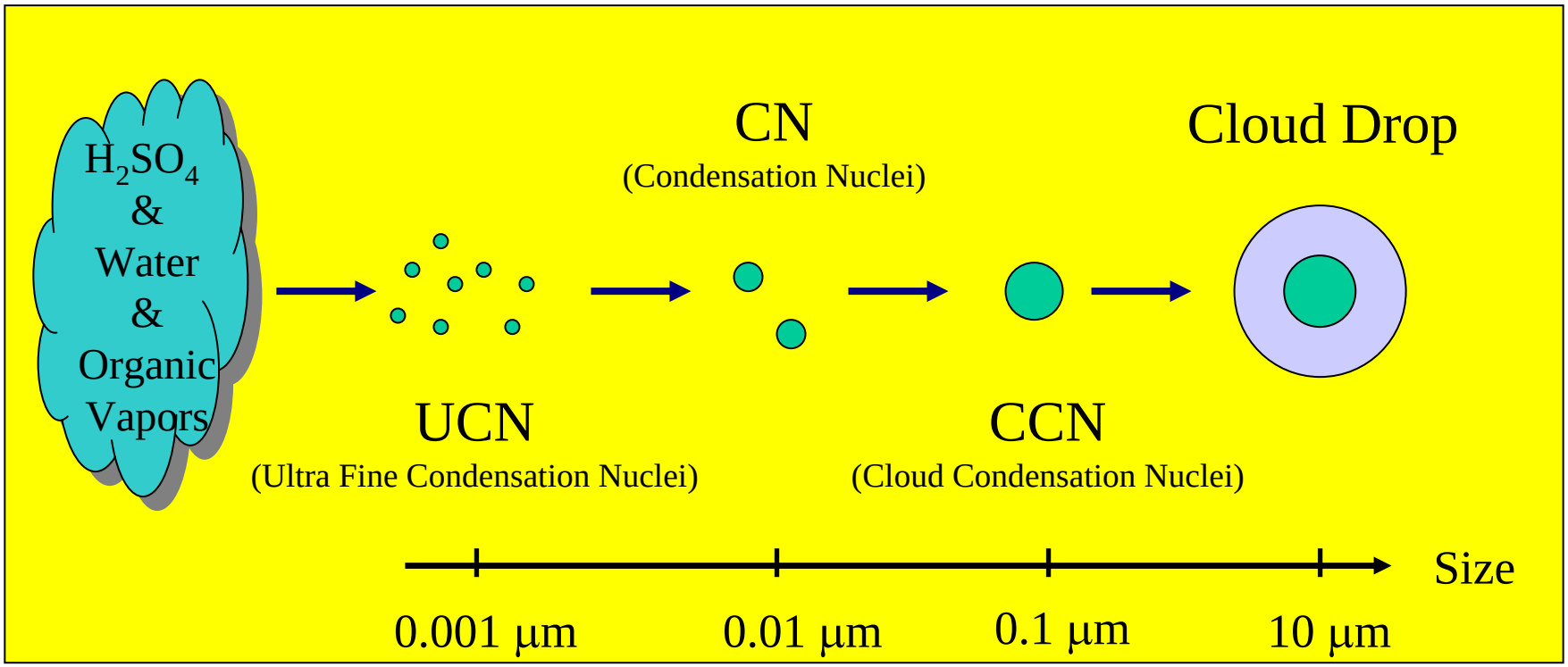
Empirical evidence for a relation between cosmic rays and climate



If the link is between cosmic rays and clouds, what would the mechanism be?

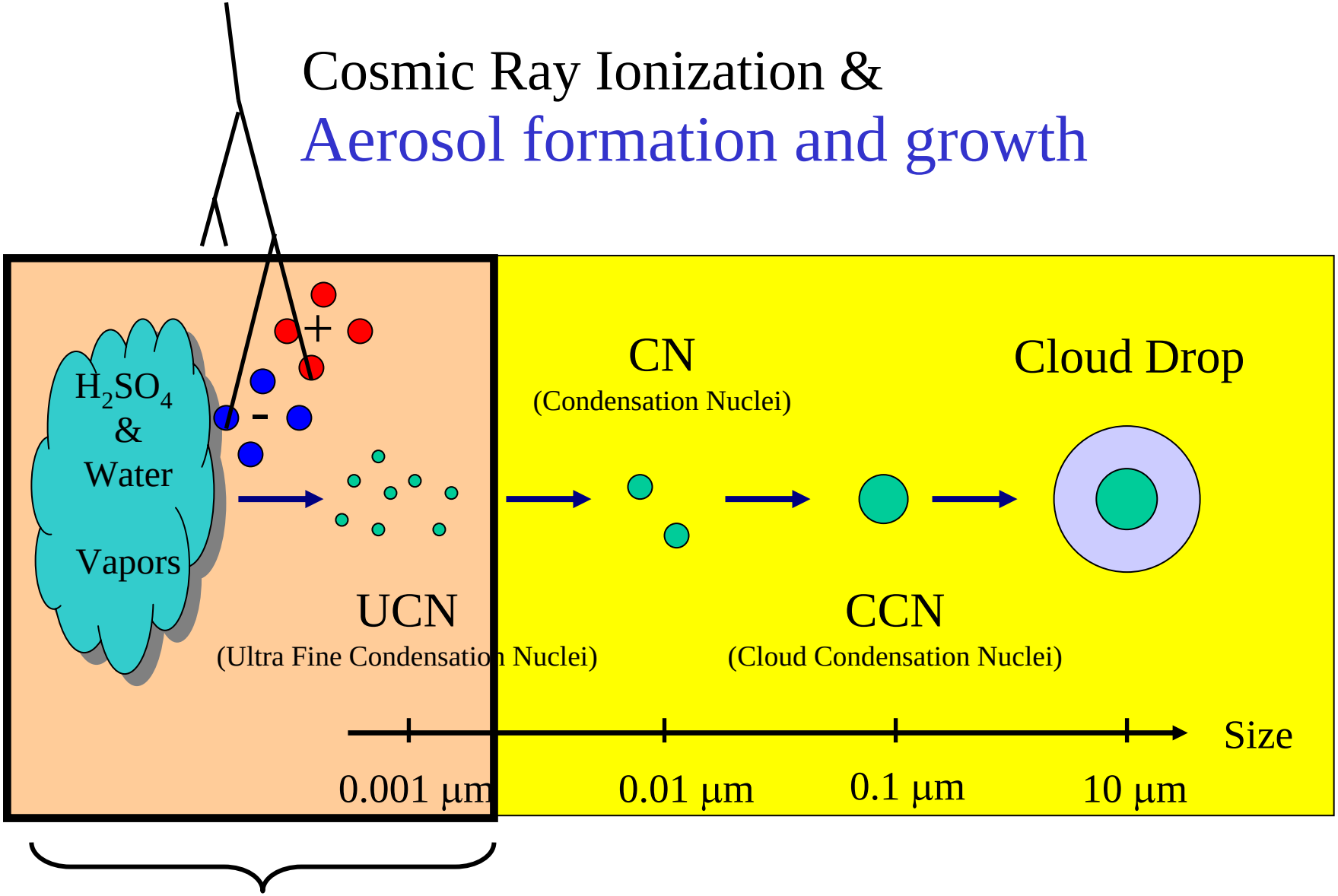
Aerosol formation and growth

Possible link between clouds and cosmic rays



Nucleation process
has been a mystery

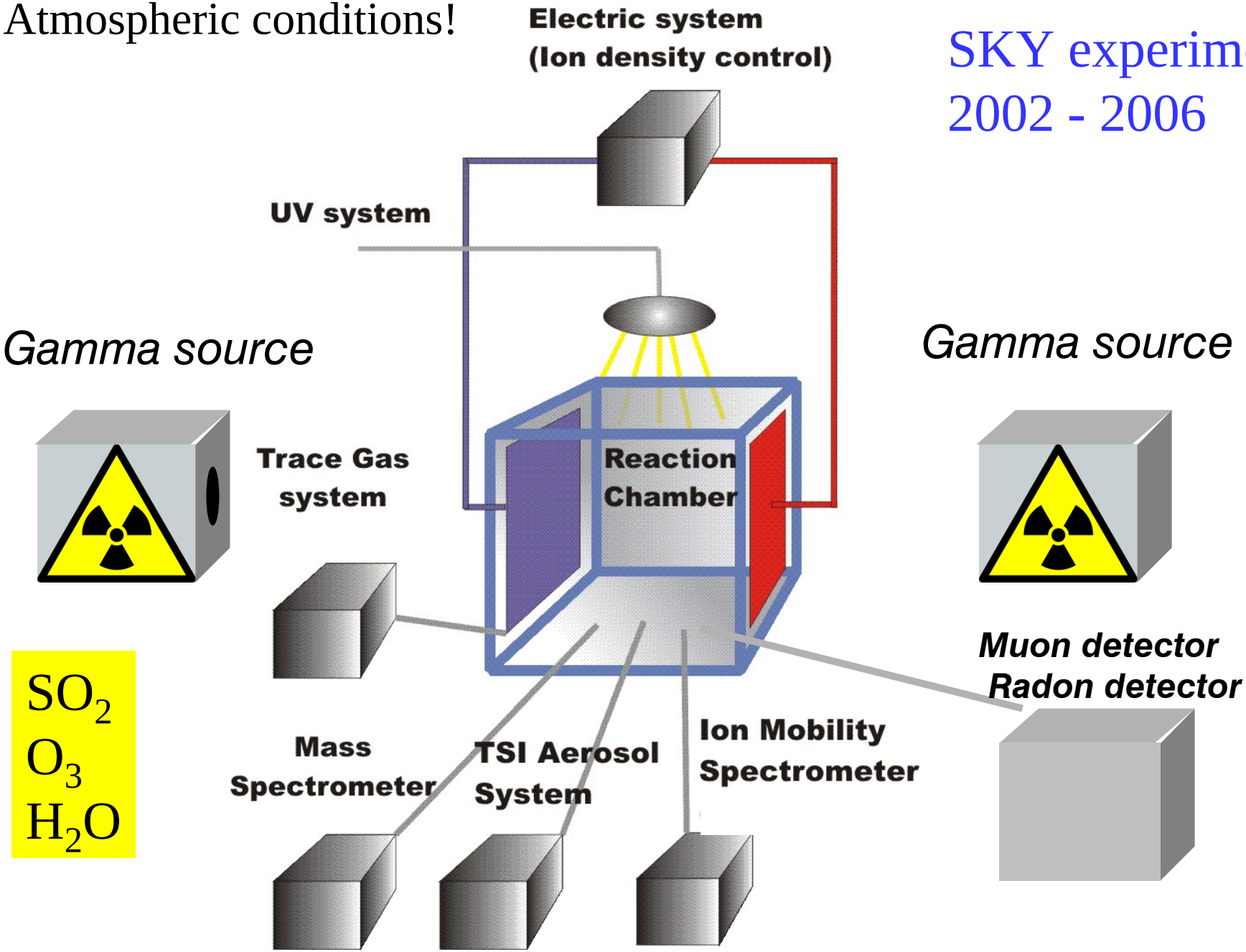
Cosmic Ray Ionization &
Aerosol formation and growth

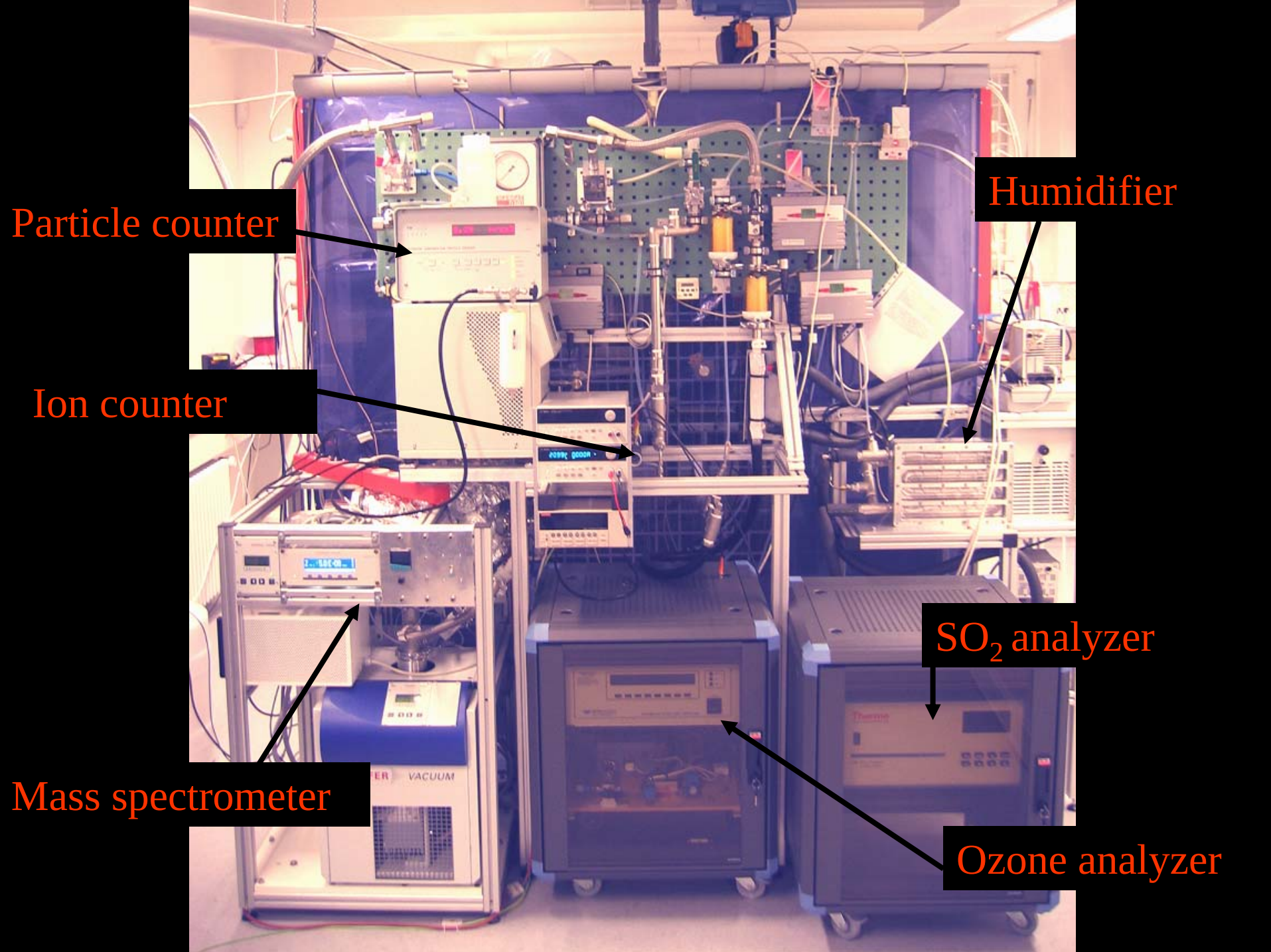


What is the importance of IONS ?

Atmospheric conditions!

SKY experiment
2002 - 2006




Particle counter
Humidifier
Ion counter
SO_2 analyzer
Mass spectrometer
Ozone analyzer

Experimental conditions

Fixed:

P = 1000 mbar

T = 293 K

Variable:

Trace-gases

SO_2 ~ 60- 10.000 ppt

O_3 ~ 1 - 40 ppb

H_2O ~ 1 – 100% RH

Carrier Gasses

Filtered air

Syntetic air (from liquid N2 and O2)

Argon/oxygen

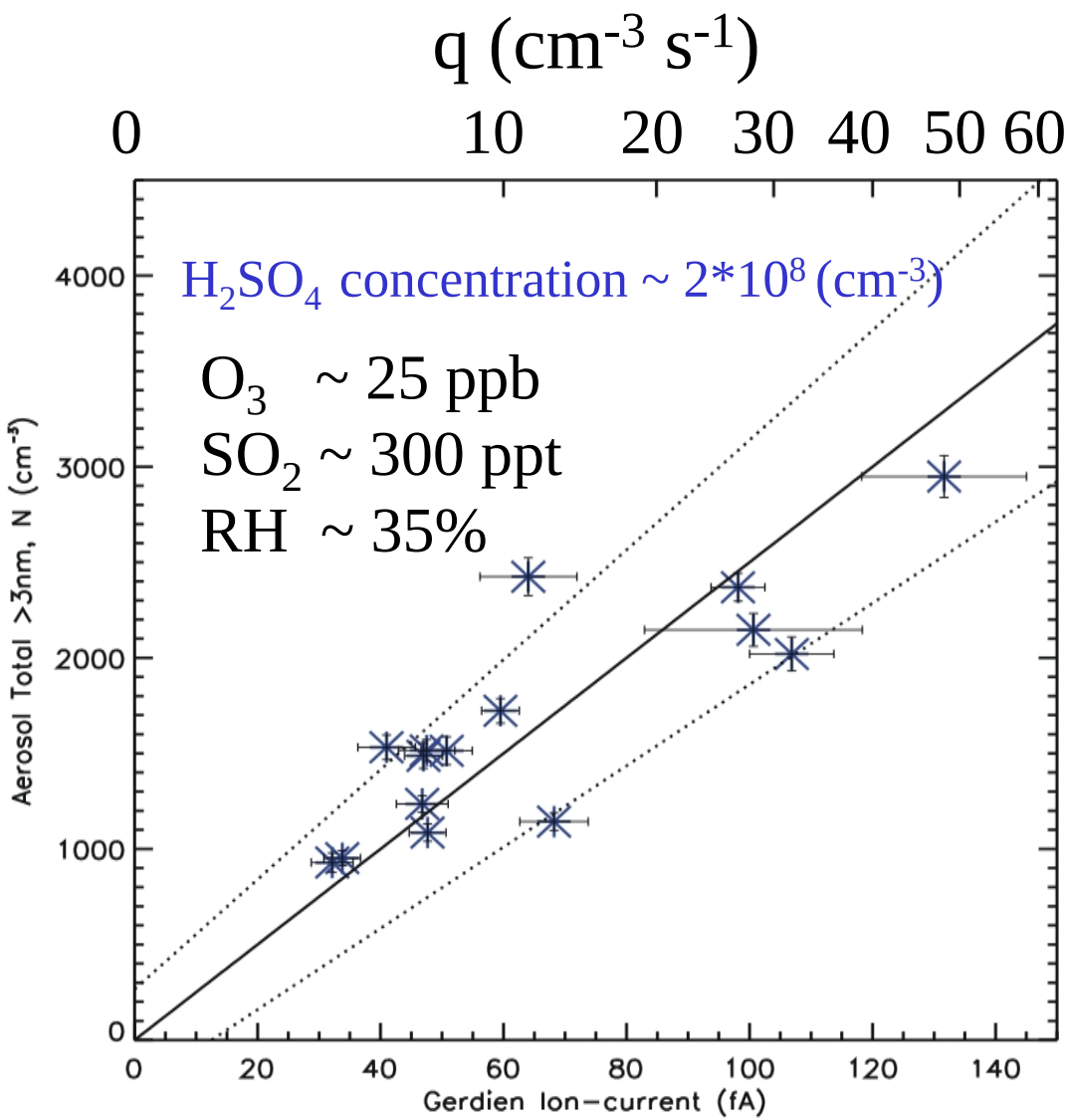
Ions

3 ionpar/cm^3 s from Cosmic Rays

0 – 45 ionpar/cm^3 s from 2 gamma ray sources

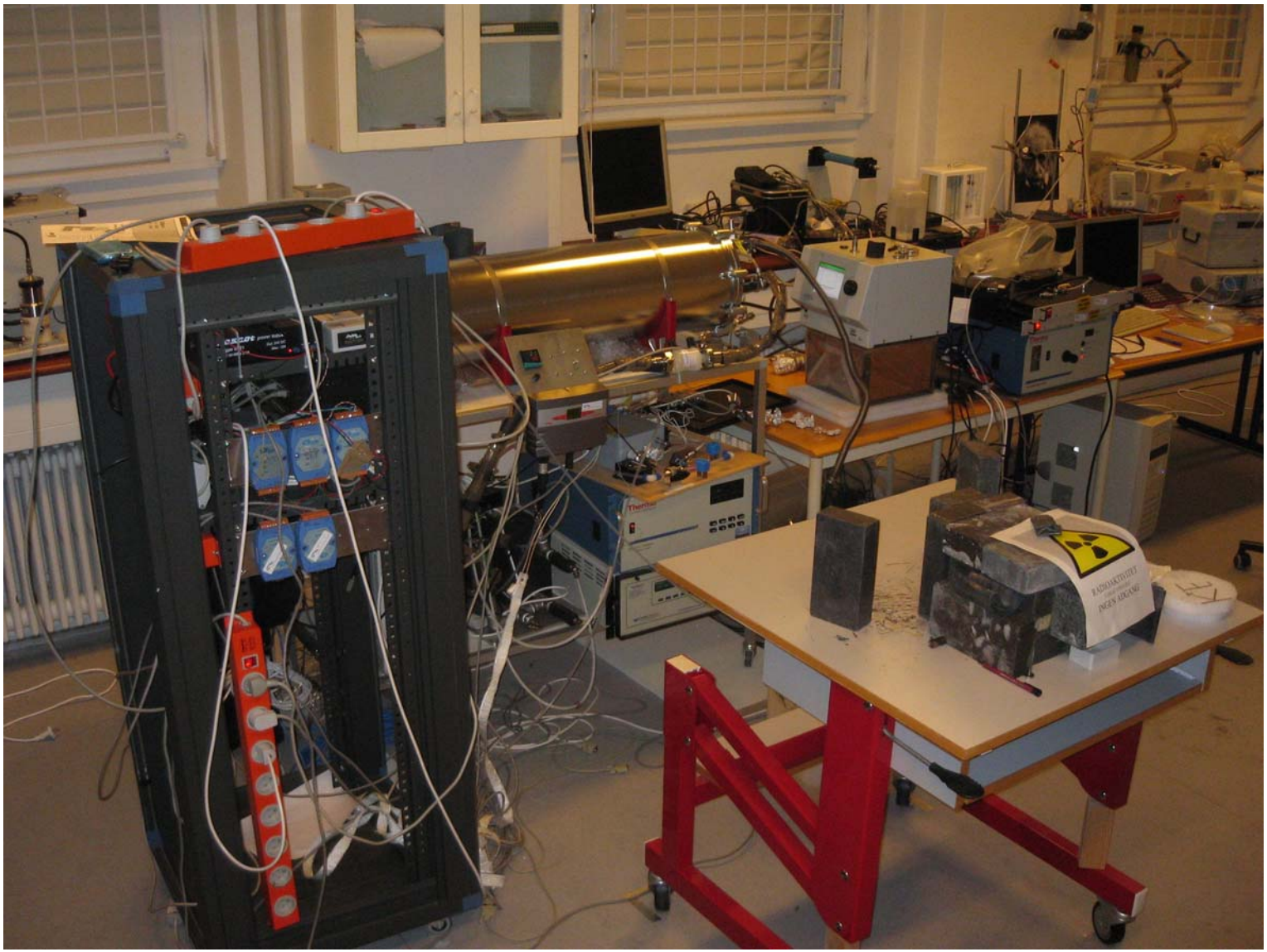
Ion density reduced 1/1000 (electrical field)

Steady state experiment



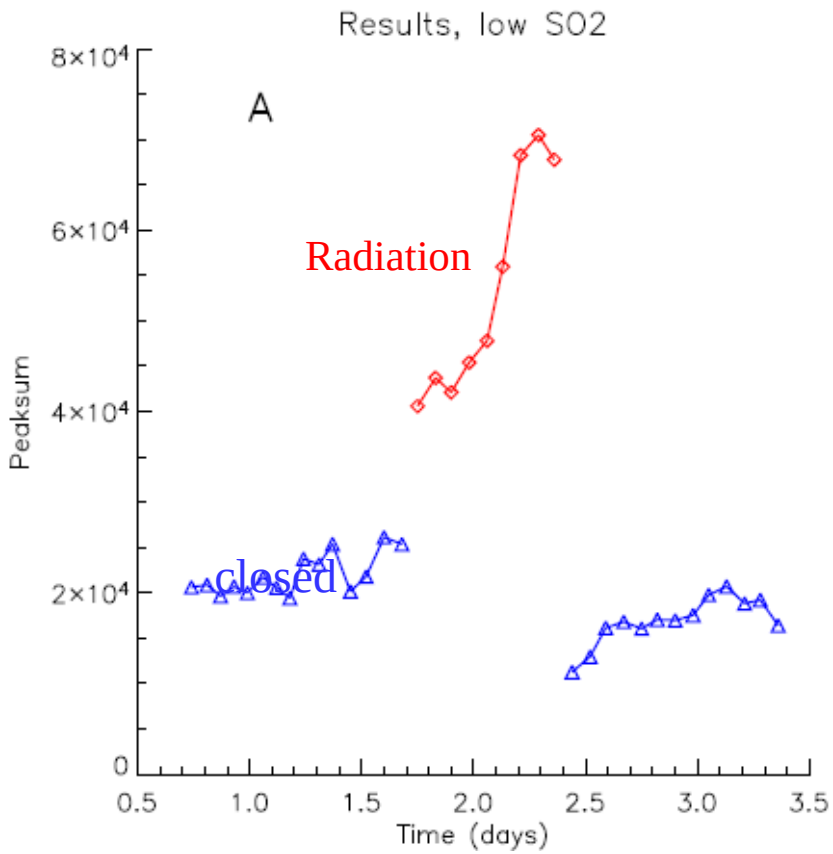
Svensmark et al. Proc. R. Soc. A (2007) 463, 385–396

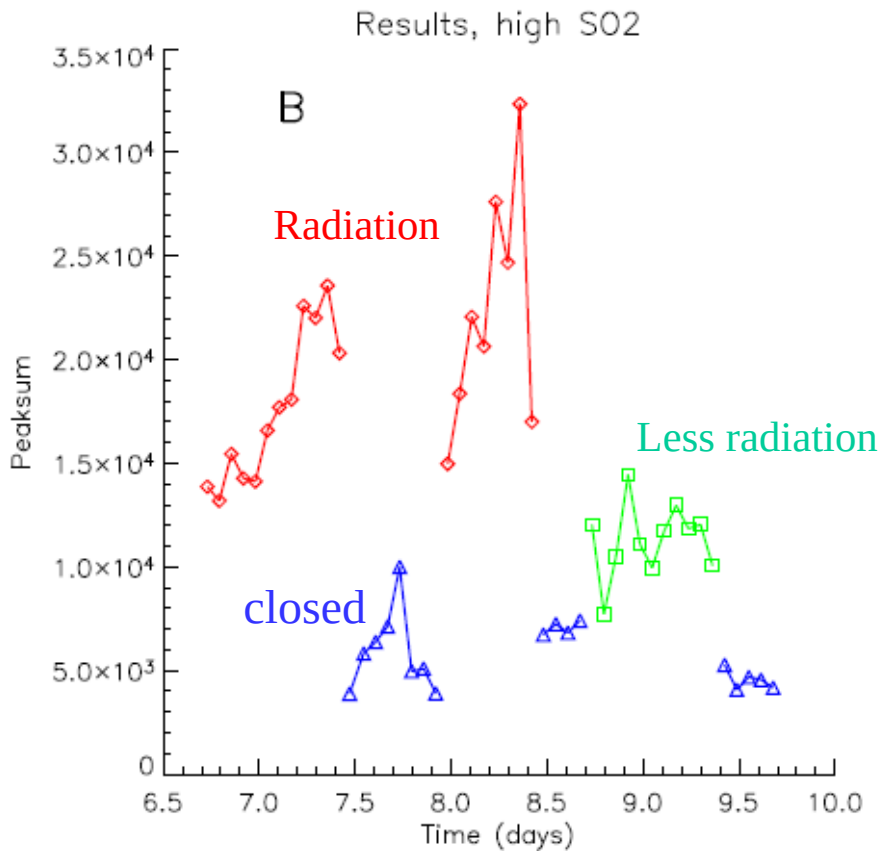
Copenhagen – SKY experiment



Evidence for the role of ions in Aerosol Nucleation

Martin B. Enghoff,1 Jens Olaf Pepke Pedersen,1 Torsten Bondo,1
Matthew S. Johnson,2 Sean Paling,3 and Henrik Svensmark

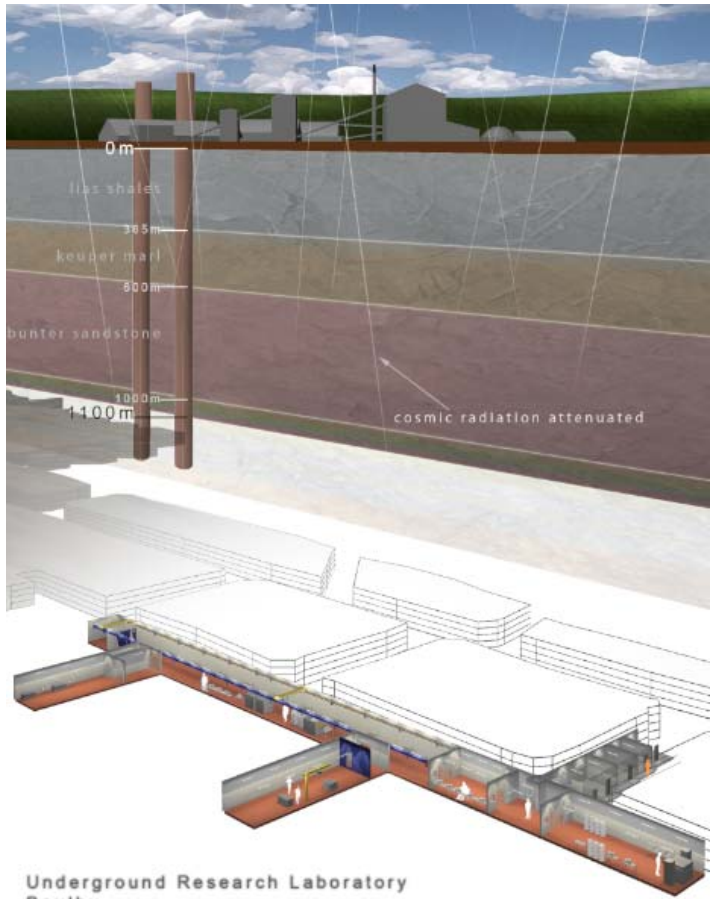




Boulby Underground Laboratory

Above

In the mine (-1.1 km)



Underground Research Laboratory
Boulby

The Lab

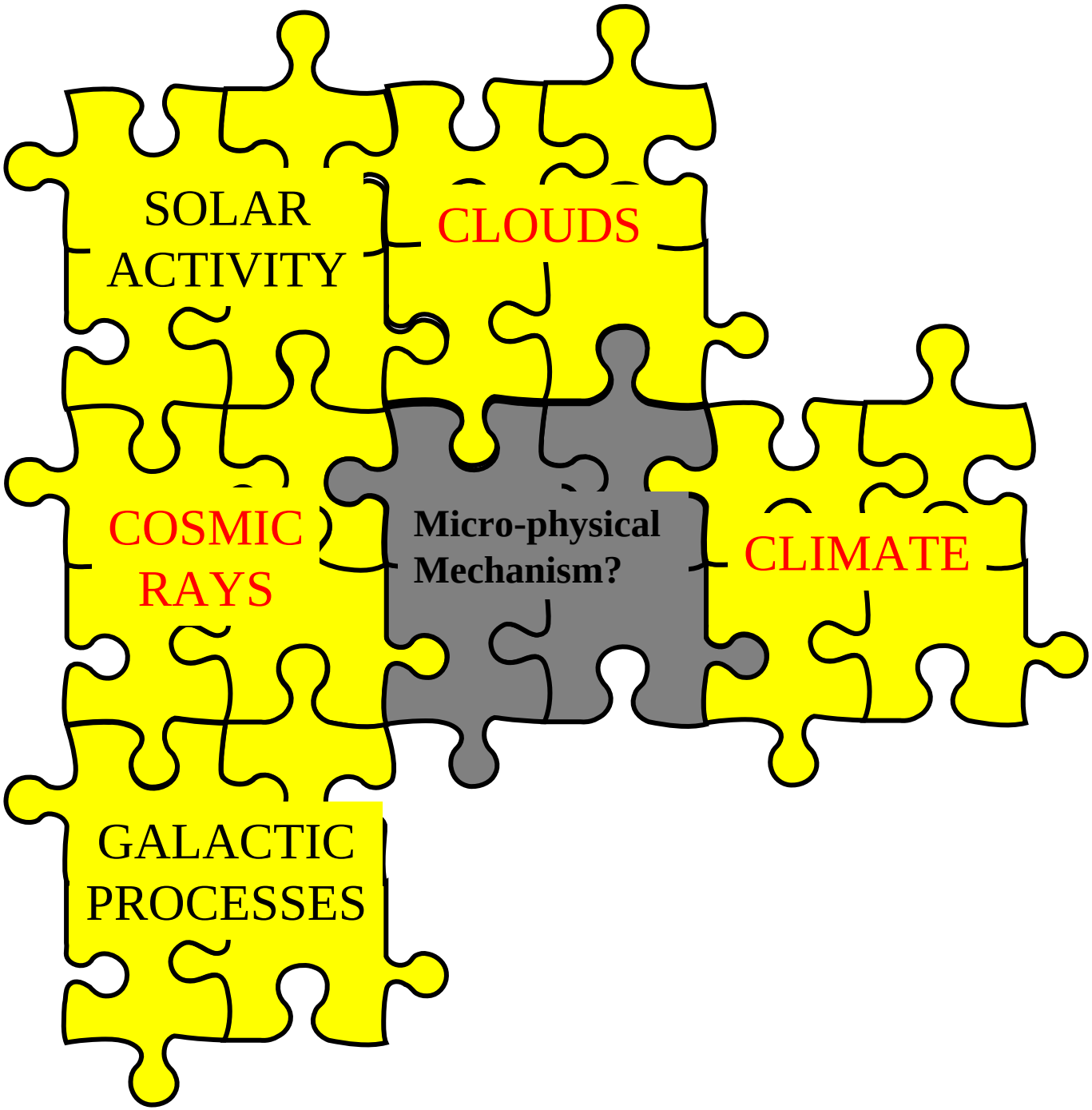
November 2008-
Januar 2009

Shielding the experiment

Does it work in the real atmosphere?

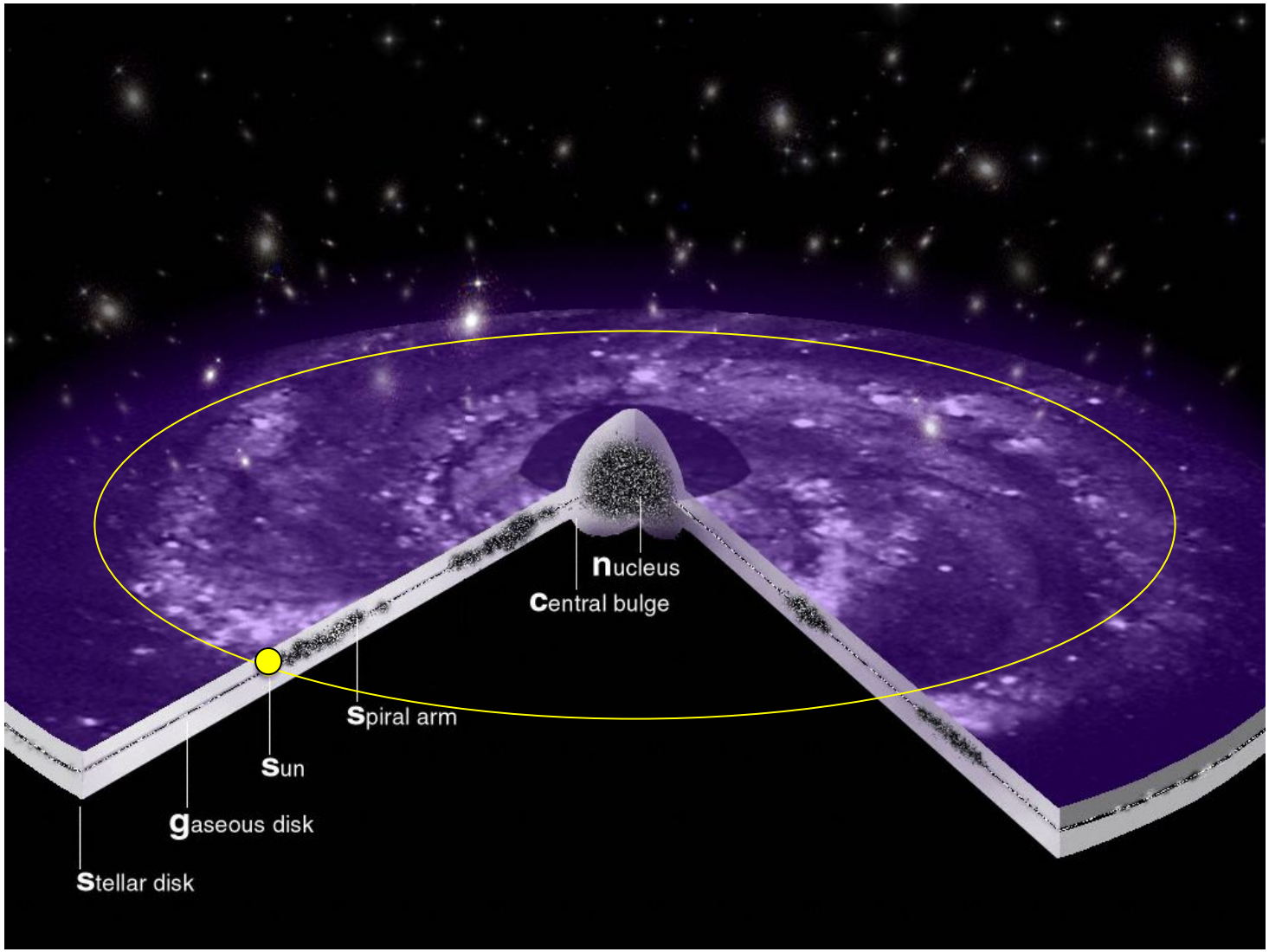
Statements

1. There are always plenty of CCN in the atmosphere a few more will not matter.
2. The experiment is not relevant for the atmosphere
3. Not Cosmic rays but other solar parameters like TSI or UV are important.
4. It is not important

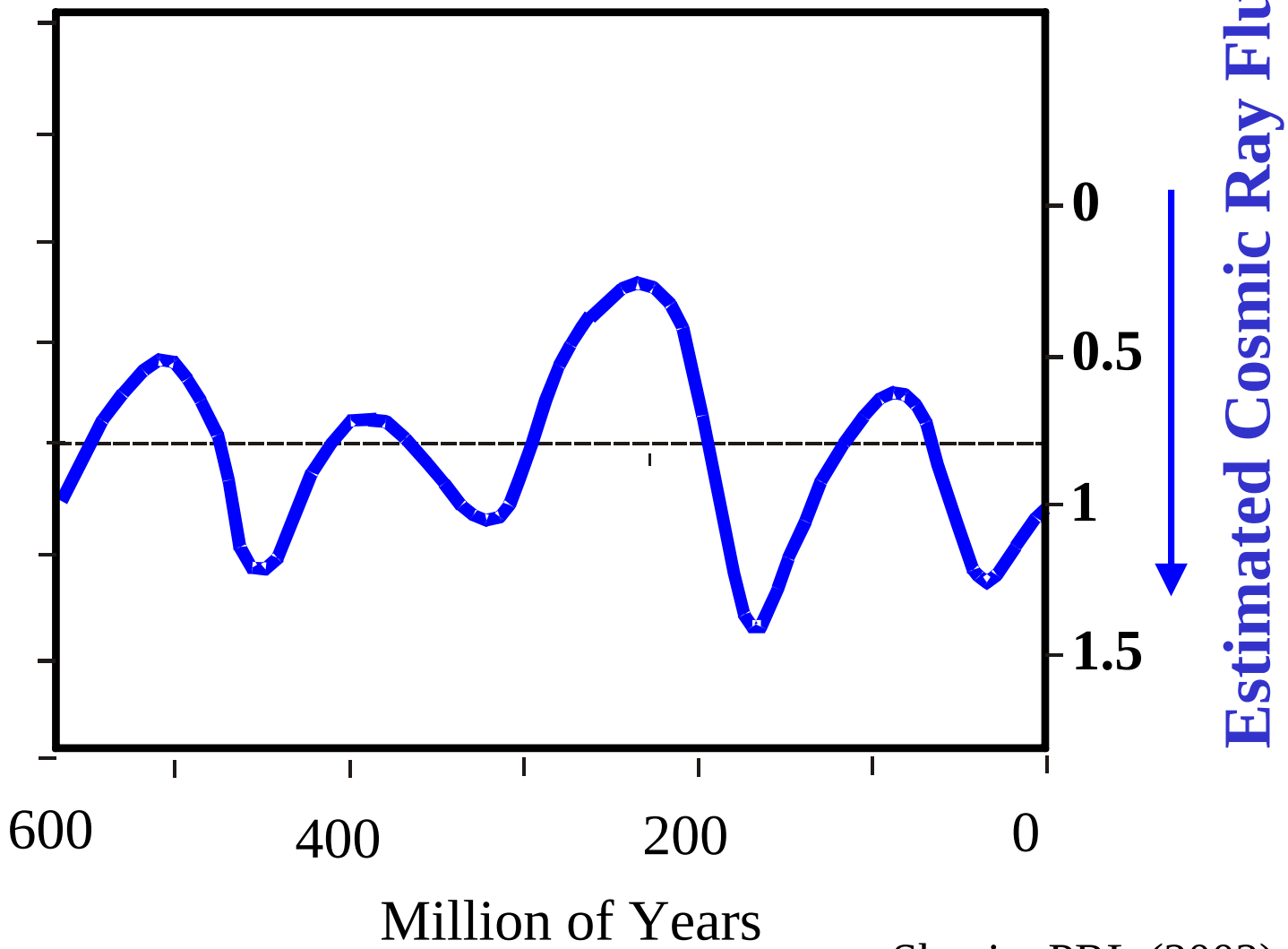

SOLAR ACTIVITY
CLOUDS
COSMIC RAYS
Micro-physical Mechanism?
CLIMATE
GALACTIC PROCESSES

The Milky Way, Super Novae and Cosmic Rays

The Milky Way, Super Novae and Cosmic Rays

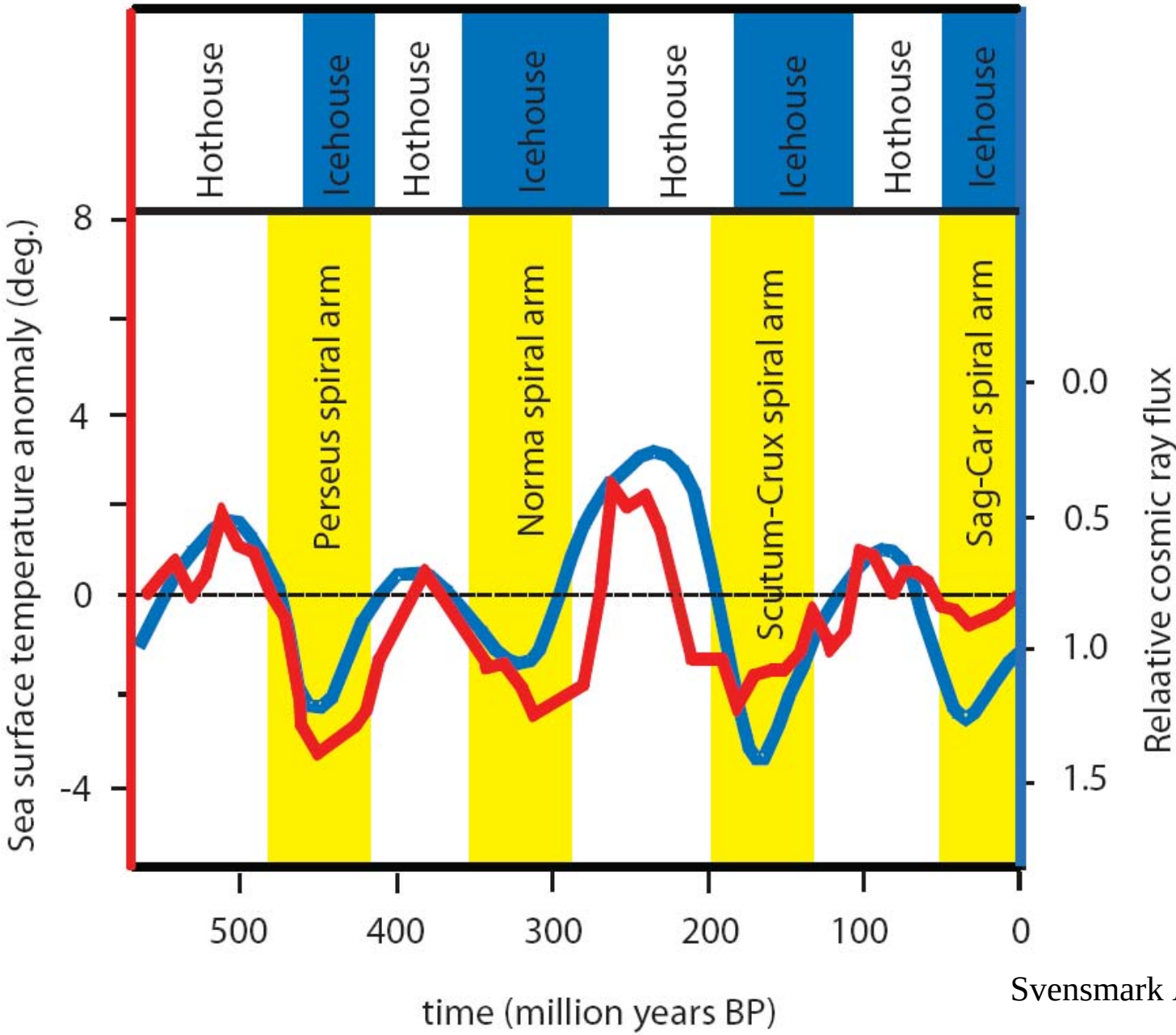


Cosmic rays and spiral arm crossing



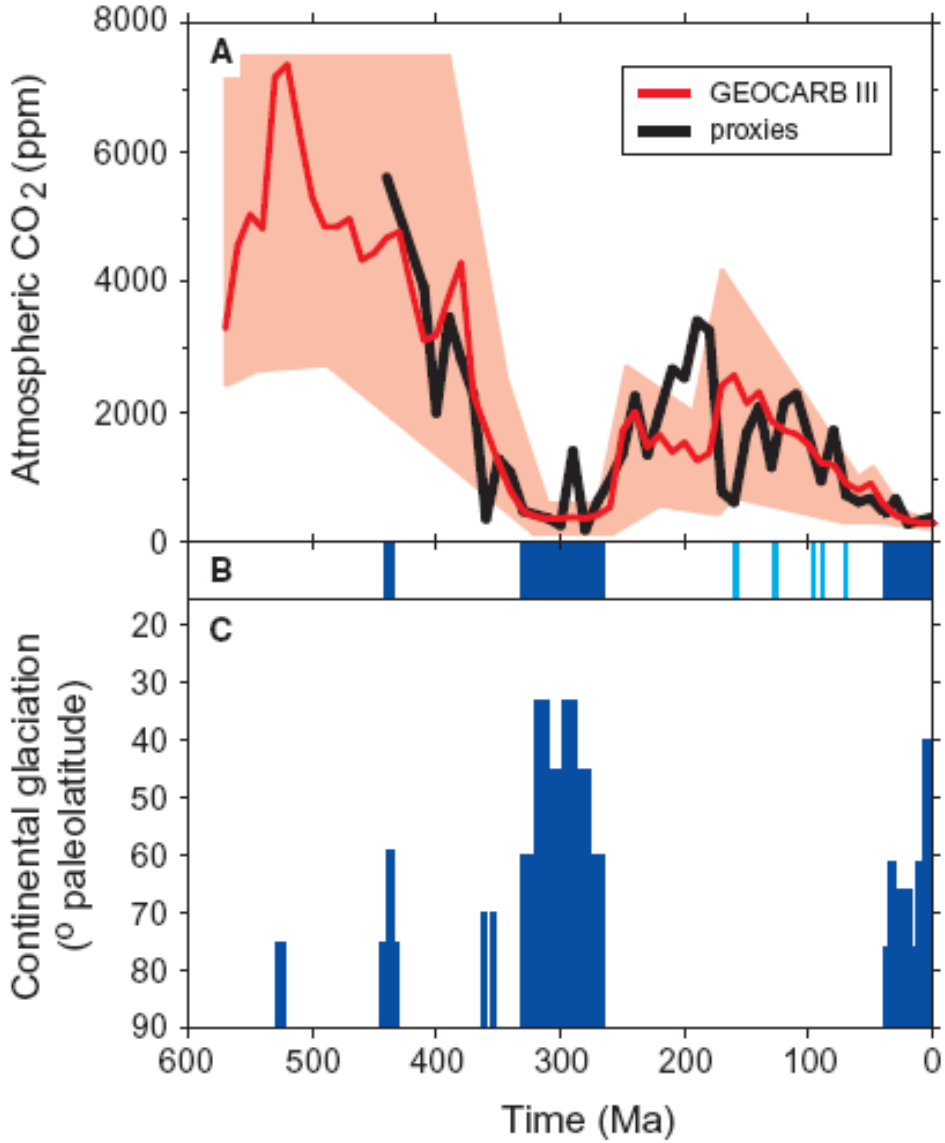
Shaviv, PRL (2002)

Shaviv & Veizer



Svensmark A&G 2007

CO_2 as a primary driver of Phanerozoic climate

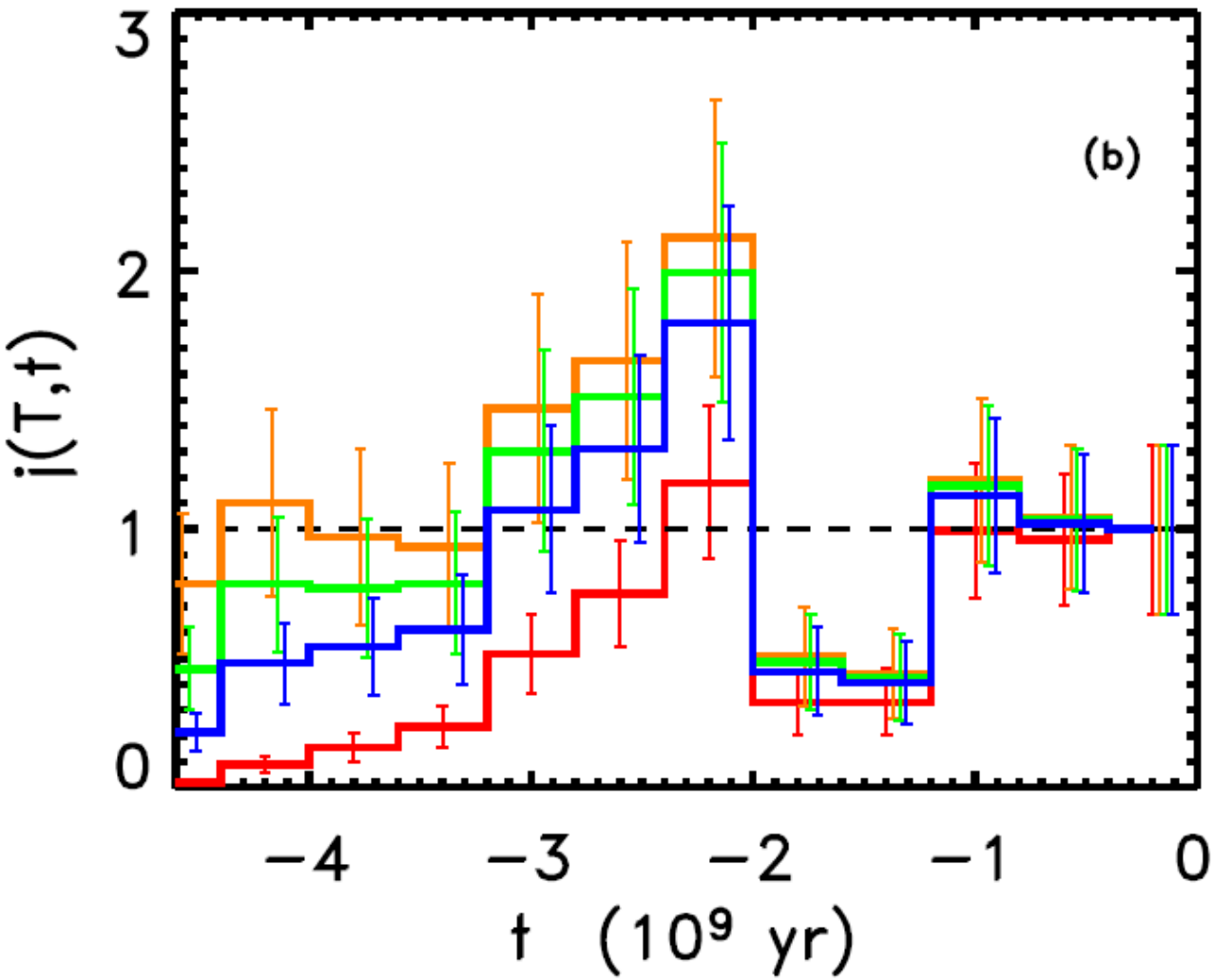


What about longer time scales, i.e over the history of the Earth 4.6 Billion years?

Although Cosmic ray fluxes are not known so far back in time, they can be constructed from knowledge of

1. Solar Evolution
2. History of Star Formation Rate in the Milky Way

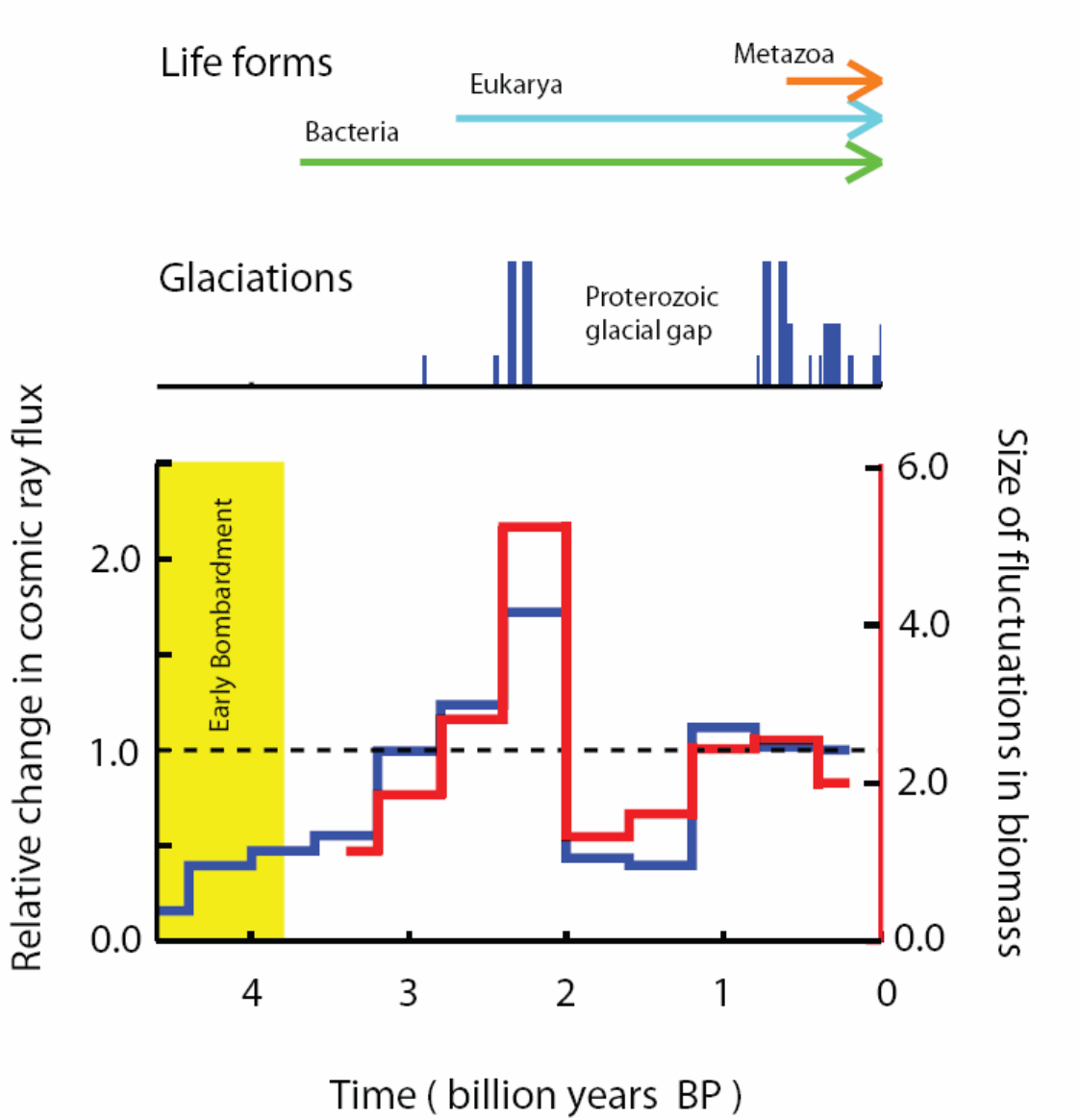
Solar Evolution, Star Rate Formation and Cosmic Rays



Svensmark, Astronomical Notes 2006

Interaction between galaxies

Cosmic Rays and the Biosphere in 4 Billion Years

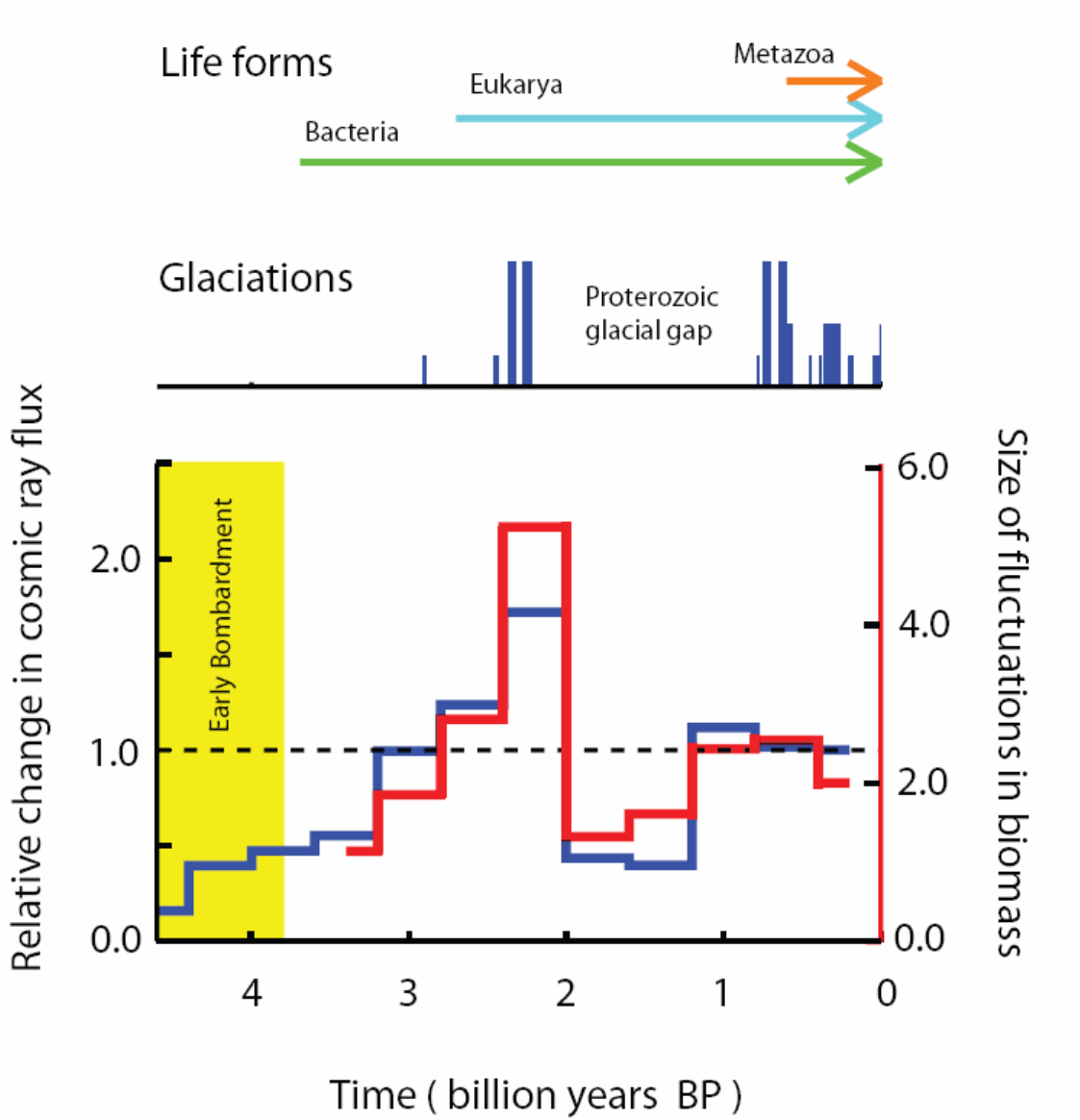


Svensmark, Astronomical Notes 2006

Snowball Earth

Hofman and Schrag point to glaciomarine dropstone

Cosmic Rays and the Biosphere in 4 Billion Years



Svensmark, Astronomical Notes 2006

Conclusion

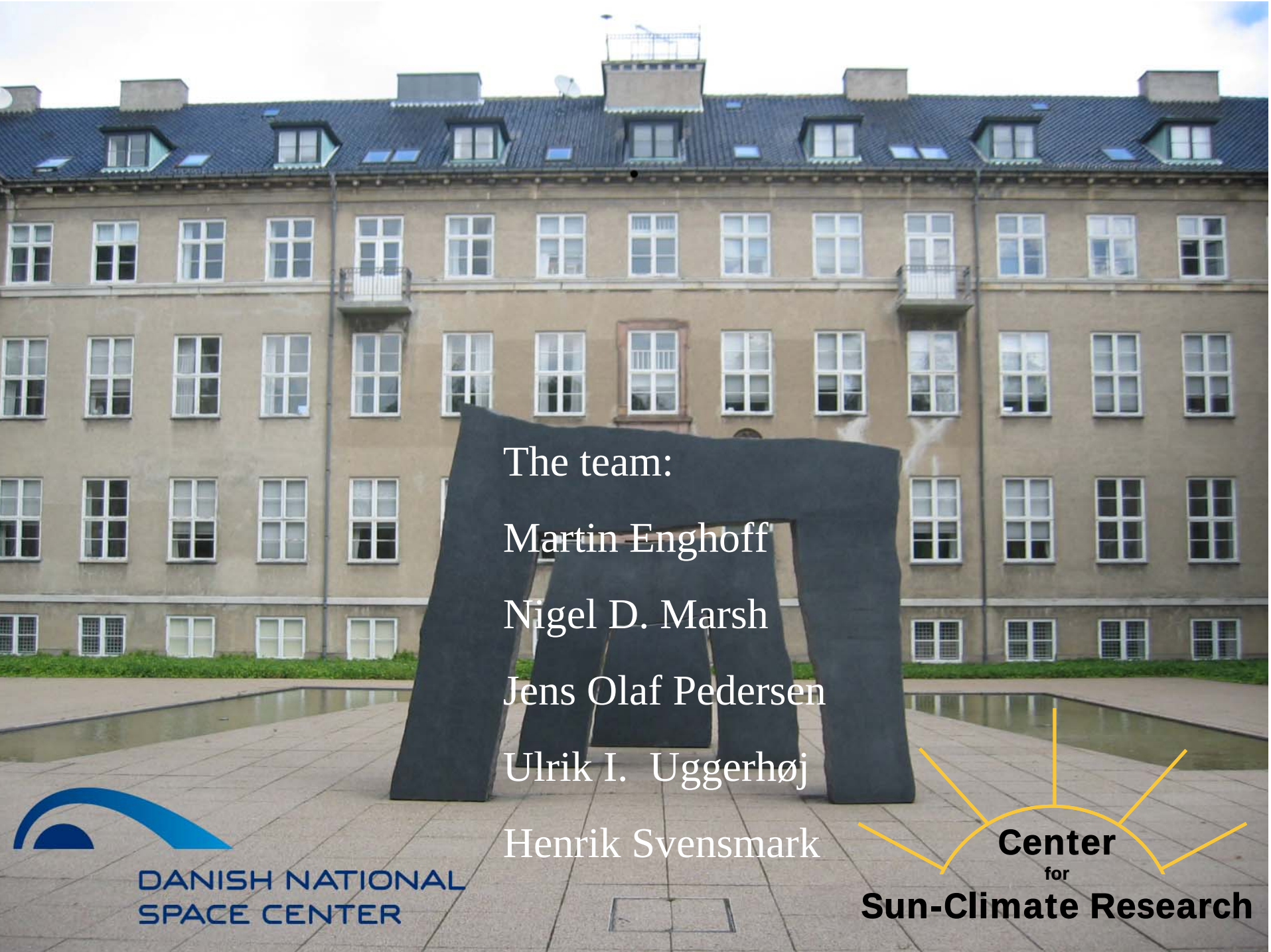
Particles from space influence Earths climate, ranging from days to 10^9 years.

Part of the missing physical mechanism has been demonstrated experimentally

- **Involving ions and aerosol formation**
- **Linking to clouds and thereby the energy budget of the Earth**

Understanding the cosmic ray climate link could have large implications in our understanding of climate changes and possible evolution on Earth.

The evolution of the Milky Way and the Earth is linked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DANISH NATIONAL SPACE CENTER
Center for Sun-Climate Research

Scientists agree that over the last century the Earth has become warmer. But do we really know why this has happened?

A deftly written and enjoyable read, *The Chilling Stars* outlines a brilliant, daring and undoubtedly controversial new theory that will provoke fresh thinking about global warming.

As prize-winning science writer Nigel Calder and climate physicist Henrik Svensmark explain, an interplay of the clouds, the Sun and cosmic rays – sub-atomic particles from exploded stars – seems to have more effect on the climate than man-made carbon dioxide.

This conclusion stems from Svensmark's research at the Danish National Space Center which has recently shown that cosmic rays play an unsuspected role in making our everyday clouds. And during the last 100 years cosmic rays became scarcer because unusually vigorous action by the Sun batted many of them away. Fewer cosmic rays meant fewer clouds and a warmer world.

The theory, simply put here but explained in fascinating detail in the book, emerges at a time of intense public and political debate about climate change. Motivated only by their concern that science must be trustworthy, Svensmark and Calder invite their readers to put aside their preconceptions about man-made global warming and look afresh at the role of Nature in this hottest of world issues.

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THE CHILLING STARS

Henrik Svensmark & Nigel Calder

THE CHILLING STARS

A New Theory of Climate Change

Henrik Svensmark & Nigel Calder