Cosmo-Climatology

Cosmic rays, Clouds, and Climate

Henrik Svensmark,

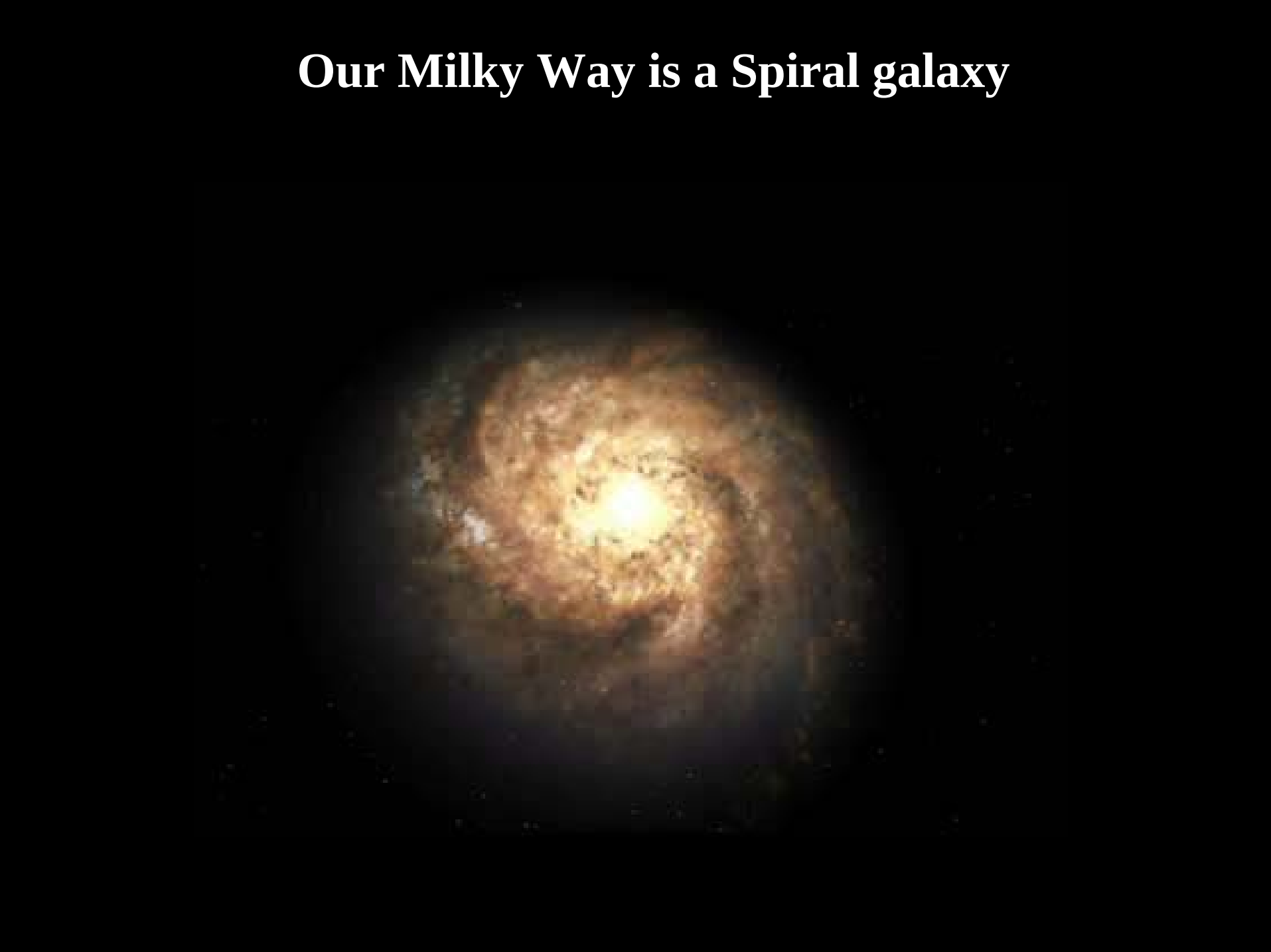
Center for Sun Climate Research

Space- DTU

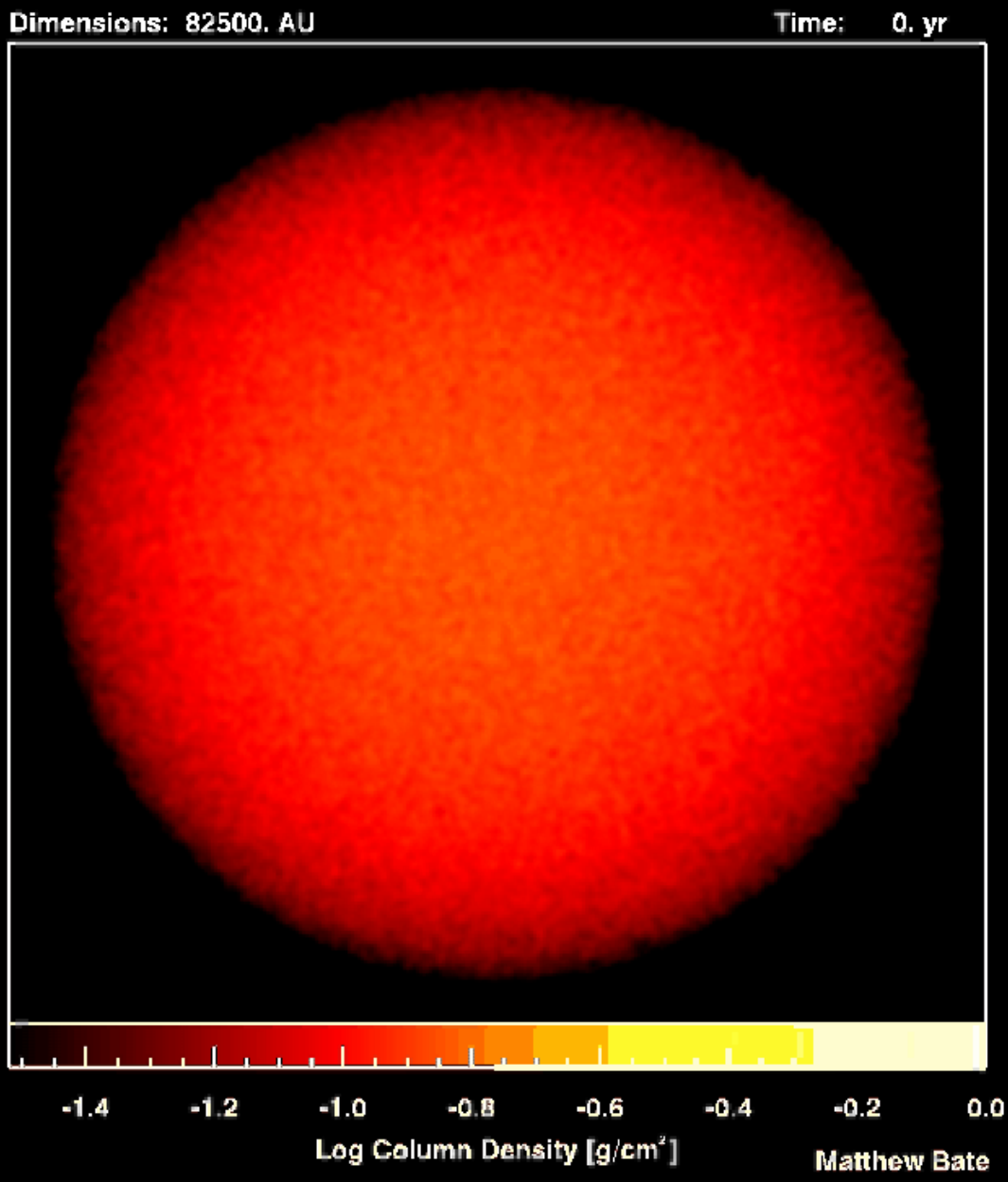
Cosmoclimatology

- 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)

Our Milky Way is a Spiral galaxy



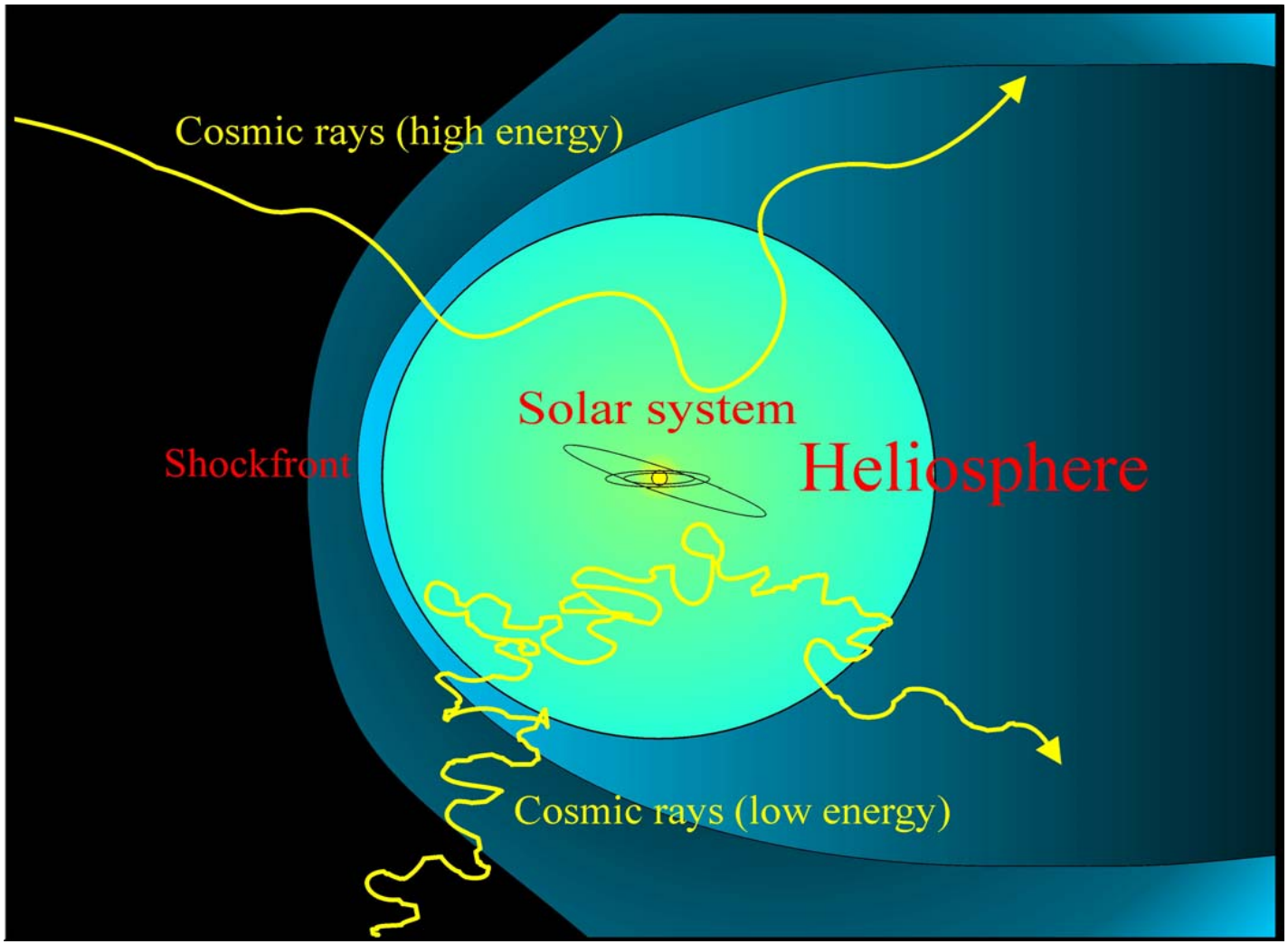
Star formation from a cloud of gas of hydrogen



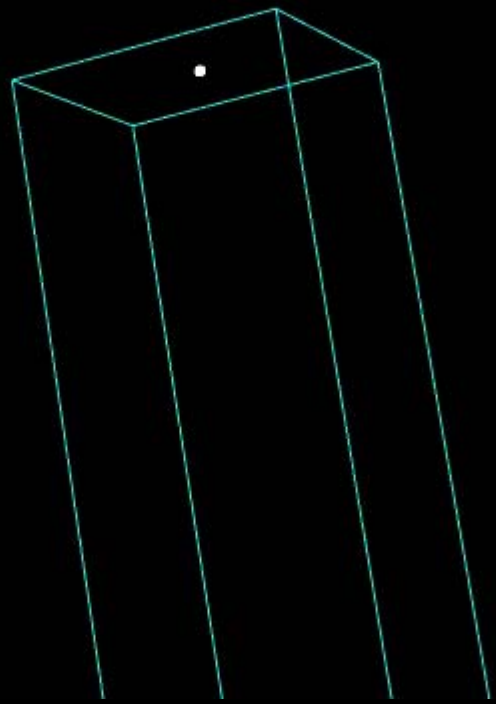
Super Nova explosions happens for heavy stars (> $8M_{sun}$)

What are Cosmic Rays?

Heliosphere, Cosmic Rays and Solar Activity

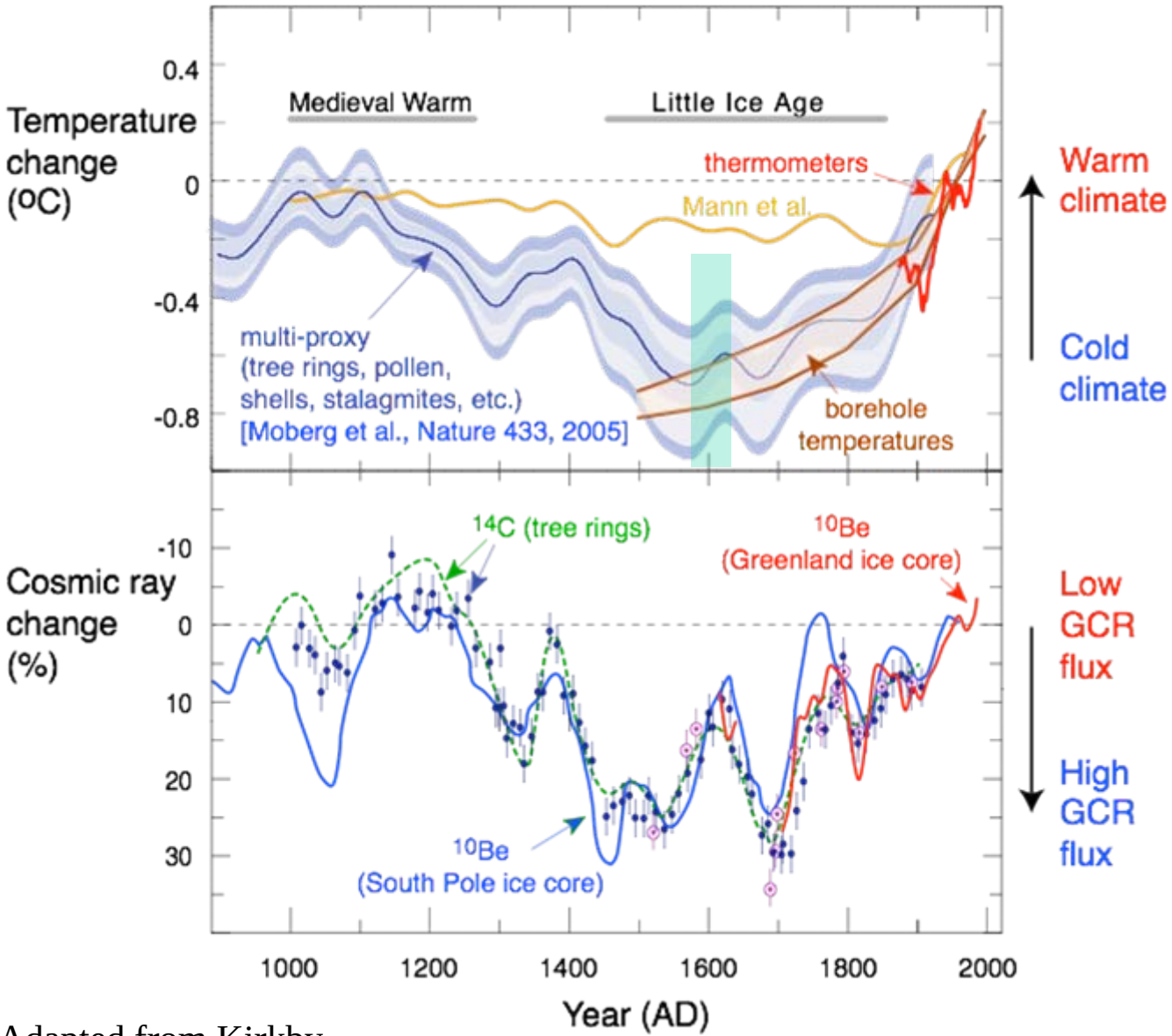


Cosmic ray shower (Movie)



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

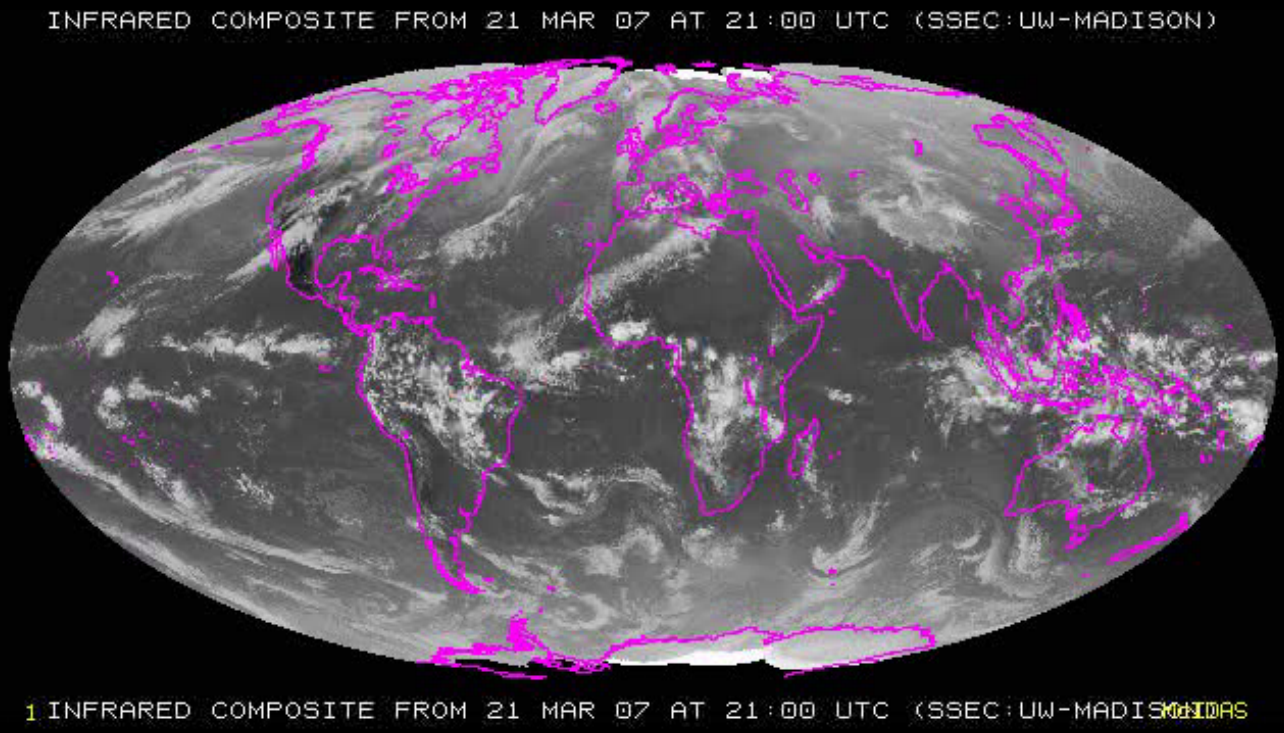
Cosmic rays and climate over the last millennium



”Since everybody thought that the continous crop faliure was caused by witches from devilish hate, the whole contry stood up for their eradication”
Johann Linden Travis
ca. 1590

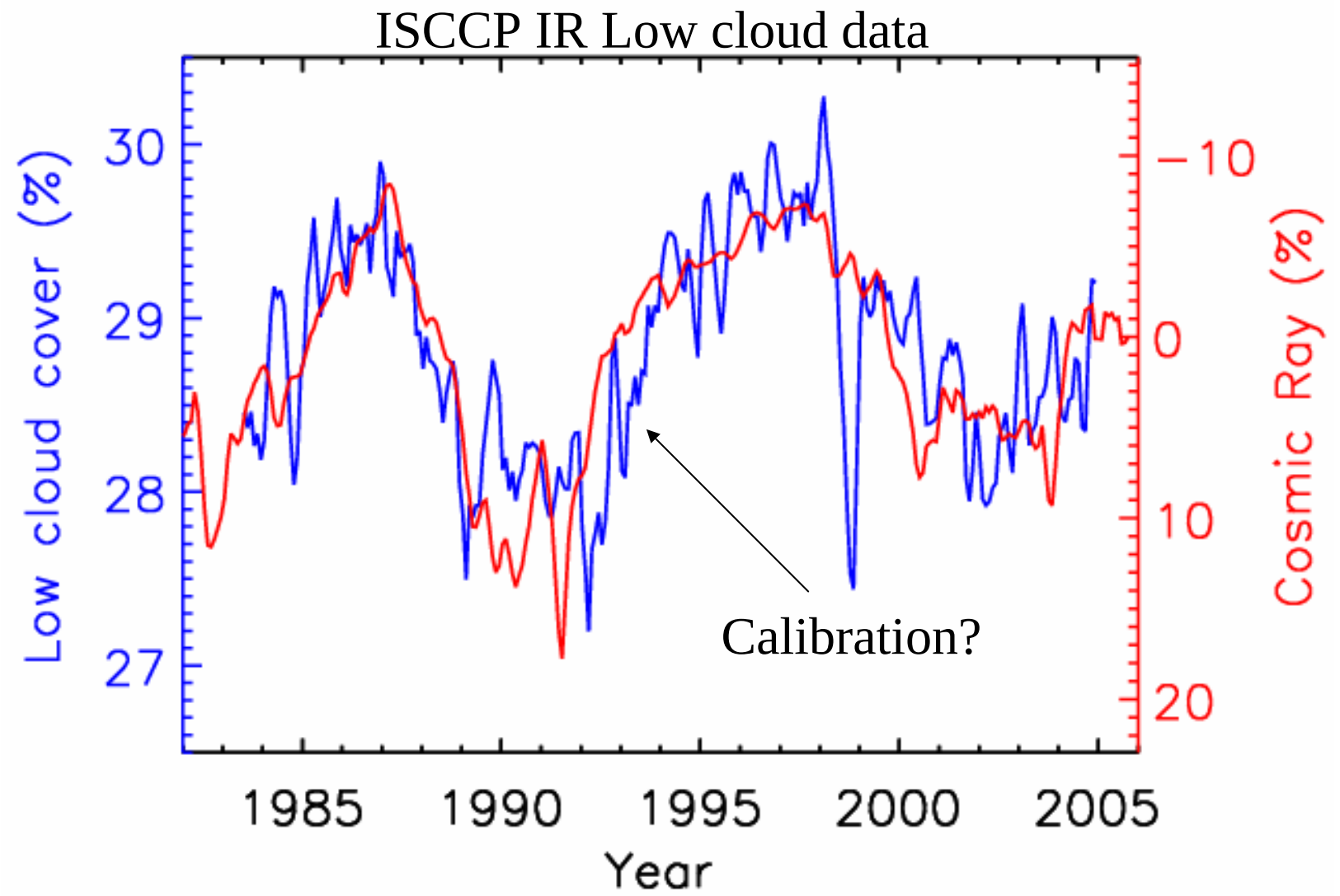
Adapted from Kirkby

How can STARS influence Climate?



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

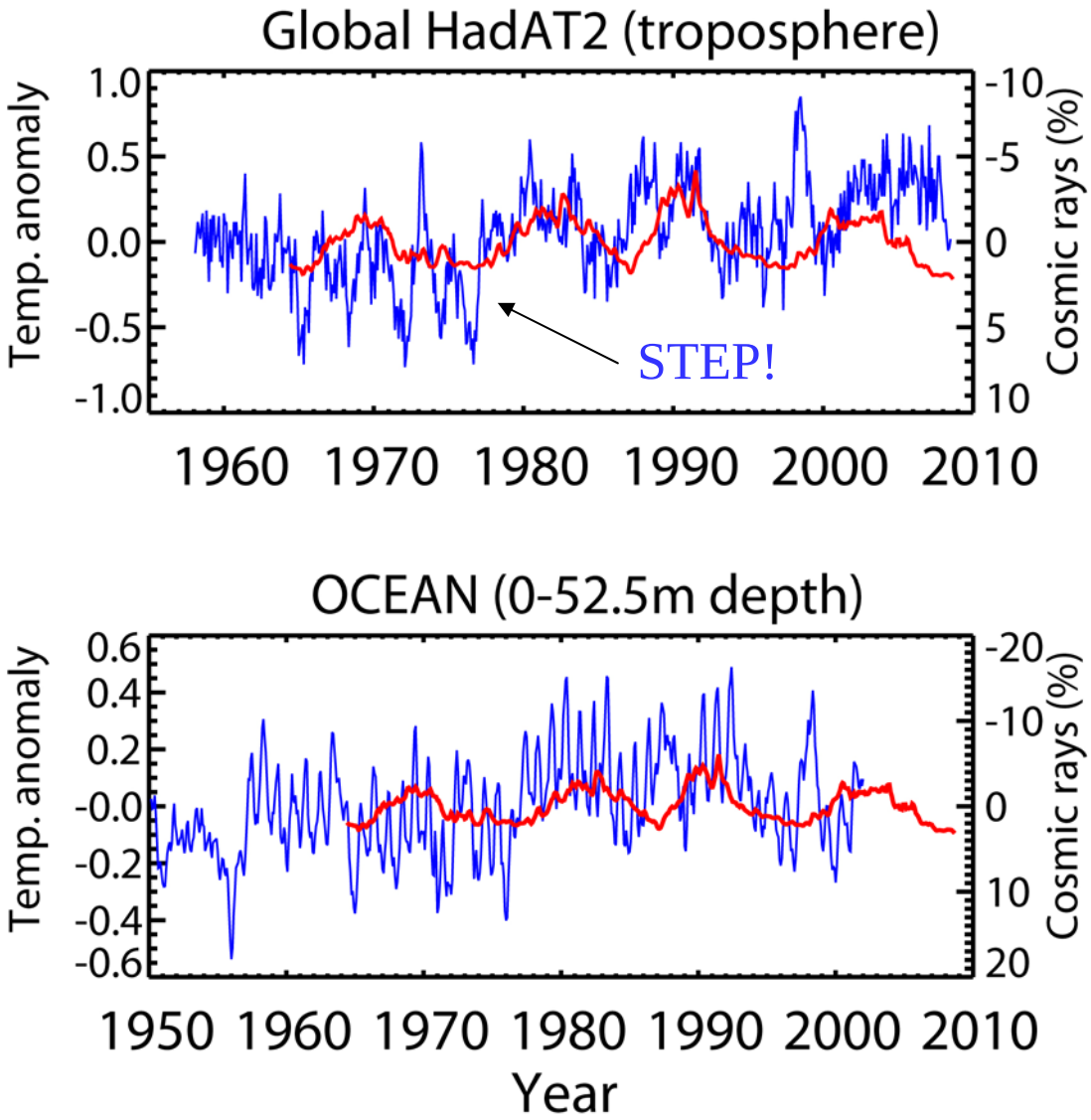
Link between Low Cloud Cover and Galactic Cosmic Rays?



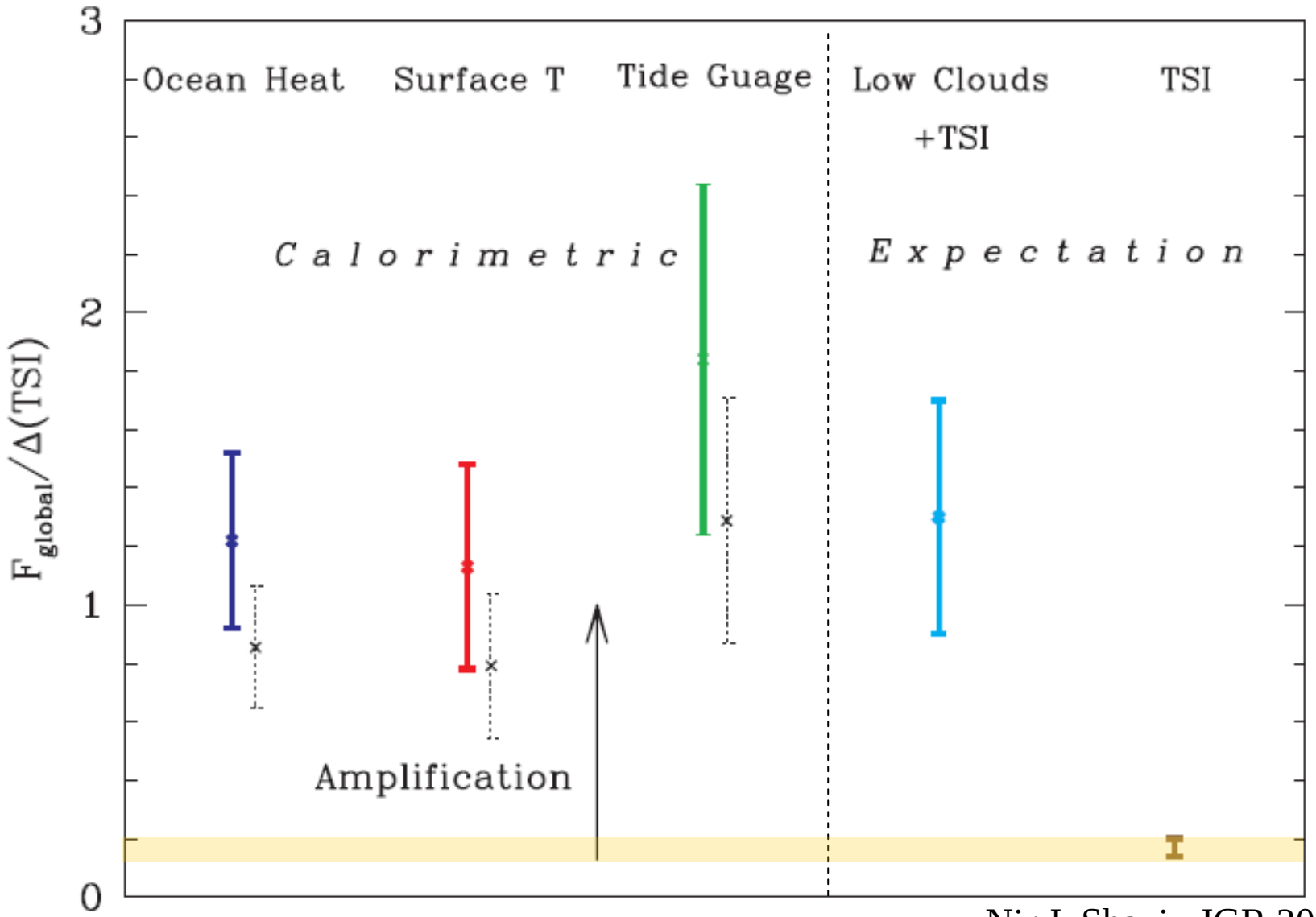
Svensmark & Friis-Christensen, JASTP 1997, Svensmark, PRL 1998, Marsh & Svensmark, PRL, 2000. (update 2005)

Cosmic Rays and 1960 -2008 tropospheric temperatures

Average temperature between 0-10 km

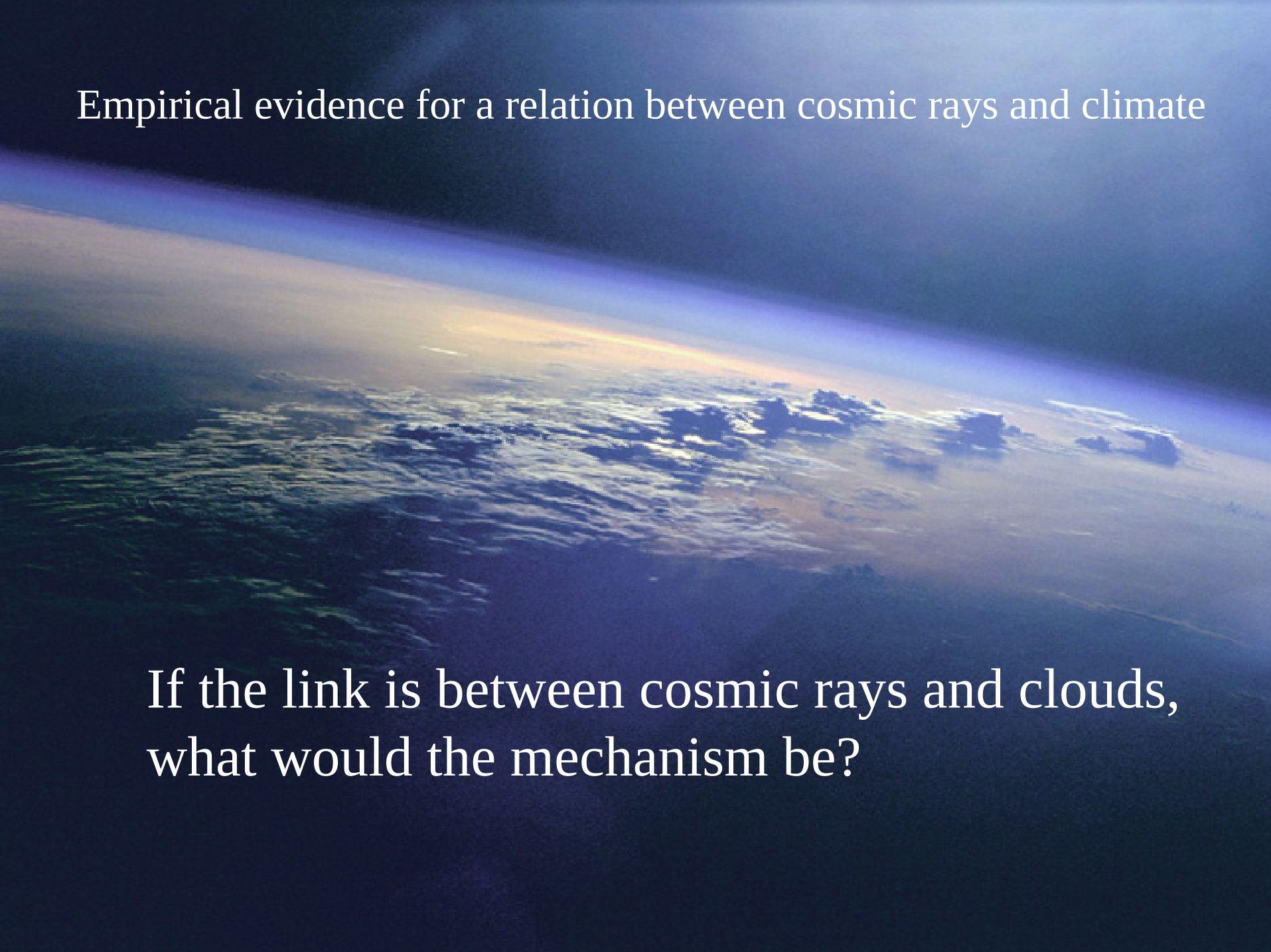


Using the oceans as a calorimeter to quantify the solar radiative forcing



Nir J. Shaviv JGR 2009

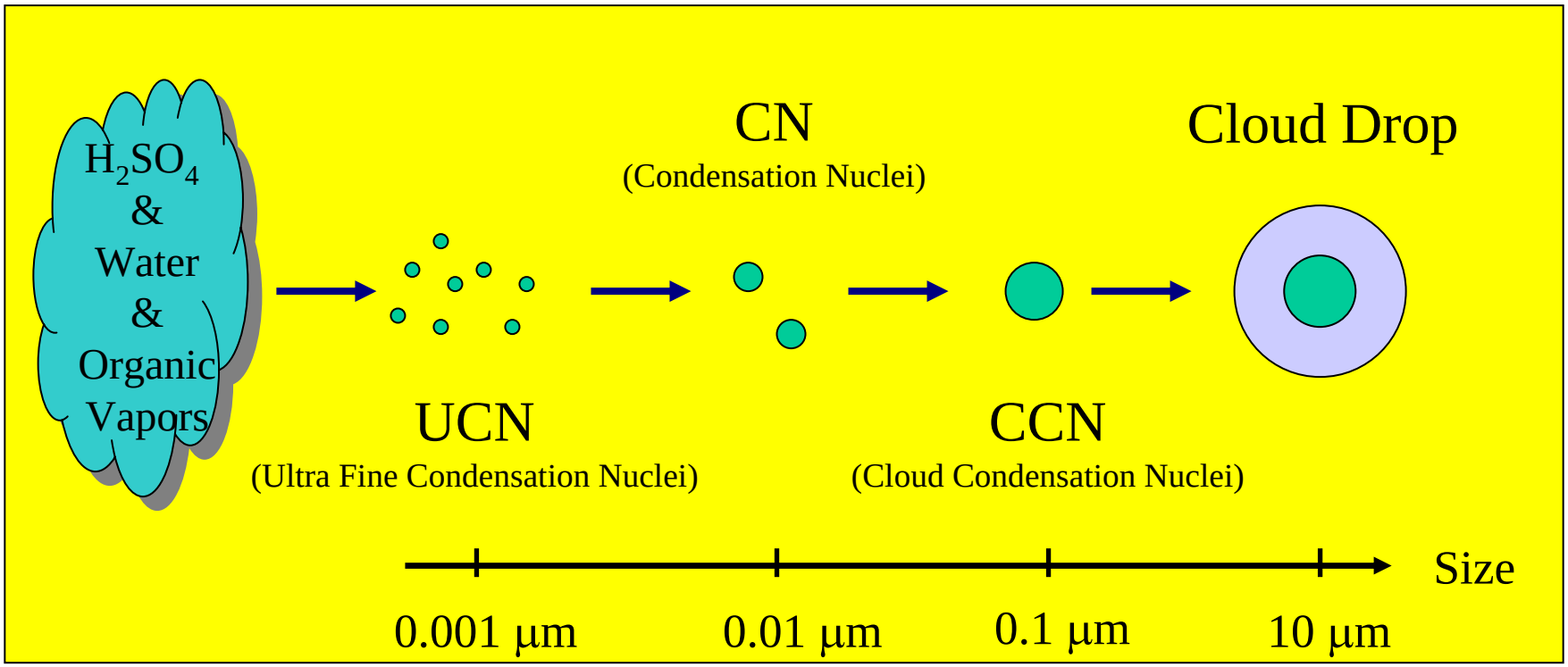
Empirical evidence for a relation between cosmic rays and climate



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

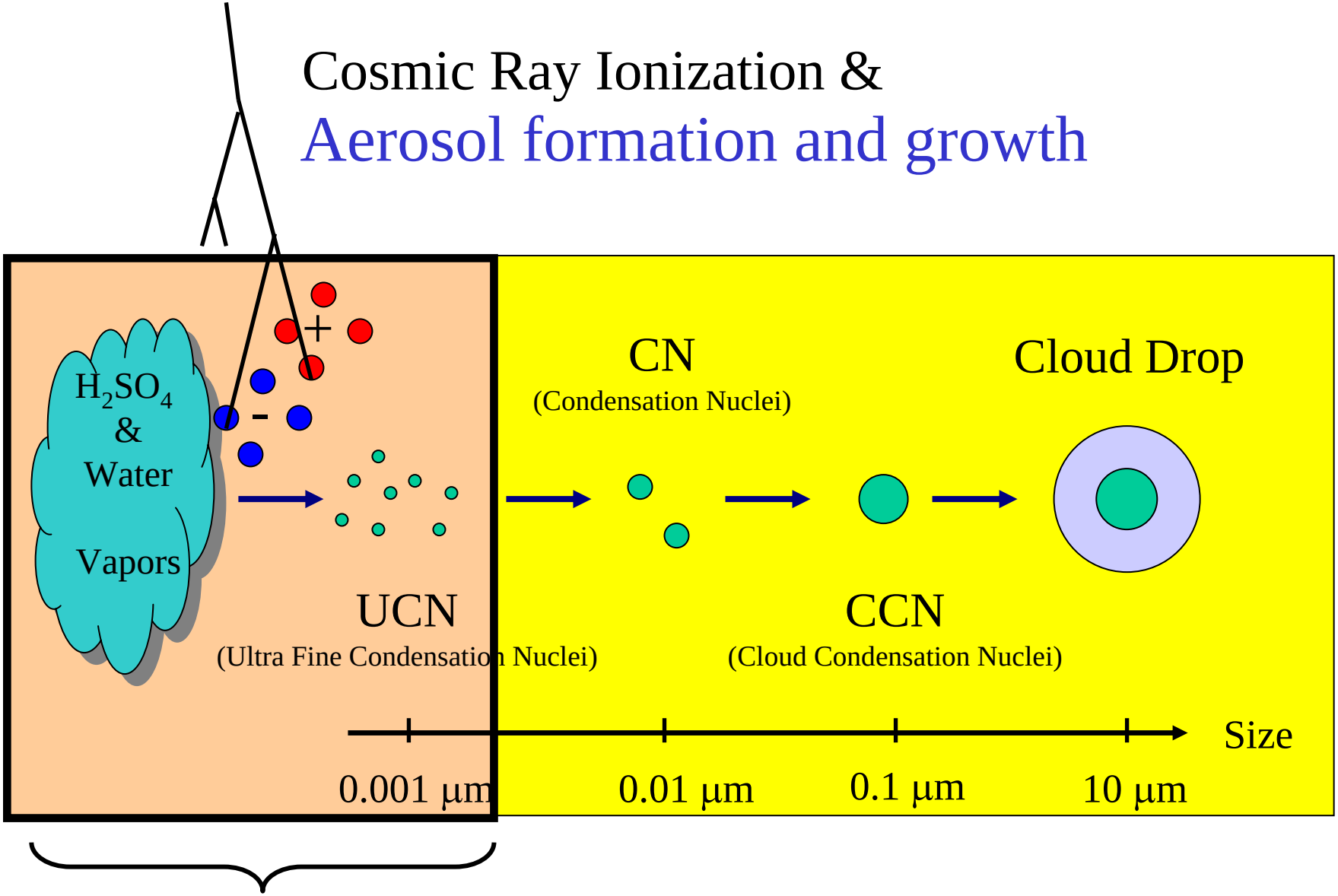
Aerosol formation and growth

Possible link between clouds and cosmic rays



Nucleation process
has been a mystery

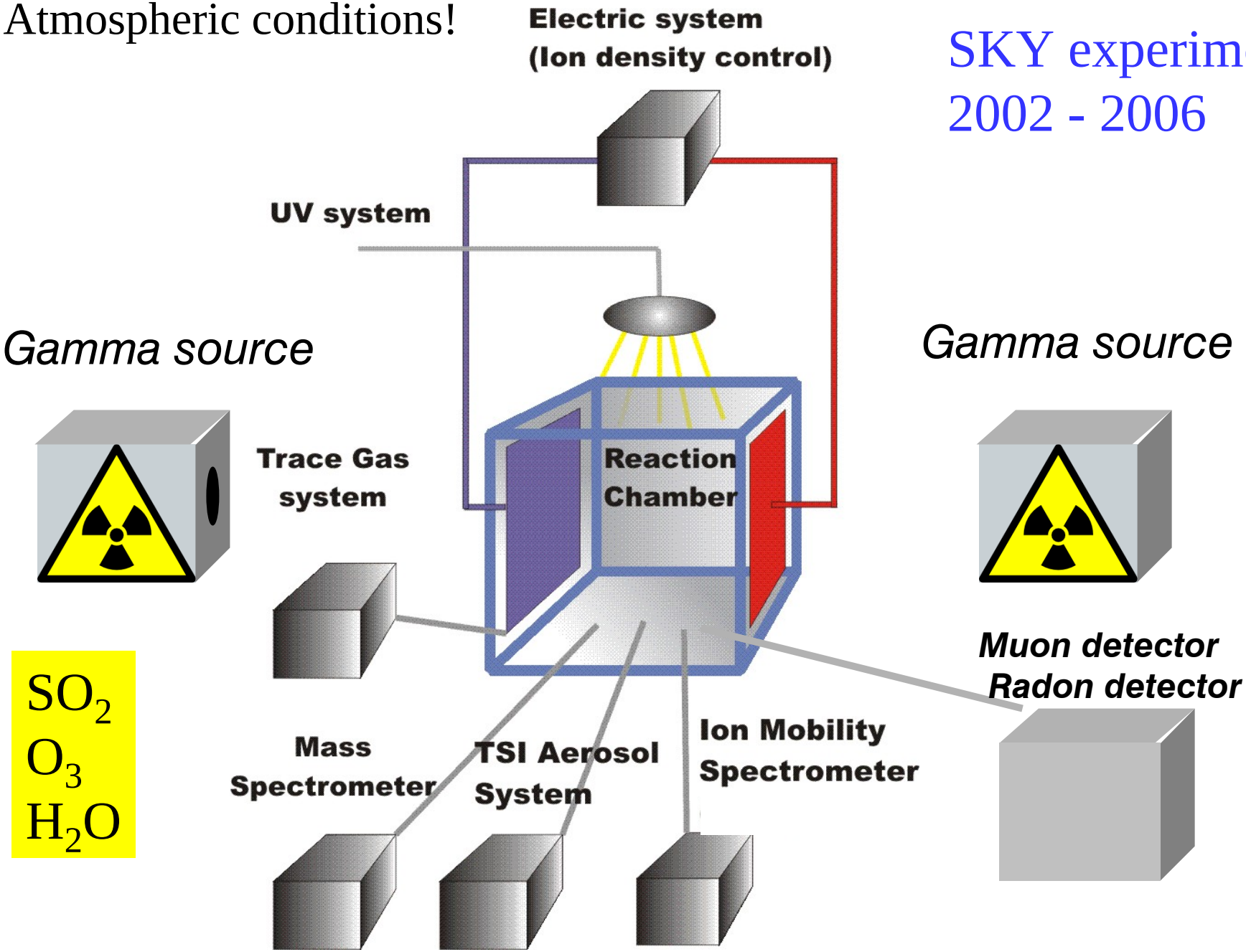
Cosmic Ray Ionization &
Aerosol formation and growth

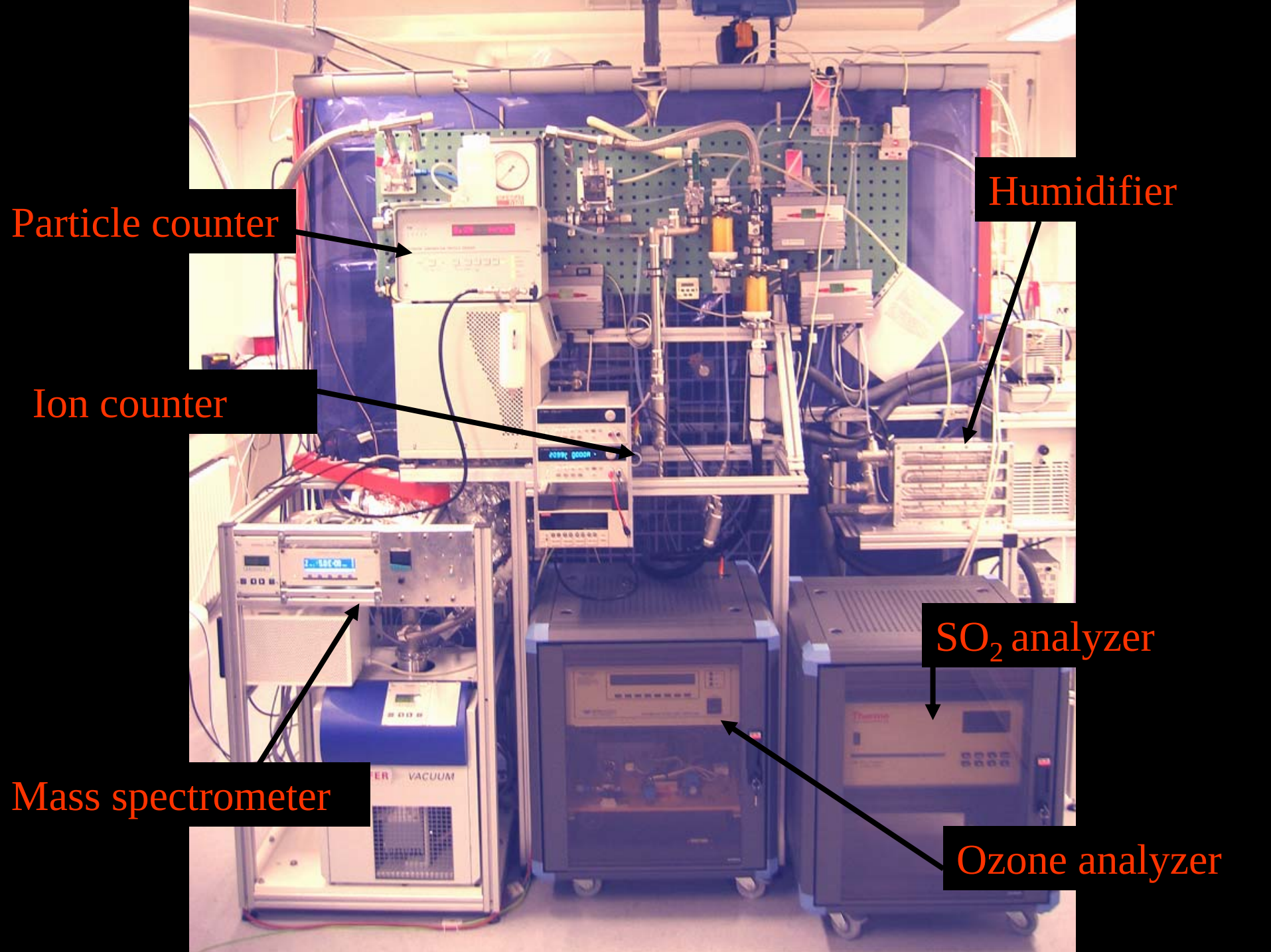


What is the importance of IONS ?

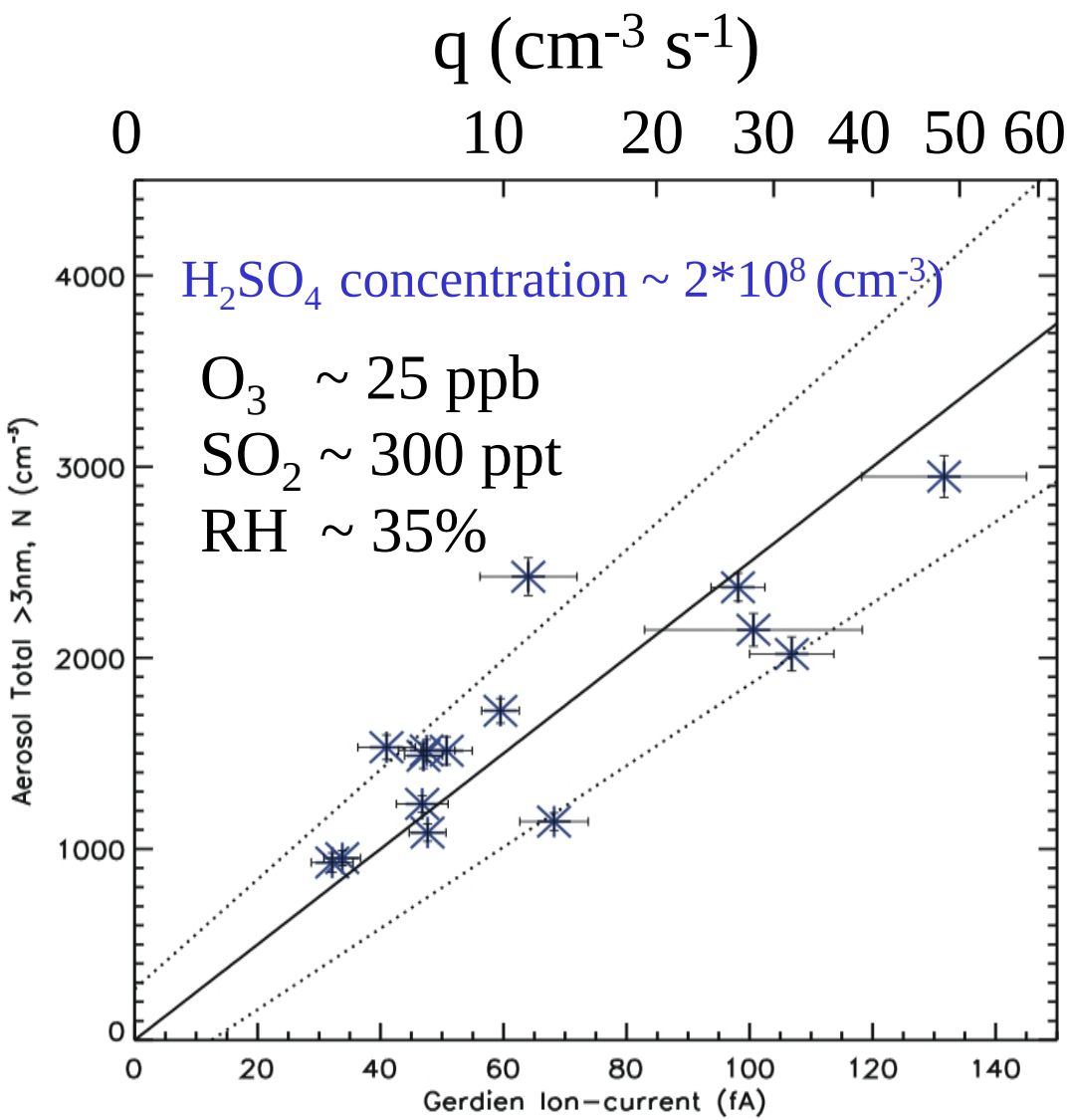
Atmospheric conditions!

SKY experiment
2002 - 2006




Particle counter
Humidifier
Ion counter
SO_2 analyzer
Mass spectrometer
Ozone analyzer

Steady state experiment



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

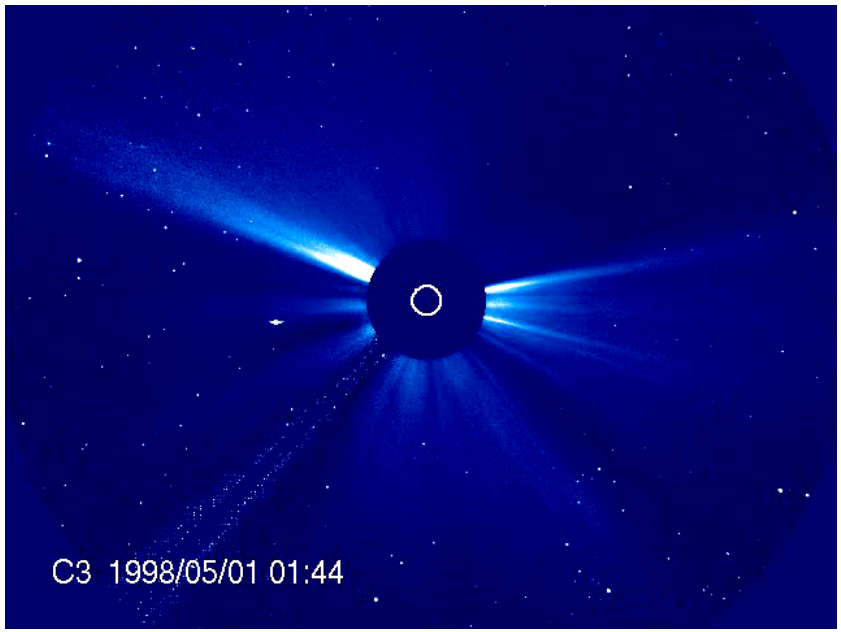
Does it work in the real atmosphere?

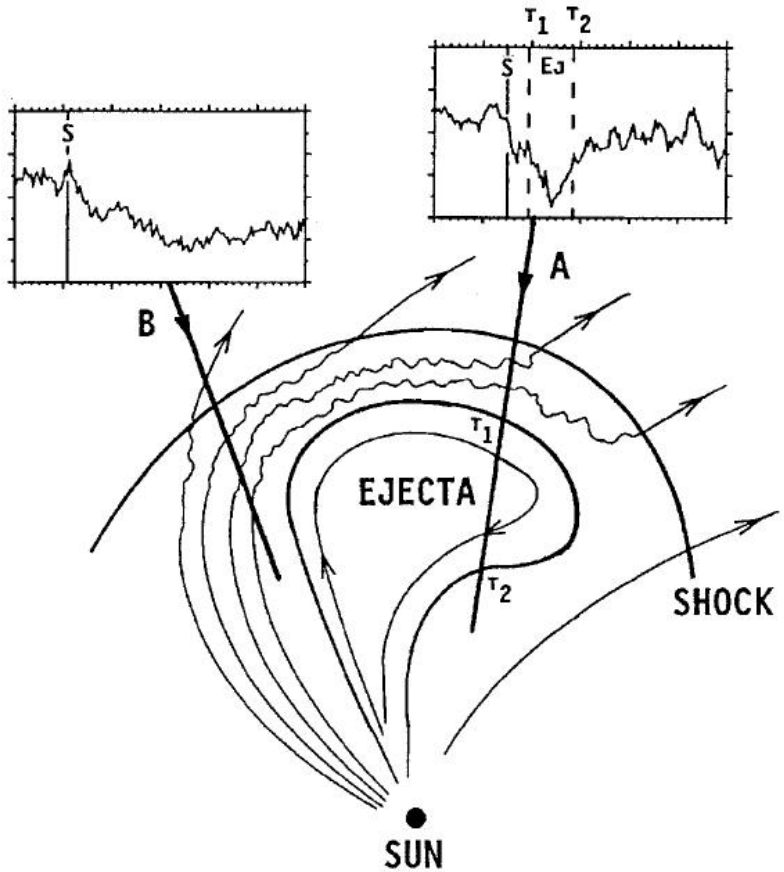
Statements

1. There are always plenty of CCN in the atmosphere a few more will not matter..
2. It is not important

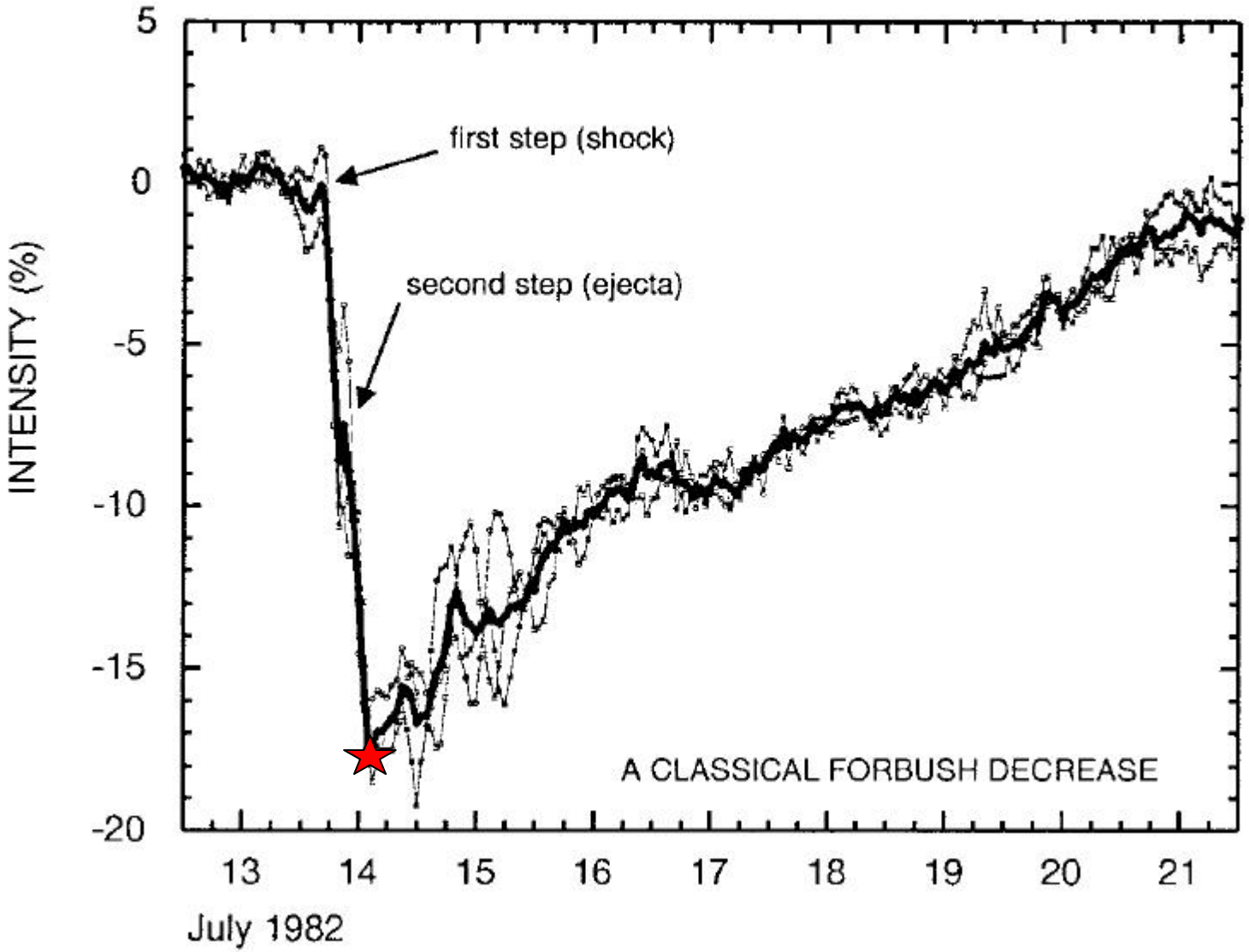
Coronal Mass Ejections

Natural experiments for testing the GCR-atmosphere link





A Classic Forbush Decrease



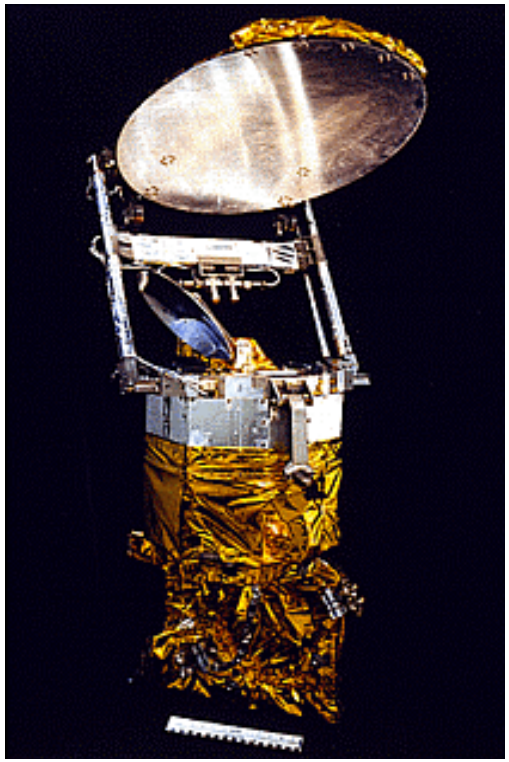
Twenty-six FD events in the period 1987-2007

Ranked according to their depression of ionization in the Earth's lower atmosphere (< 3 km)

Order	Date	Decrease (%)	Order	Date	Decrease (%)
1	**31/10/2003**	120	14	**17/7/2005**	51
2	13/6/1991	89	15	**27/8/1998**	51
3	**16/7/2000**	86	16	**26/9/2001**	51
4	29/10/1991	84	17	**31/5/2003**	48
5	15/3/1989	75	18	10/5/1992	45
6	**19/1/2005**	73	19	**15/5/2005**	44
7	24/3/1991	68	20	29/11/1989	42
8	**13/9/2005**	67	21	10/9/1992	41
9	**12/4/2001**	63	22	**25/11/2001**	38
10	**25/9/1998**	61	23	**28/8/2001**	38
11	**10/11/2004**	57	24	27/2/1992	36
12	9/7/1991	56	25	**18/2/1999**	29
13	**27/7/2004**	55	26	**2/5/1998**	27

Svensmark, Bondo and Svensmark 2008

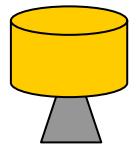
A Well Calibrated Ocean Algorithm for SSM/I (July 1987 to present)

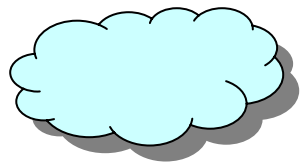


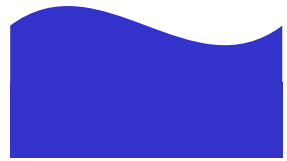
The SSM/I instrument
Measures at 19 GHz,
37 GHz and 85 GHz

OCEAN Brightness Temperature

1. Sea surface temperature TS (K)
2. Effective atmospheric temperature TE (K)
3. Near-surface wind speed W (m/s)
4. Near-surface wind direction f
5. Columnar water vapor V (mm).
6. **Columnar liquid water L (mm)**
7. Atmospheric pressure P (mb).

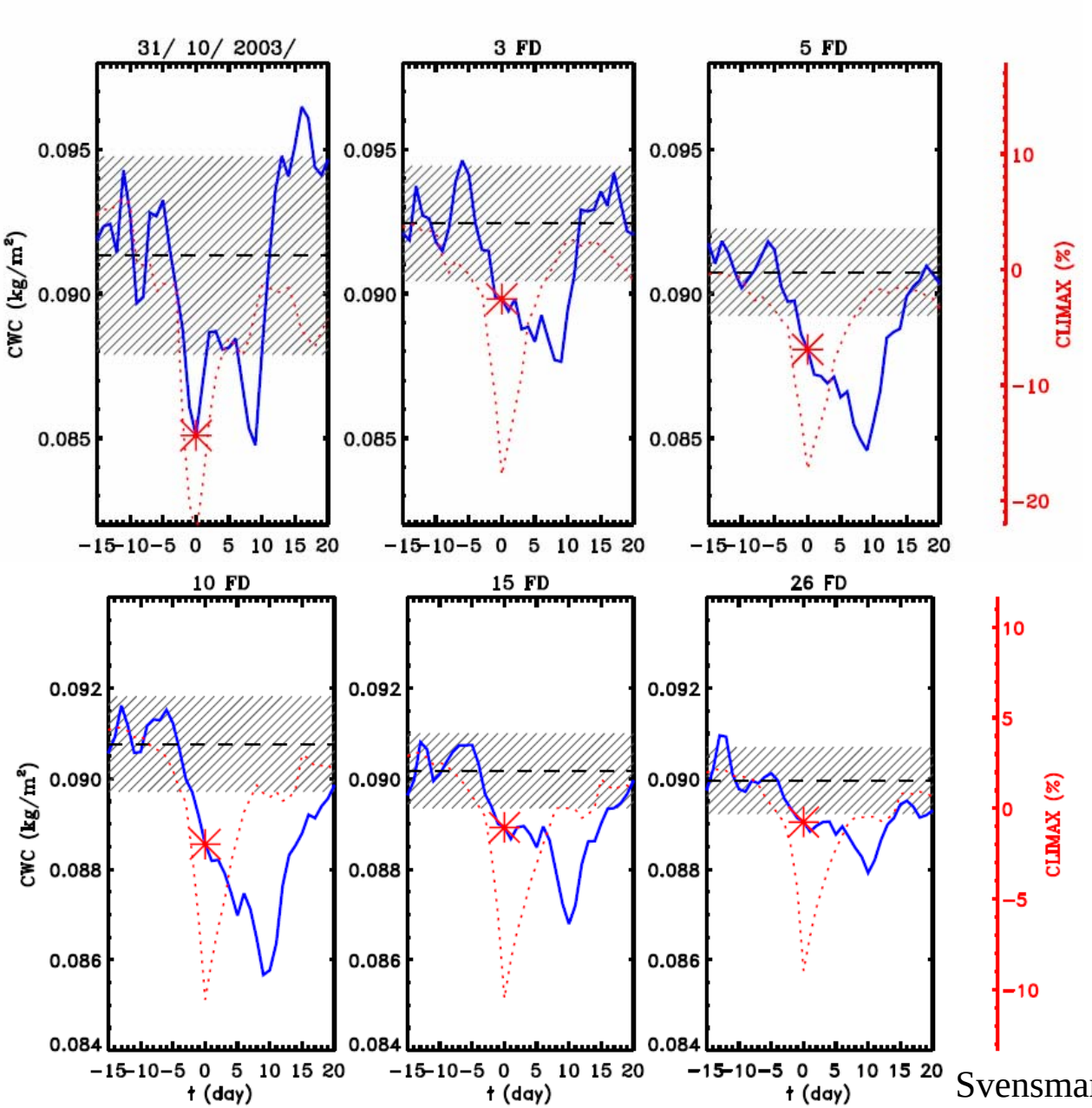






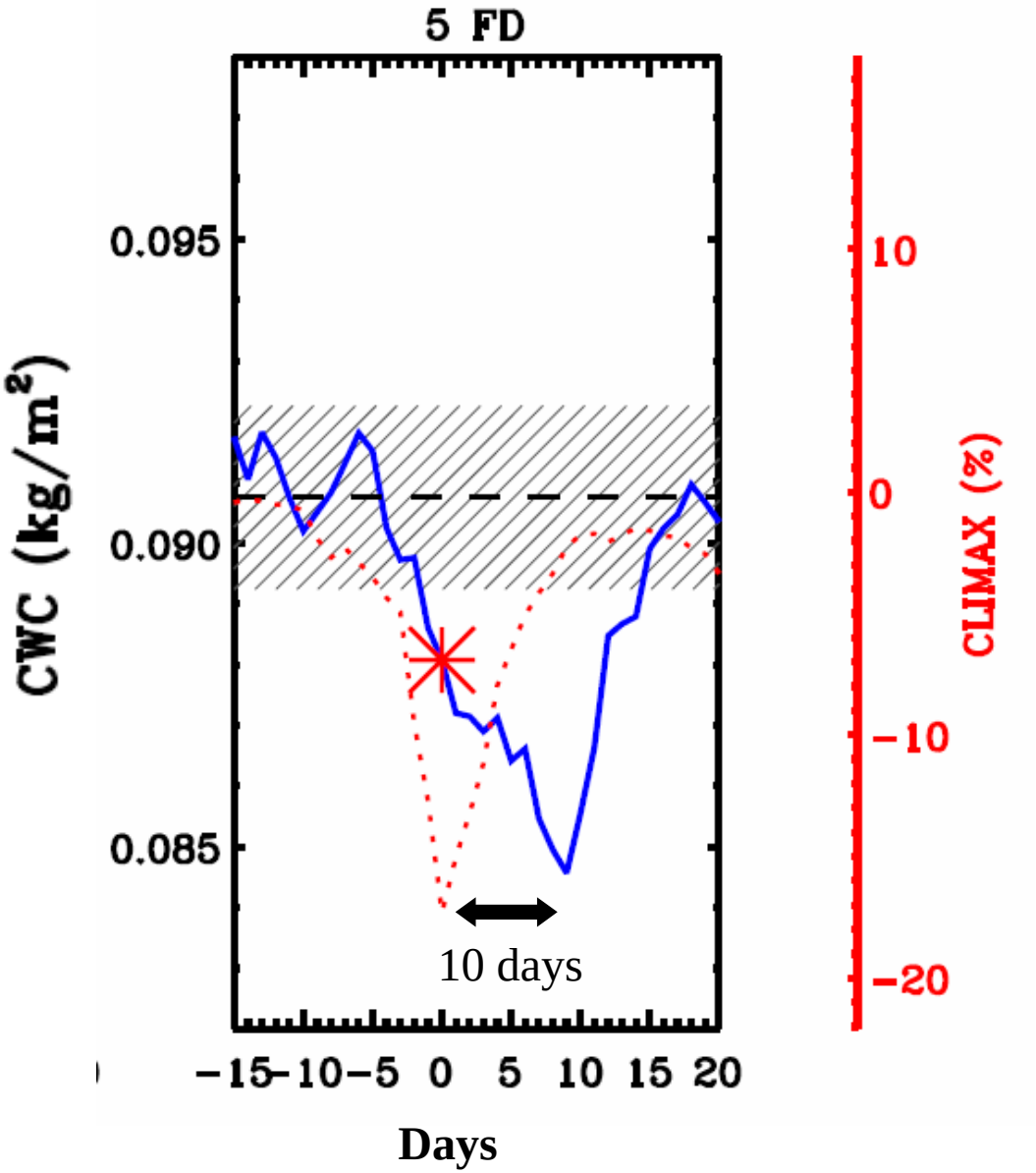
The model and algorithm are precisely calibrated using a very large *in situ* data base containing 37,650 SSM/I overpasses of buoys and 35,108 overpasses of radiosonde sites.

The impact of coronal mass ejections on the liquid water content of clouds



Svensmark, Bondo and Svensmark 2008

SSM/I data for 5 strongest Forbush decreases



Ionization change ~ 10%

Liquid water change ~ 6%

δM ~ 3 Gton

Effect also in
- MODIS data
- ISCCP data

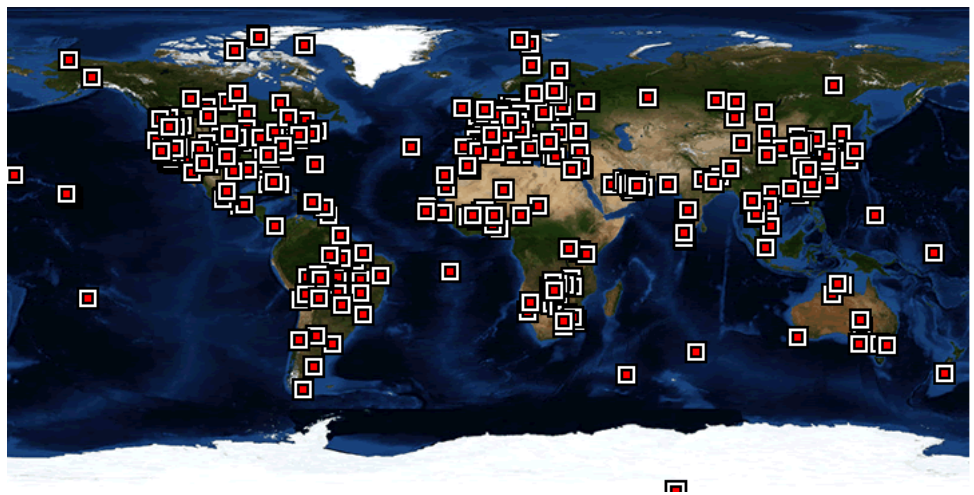
A hint from observations of a mechanism

The presence of aerosols in the atmosphere affect the color of the sun as seen from the ground.

The aerosol robotic network AERONET

Measures the optical thicknes of the atmosphere a different wavelengths using solar photometers

Presently about 400 stations

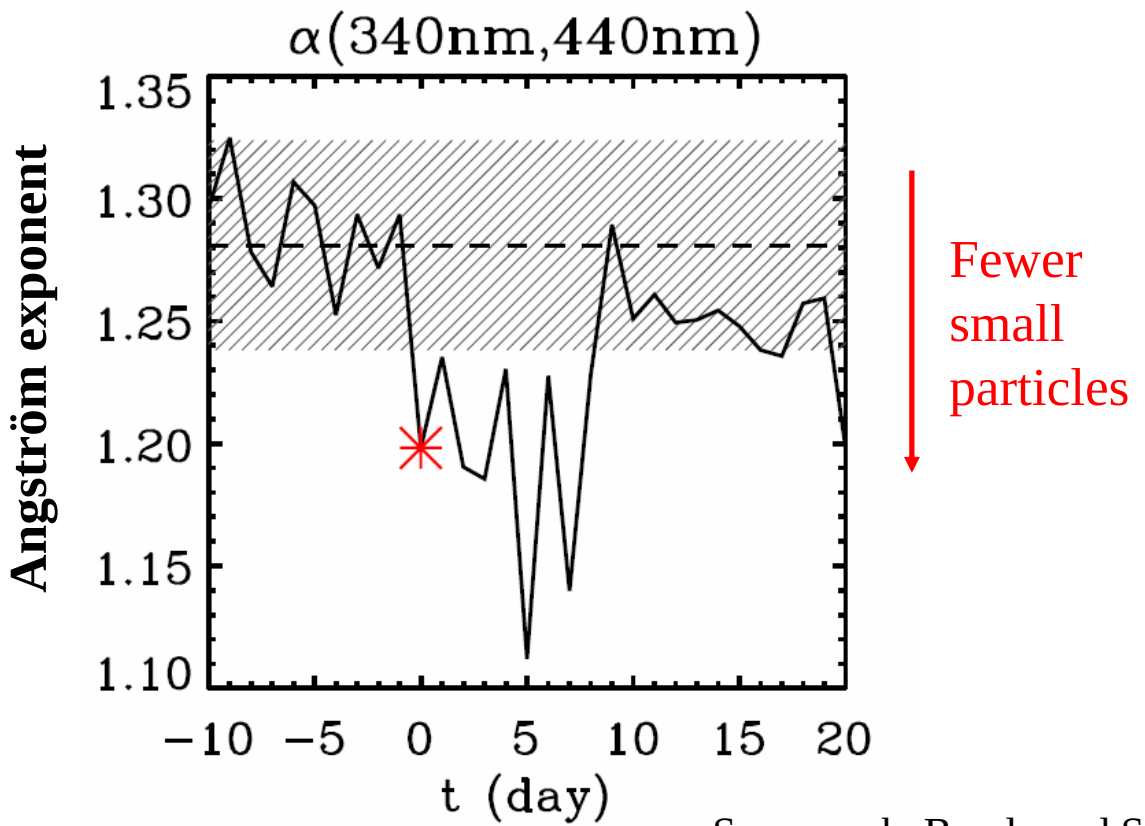


$$\tau(\lambda_i) = \tau_1 \lambda_i^{-\alpha}$$

AERONET data

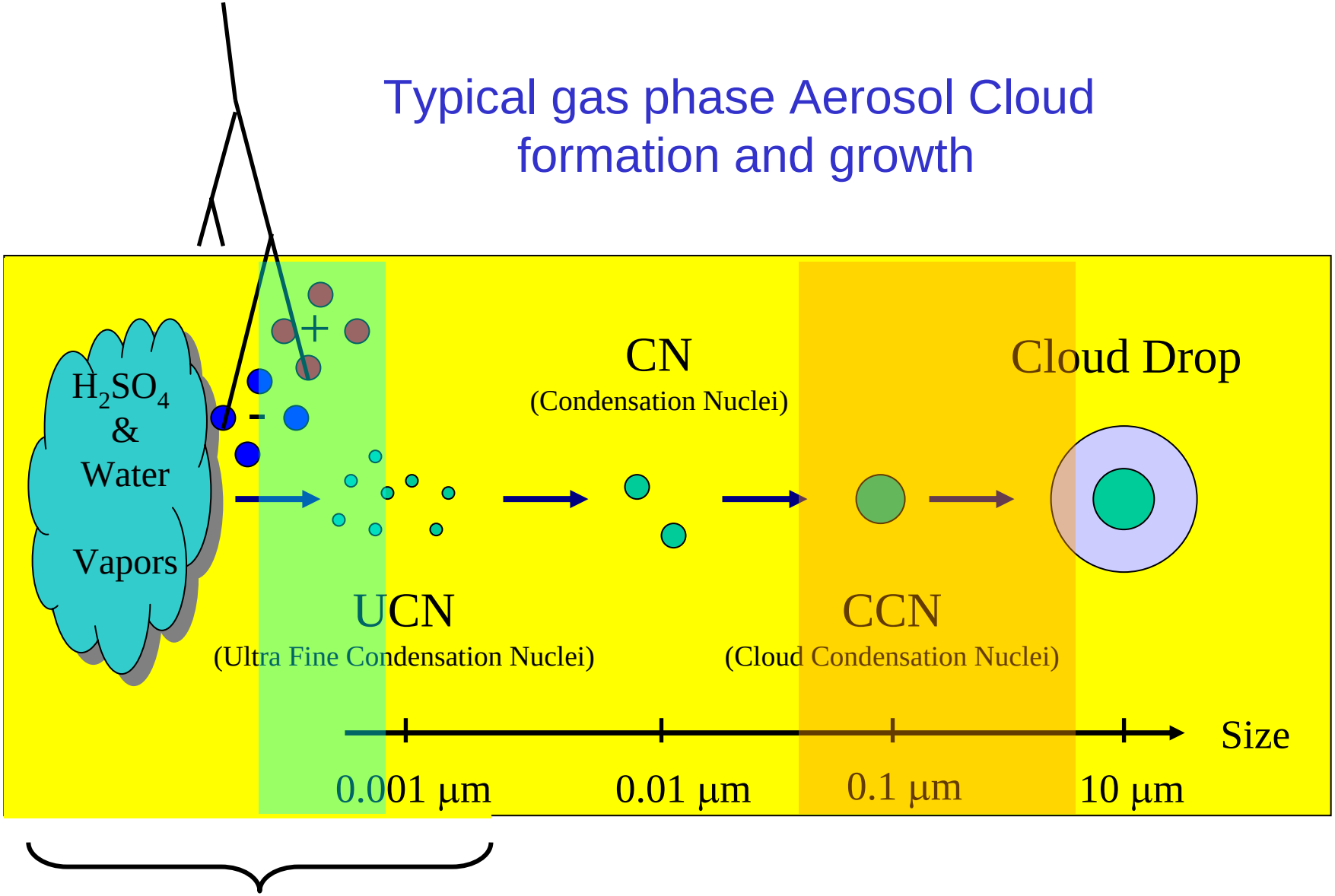
Angström exponent: is the aerosol optical thickness dependence of wavelength . The Angström exponent is inversely related to the average size of the particles: the smaller the particles, the larger the exponent. For shorter wave lengths (340,380,440,500 nm) a decrease will mean fewer small particles.

5 strongest events

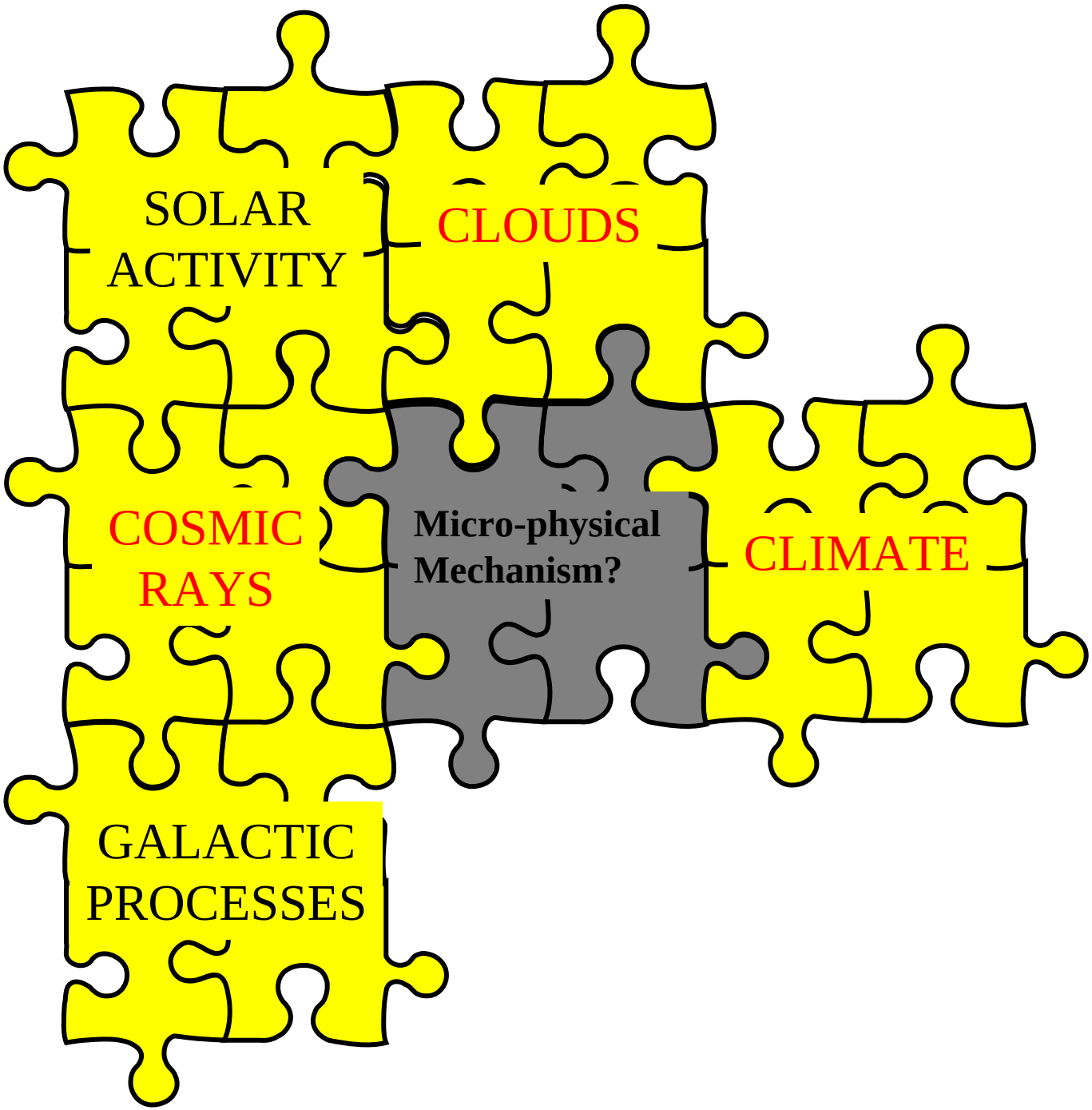


Svensmark, Bondo and Svensmark 2008

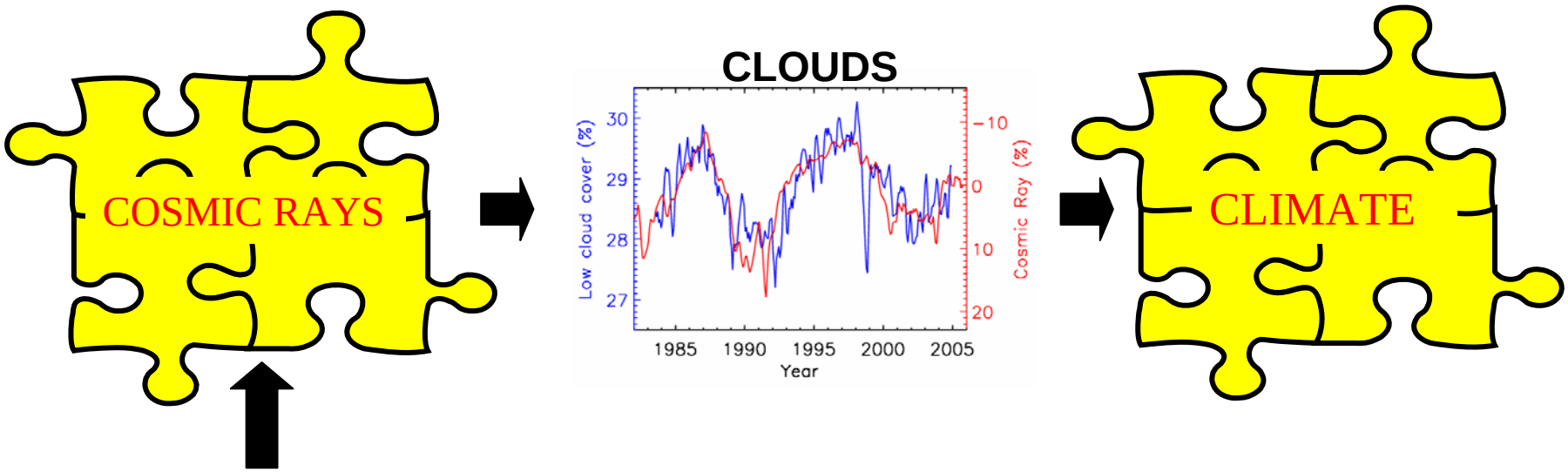
Typical gas phase Aerosol Cloud formation and growth



Ion induced formation of aerosols


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

Cosmic Rays and Climate



Super Novas

Star formation

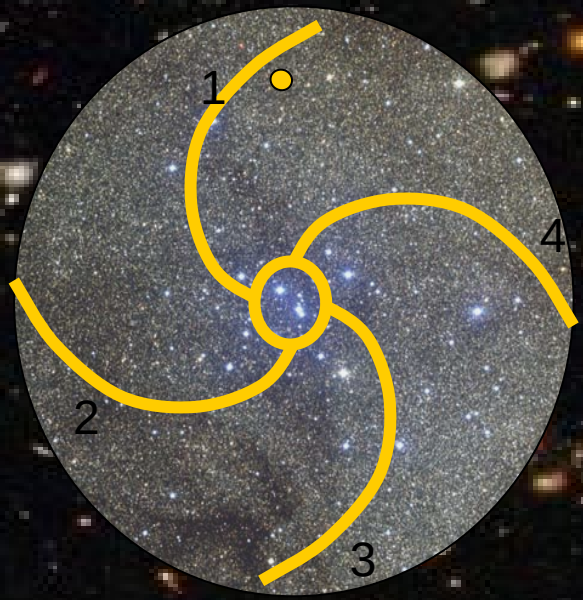
Supported by empirical, observational, and experimental evidence

Variations in Cosmic Ray Flux Cause Variations in Earths Climate.

Impact of Super Novas on the Conditions on Earth as told by Open Stellar Clusters

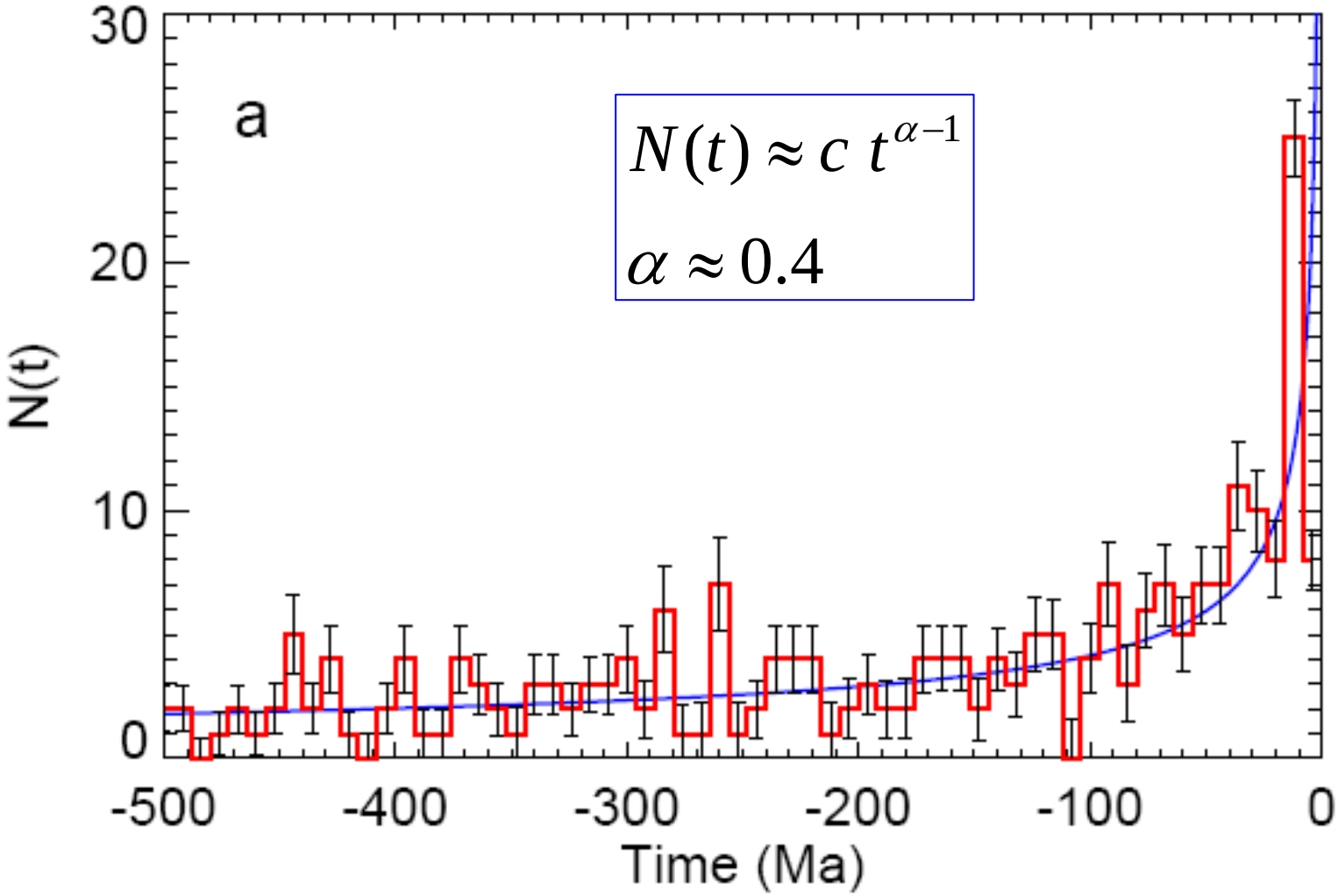
Henrik Svensmark
Space-DTU

Milky Way, Soler System, Spiral Arms



Galactic year ~ 250 myr
Pattern speed ~ 0.5 stellar speed
Overtakes spiral arm 140 myr

Histogram of Open Clusters as a function of age



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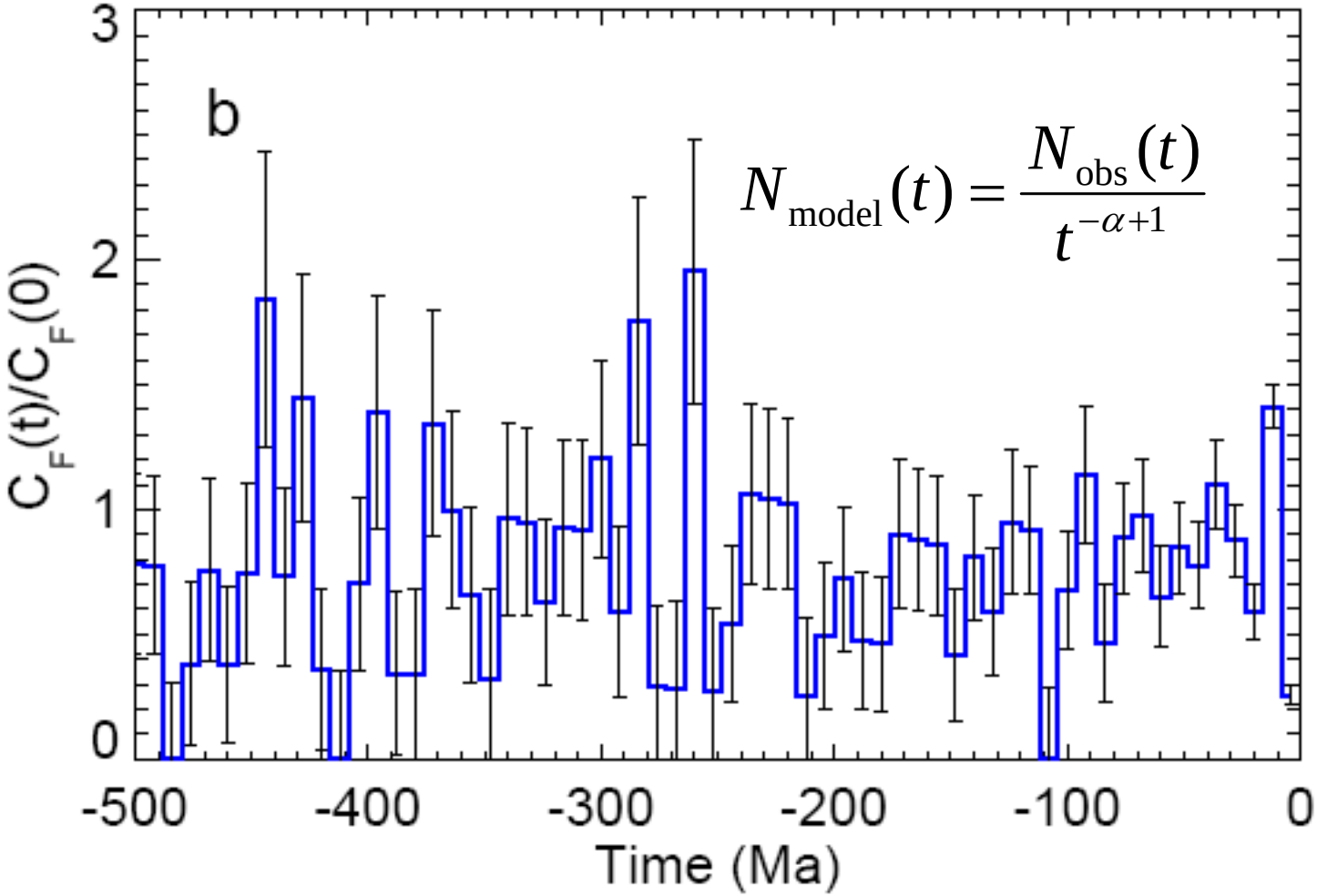
Open Clusters formation as a function of age



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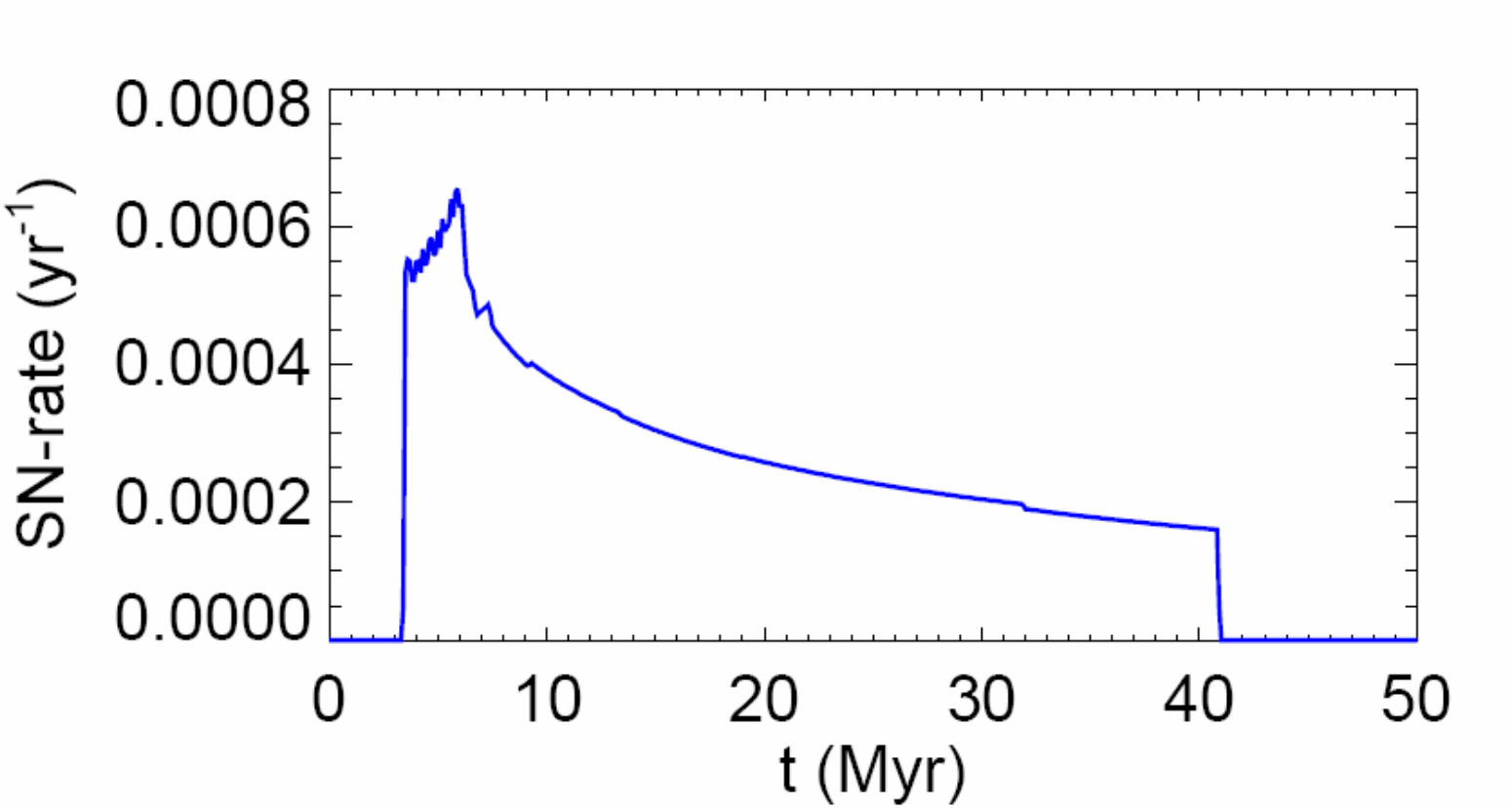
SN RESPONSE FUNCTION



Calculated using Starburst99; a data package designed to model spectro-photometric and related properties of star-forming galaxies

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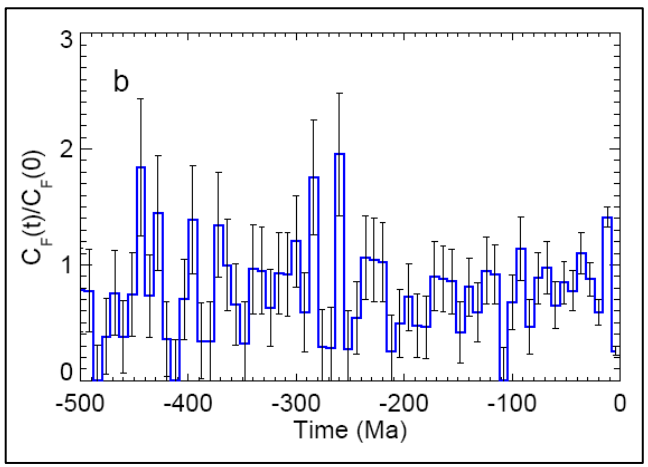
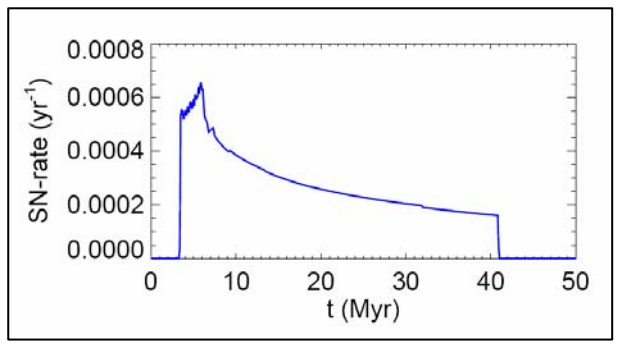
Estimating Super Nova's in the Solar Neighbourhood over the last 500 million years

$$SN_{rate}(t) = c_{sn} \int_{-\infty}^{t} C_F(t') R_{SN}(t - t')\, dt'$$

Star formation



SN respons



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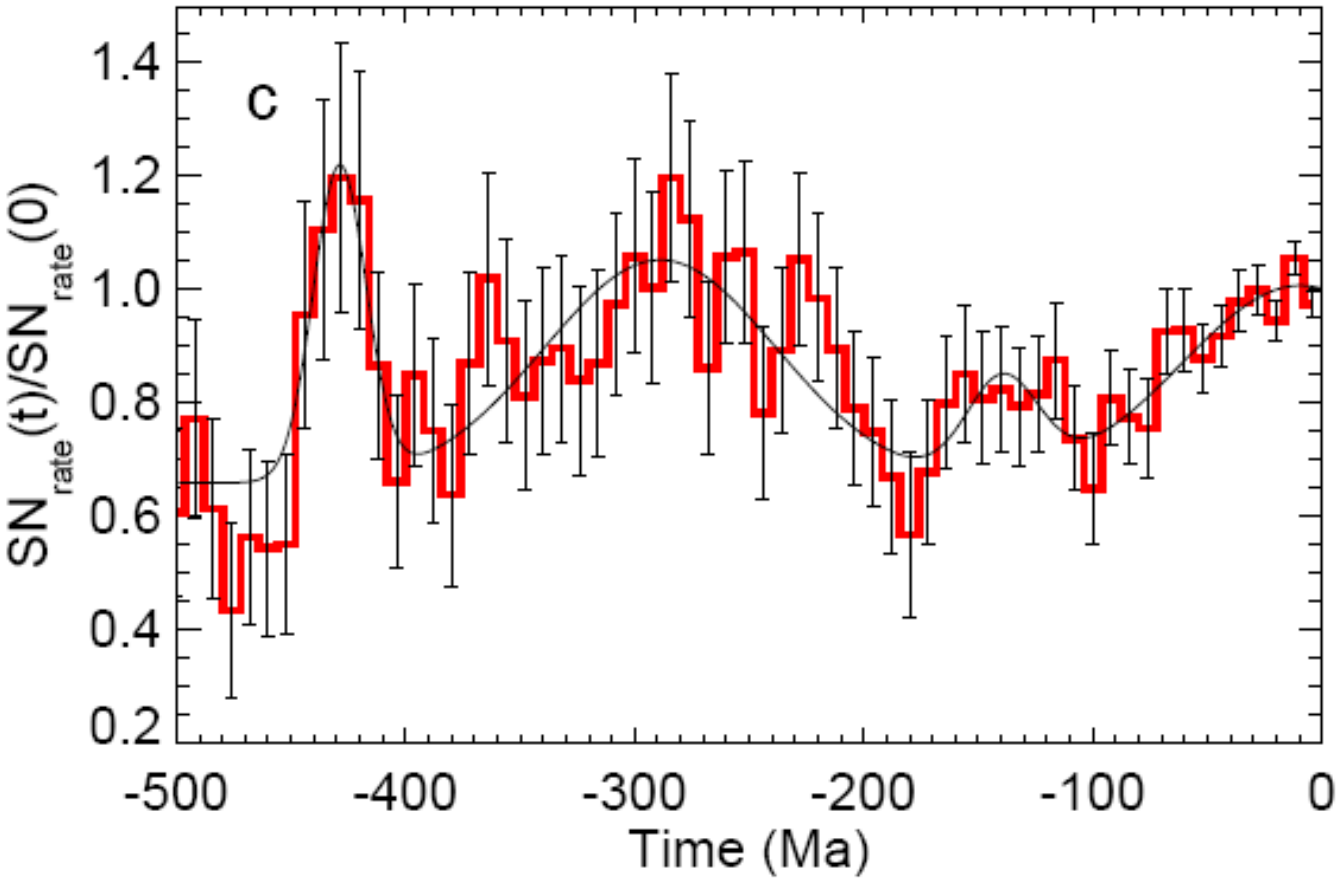
Super Nova rate during 500 Ma



Svensmark 2009

Conclusion

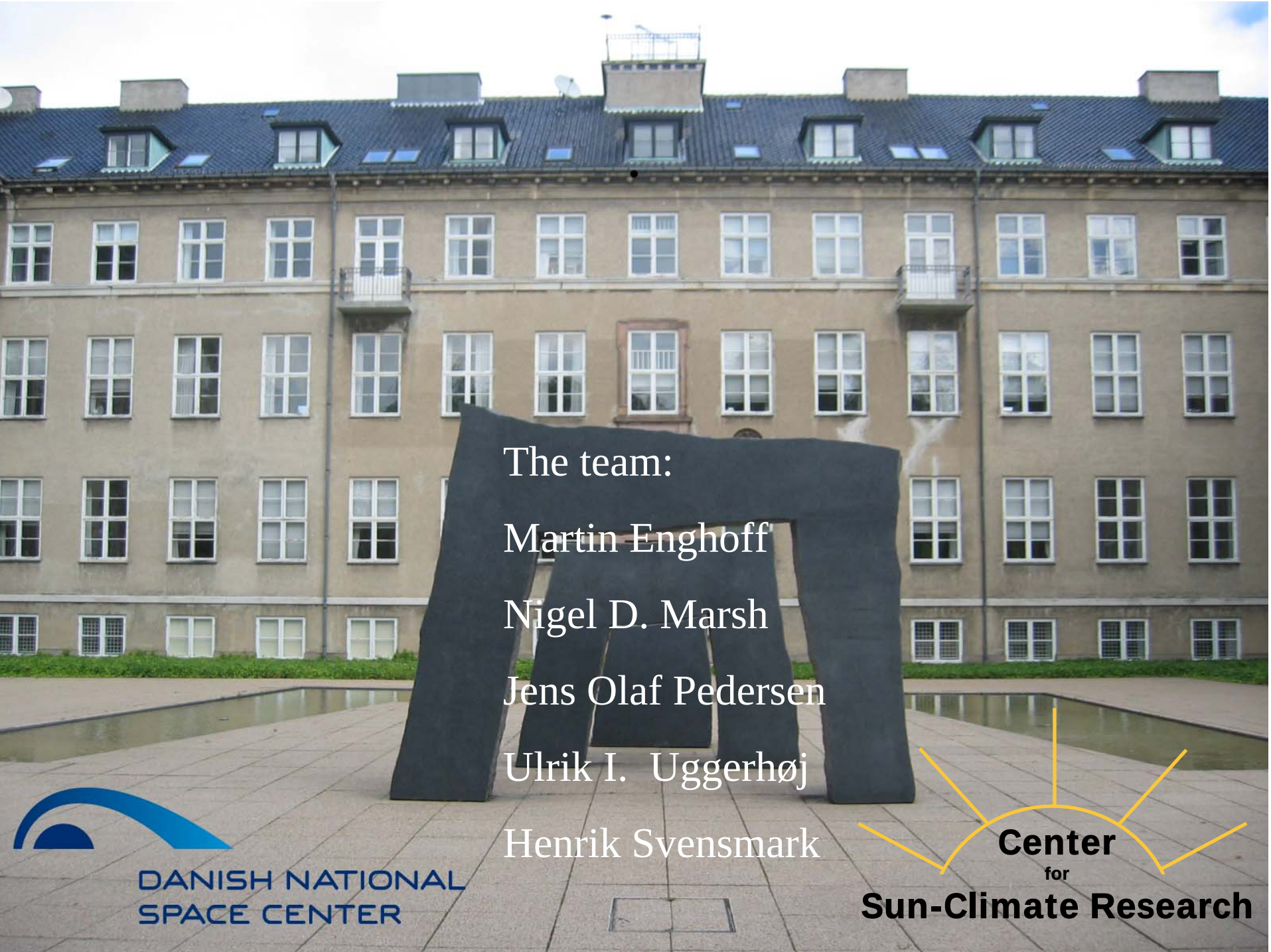
Particles from space (Cosmic Rays) influence Earths climate, ranging from days to 10^9 years.
•The empirical evidence is large and strong

Part of a physical mechanism has been demonstrated experimentally
• Involving ions and aerosol formation
• Linking to clouds and thereby the energy budget of the Earth

Clouds are forcing the Earths climate rather than being a passive component.

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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Henrik Svensmark
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