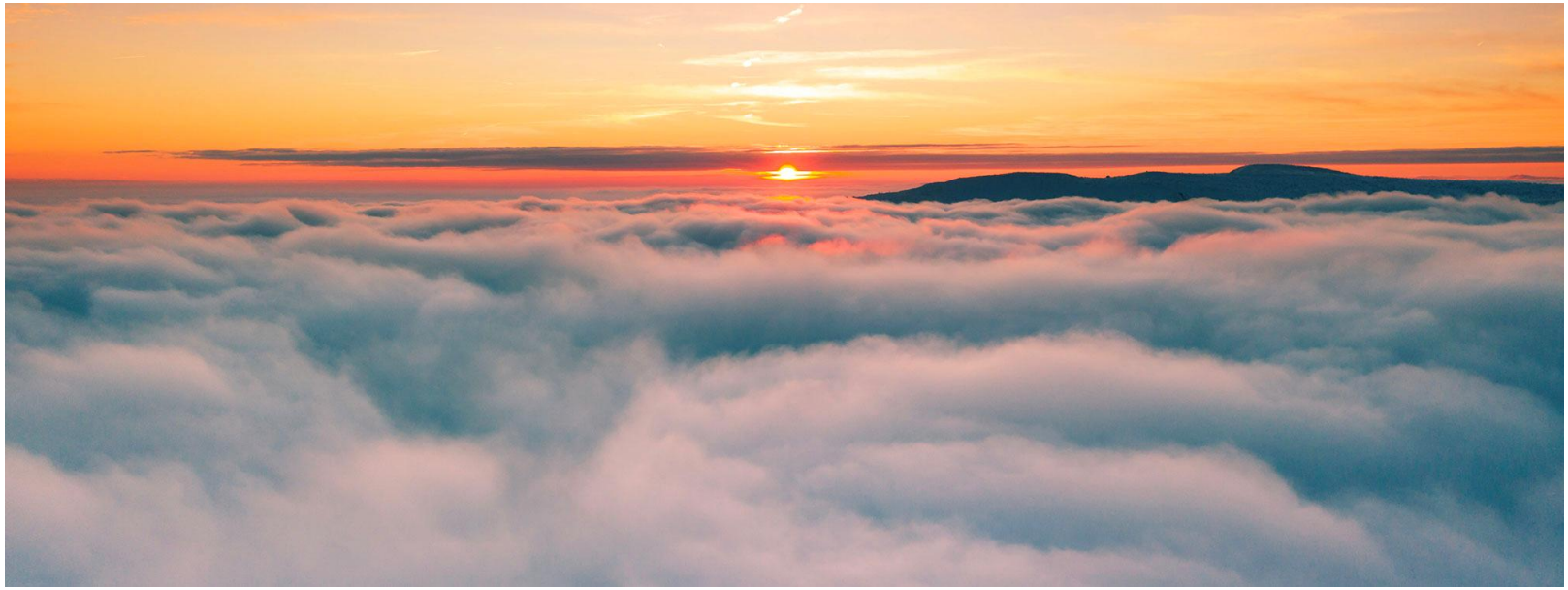
How Cosmic Rays Influence Climate
(A brief introduction)



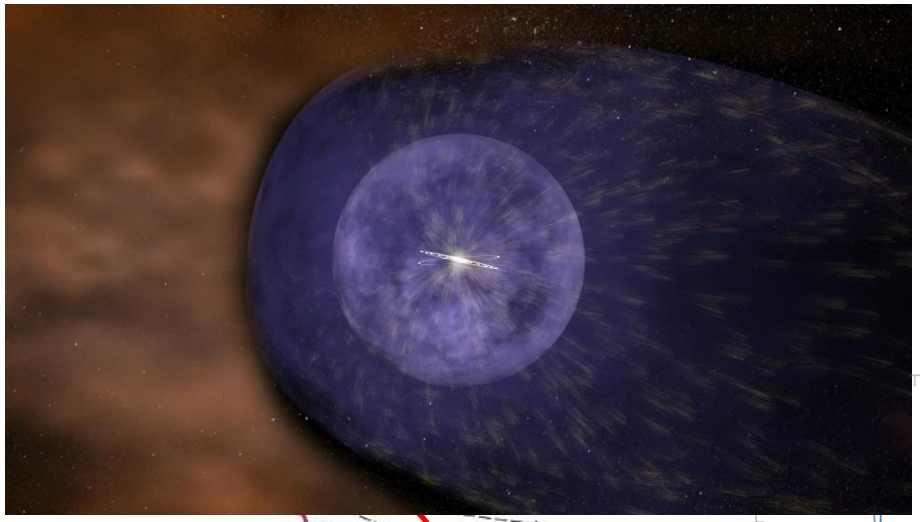
Henrik Svensmark, **DTU Space**

In collaboration with

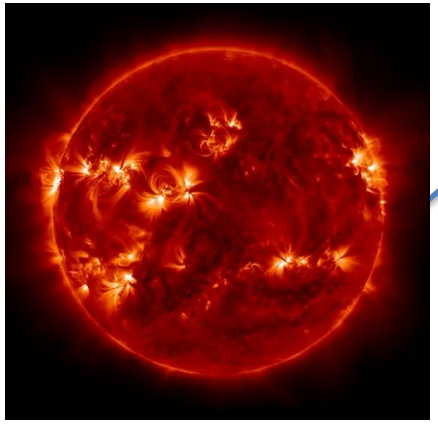
Martin Enghoff, Nir Shaviv, Jacob Svensmark, and Irina Thaler

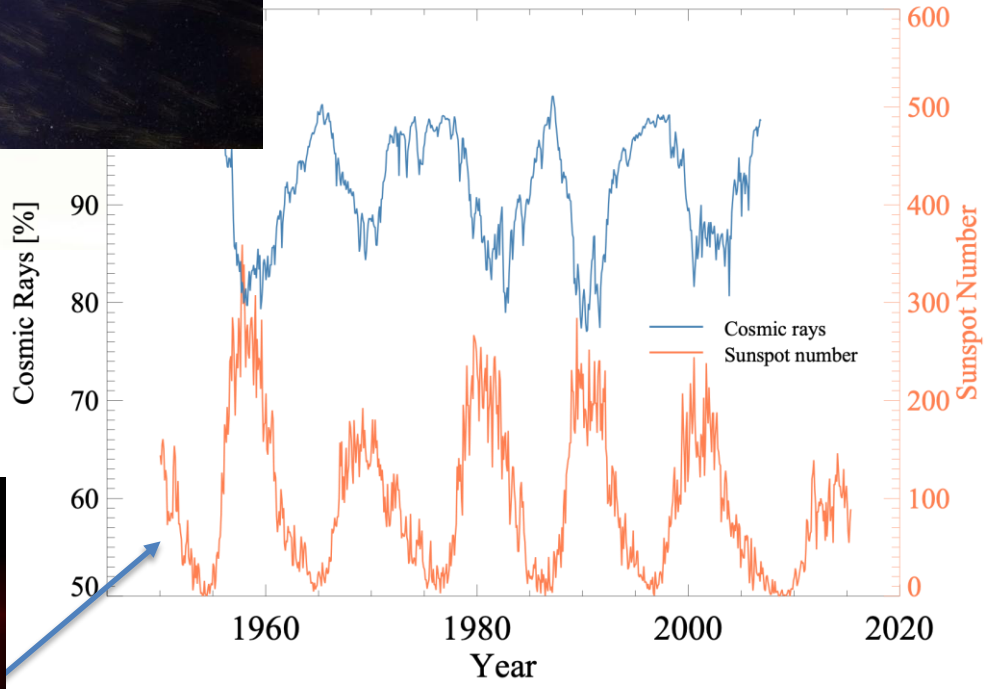
DTU - Københavns Universitet - Hebrew University of Jerusalem

Heliosphere, Cosmic Rays and Solar Activity

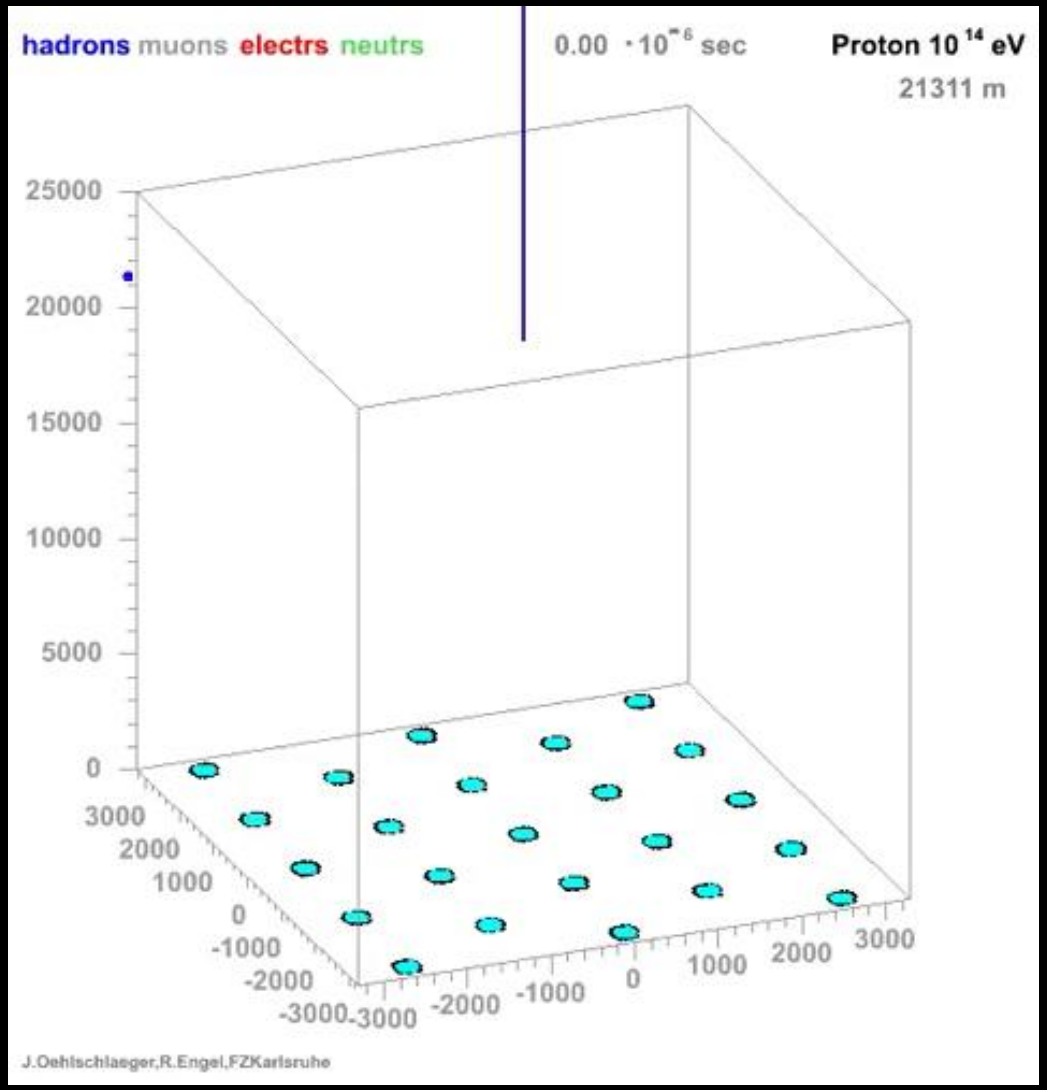


Cosmic Ray Trajectory





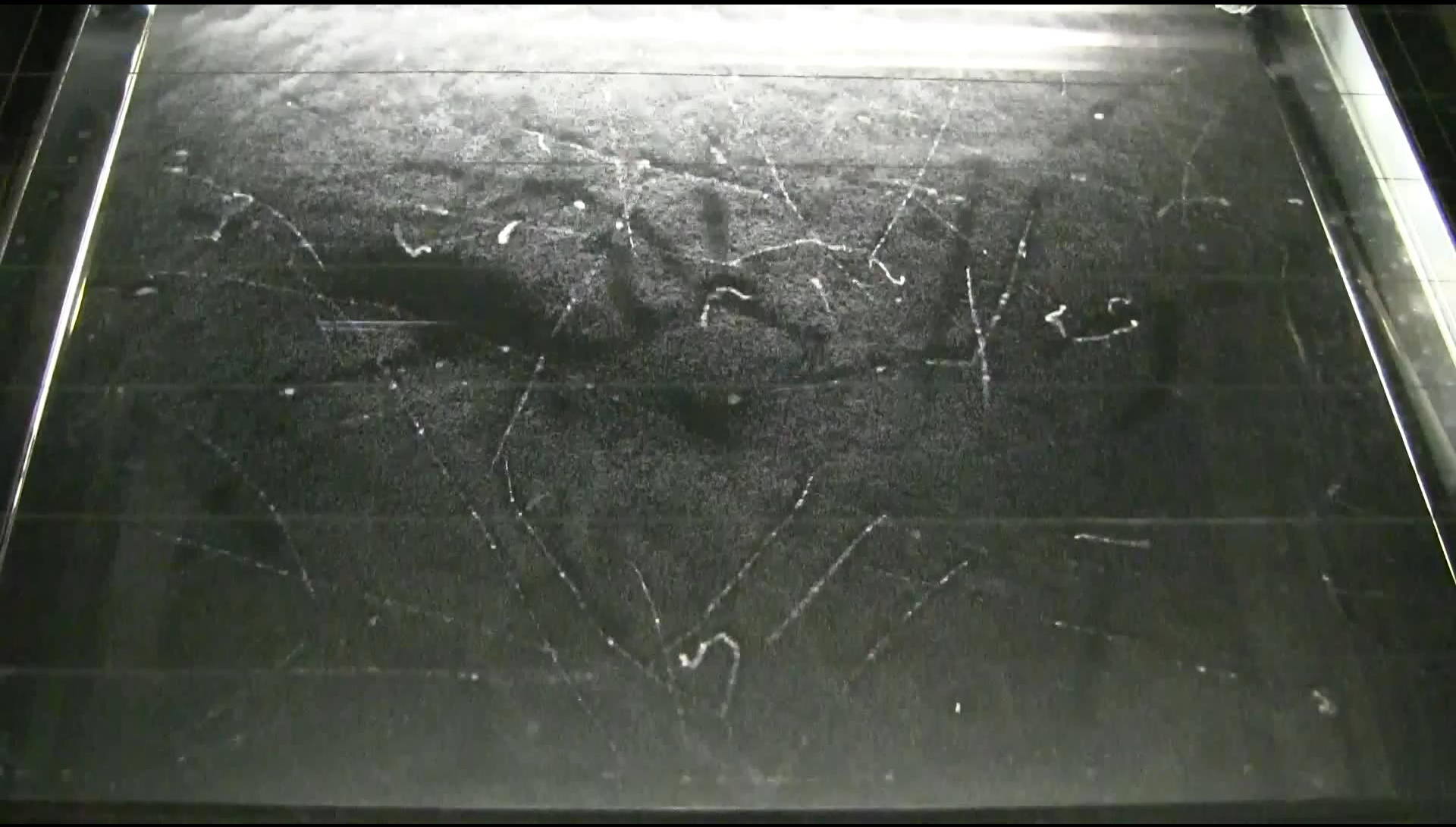
Cosmic Ray Shower



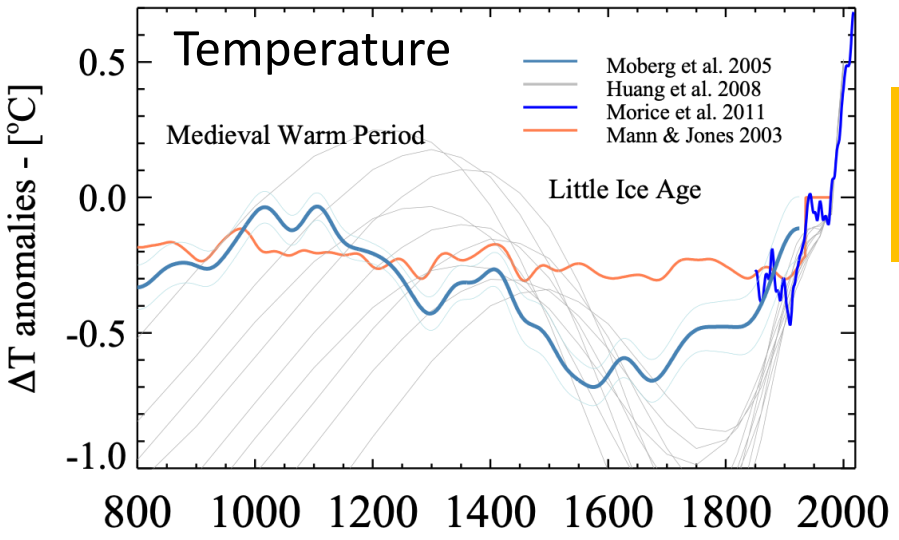
About 70 muons/s /m^2 at the Earths surface

In 24 hours about 12 million muons goes through a human body

Cloud Chamber at 2800 meter above sea level



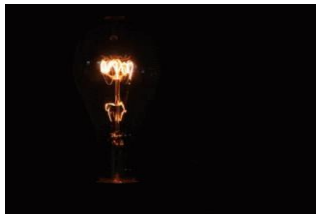
Cosmic rays and climate change



Many examples of a connection between cosmic rays and climate

Each time there is a change in cosmic rays there is a change in climate

IPCC's Consensus on Solar Activity on Climate since 1880



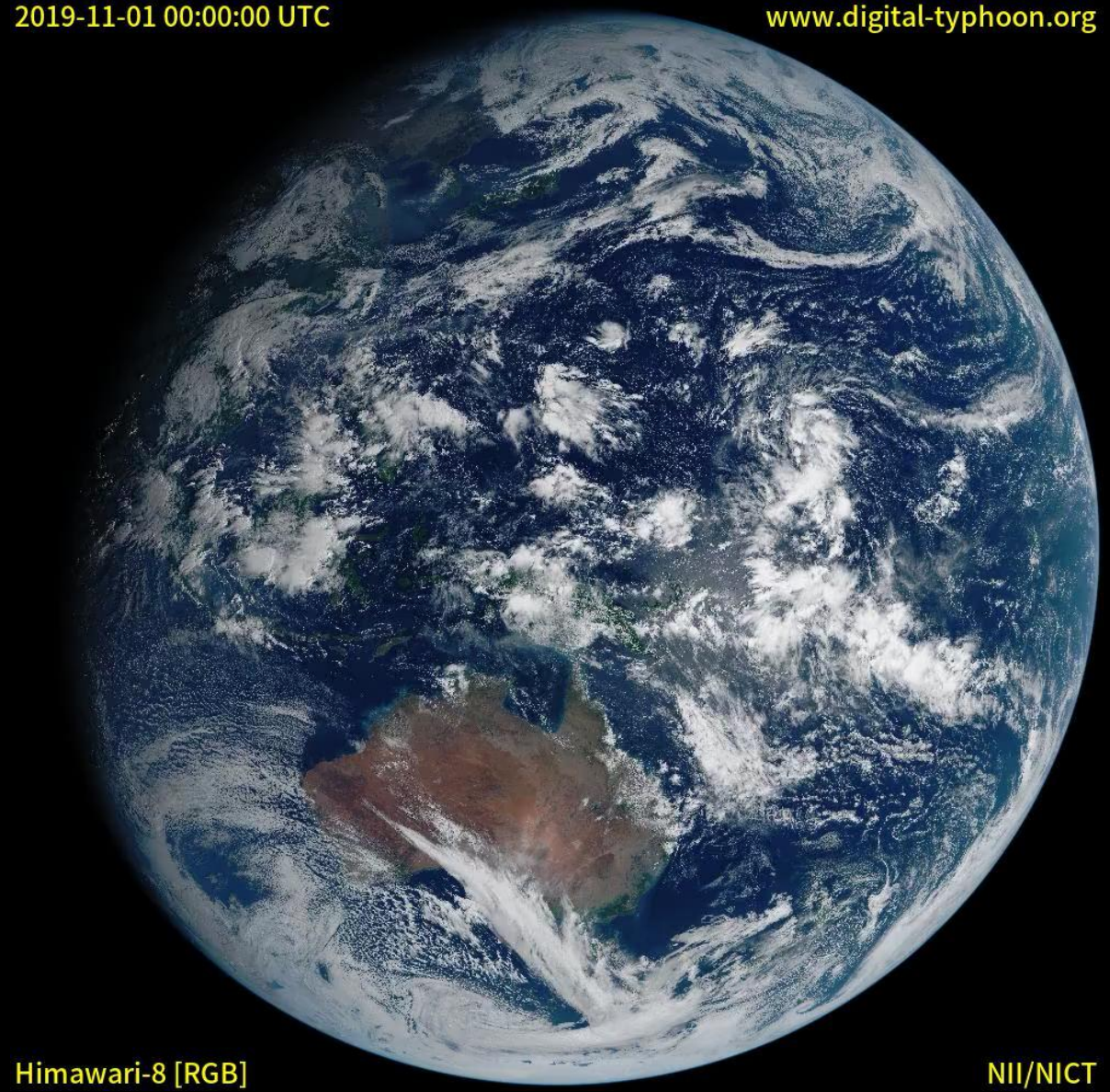
CO_2 forcing 2.3 W/m^2

IPCC only includes
Changes in solar irradiance

0.05 W/m^2 →

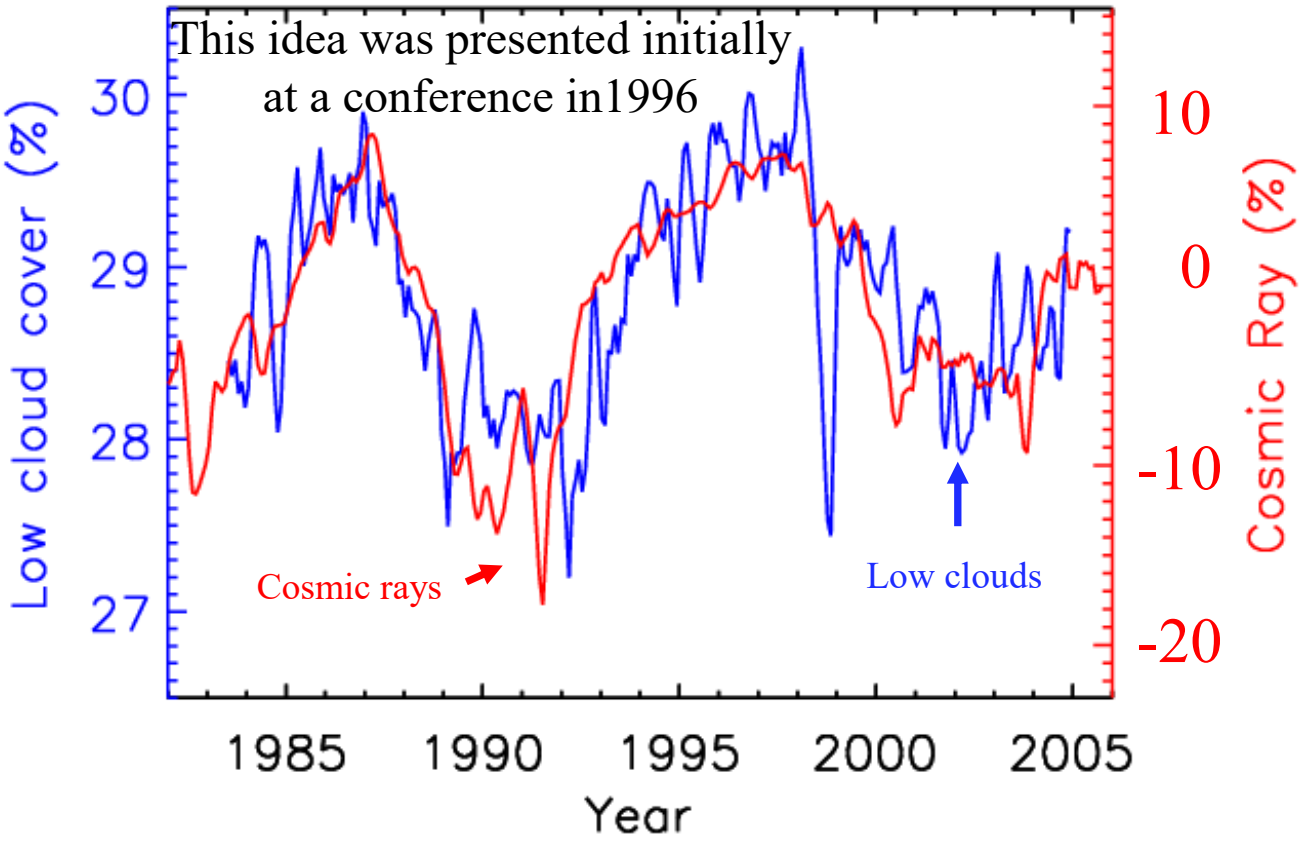
What could amplify solar activity?

How can cosmic rays influence climate?



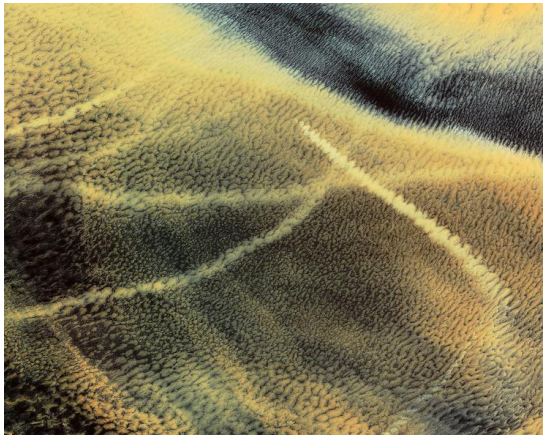
The Net effect of clouds is to cool the Earth by 20-30 W/m^2

Connection between Clouds and Cosmic Rays?

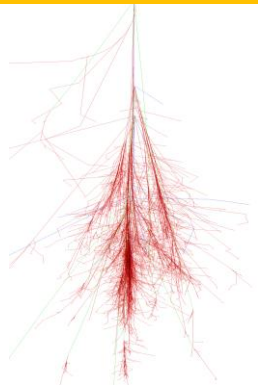


Svensmark & Friis-Christensen, JASTP 1997, Svensmark, PRL 1998 og Marsh & Svensmark, PRL, 2000. (opdateret 2005)

How can cosmic rays influence clouds?

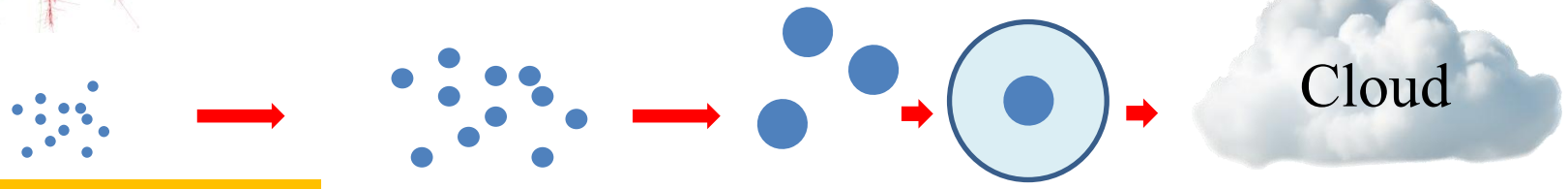


Free charges made by cosmic rays



Grows by uptake of gas and collisions

Cloud droplet



1-2 nm stable molecular clusters formed on charges

Cloud condensation nuclei > 50 nm

More than 10 years of experiments

DTU, National Space Institute

ASTRID accelerator, Aarhus Universitet

CERN

BOULBY Underground Laboratory (1.1 km underground)

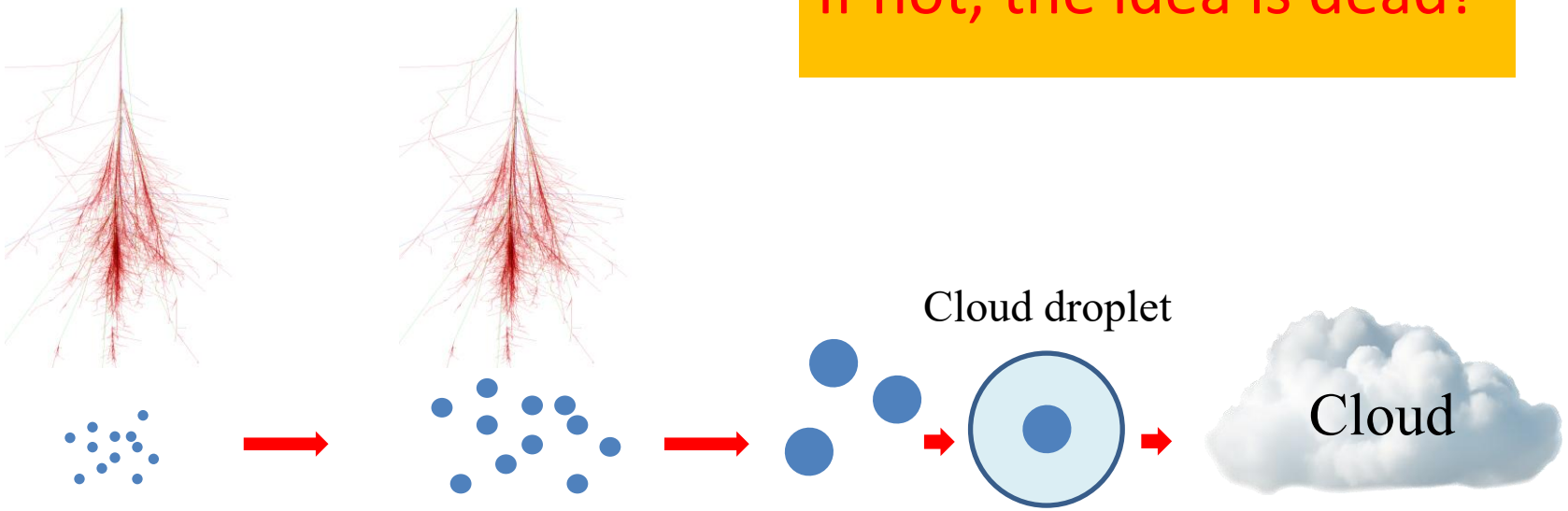
Experimentally verified: Formation of aerosols and growth to Cloud condensation nuclei

Helps the formation of aerosols 2007

Accelerates the Growth 2017

But will a change in small aerosols be able to affect clouds?

If not, the idea is dead!



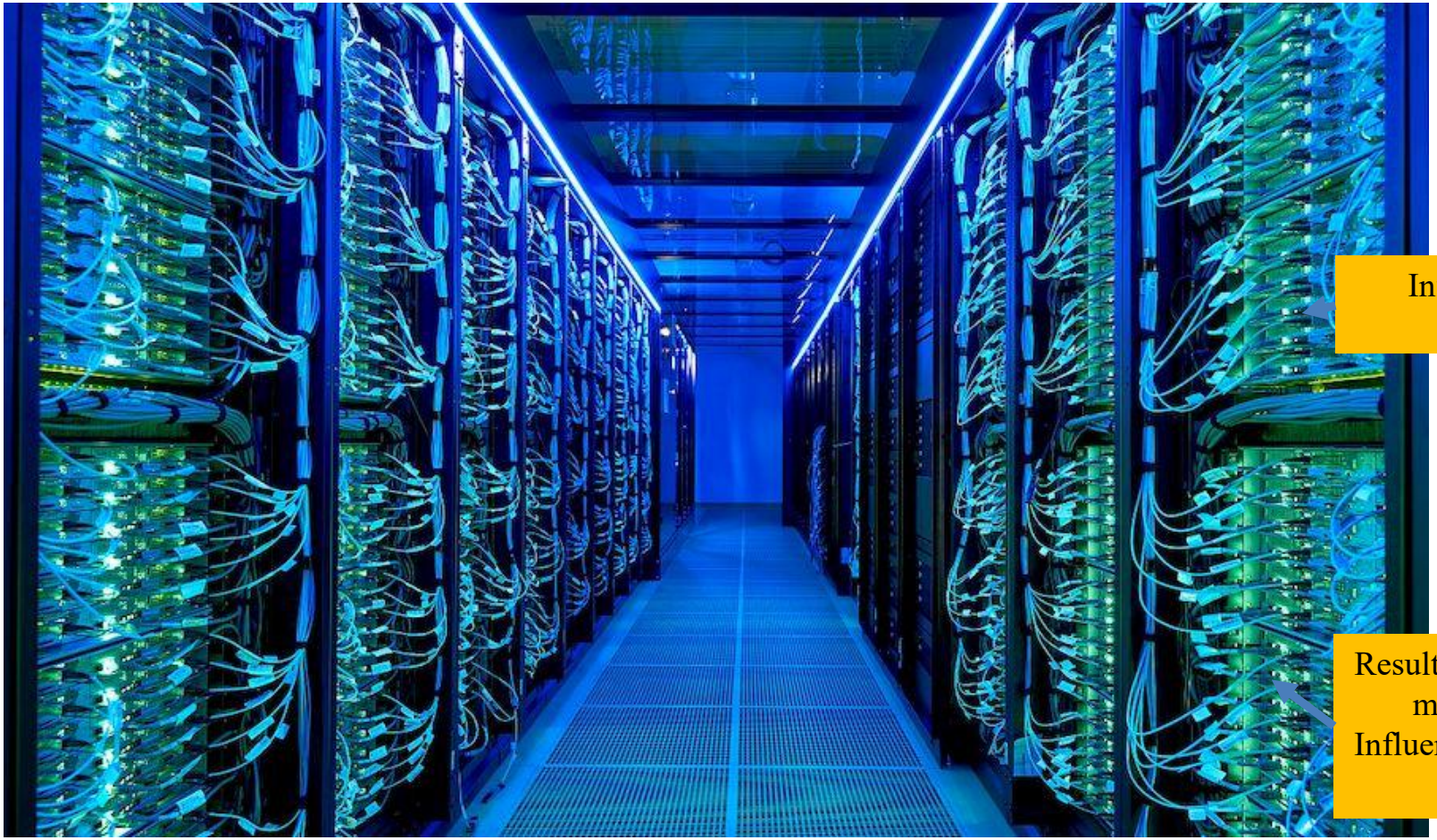
1-2 nm stable molecular clusters

Cloud condensation nuclei > 50 nm

H. Svensmark , J.O.P.Pedersen, N. Marsh, M. Engghoff U. Uggerhøj, Proc. R. Soc. A (2007)

H. Svensmark , Enghoff, Shaviv, J. Svensmark Nature communications 2017

Test of the cosmic ray aerosol cloud theory using Global Circulation Models (2009 – present)



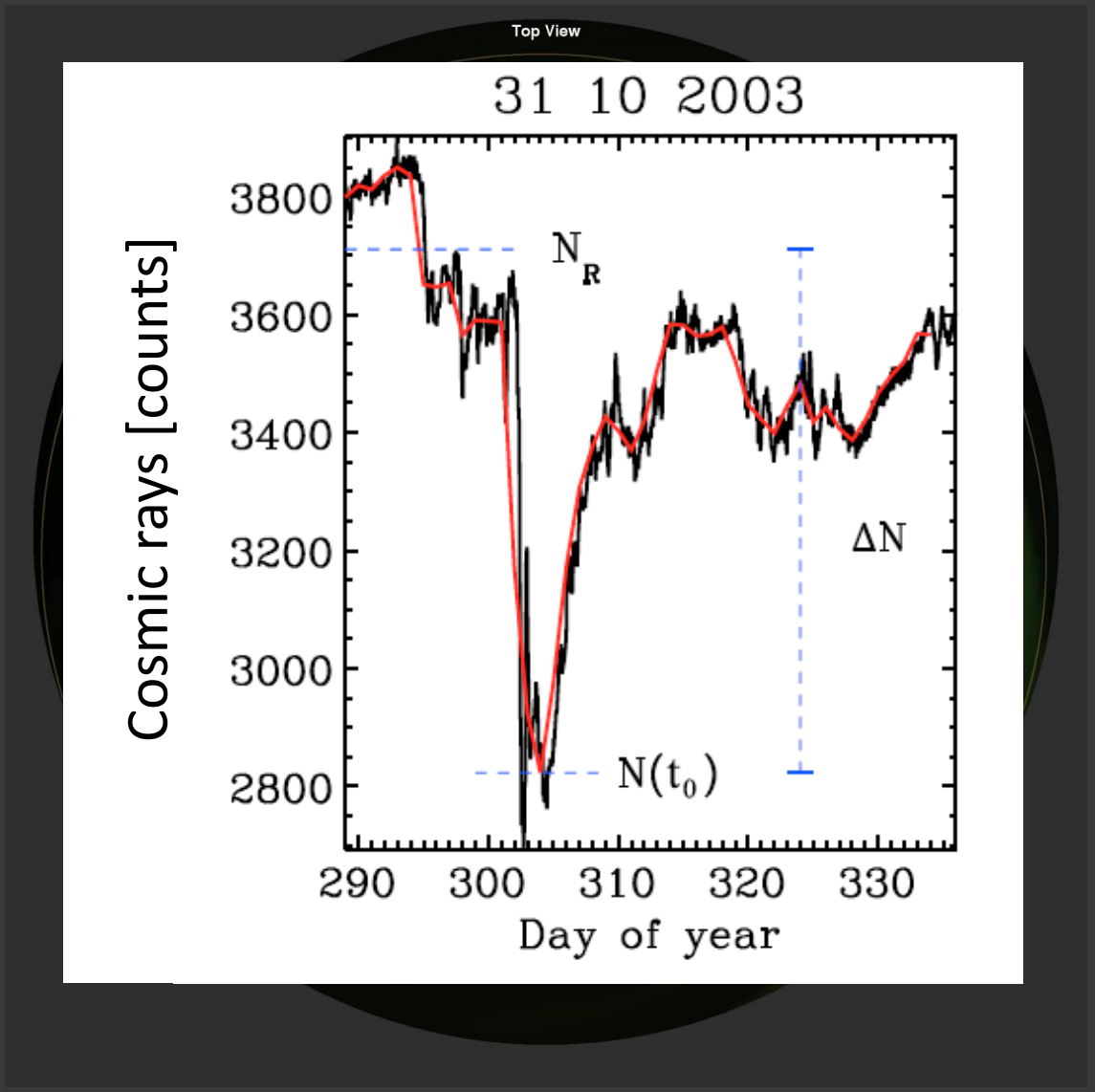
Influence on clouds

Result from aerosol models, no Influence on clouds

Data from: Snow-Kropla et al. 2011

None of these models included the effect of cosmic rays on aerosol growth

Coronal Mass Ejections
Nature's own experiments with the whole Earth

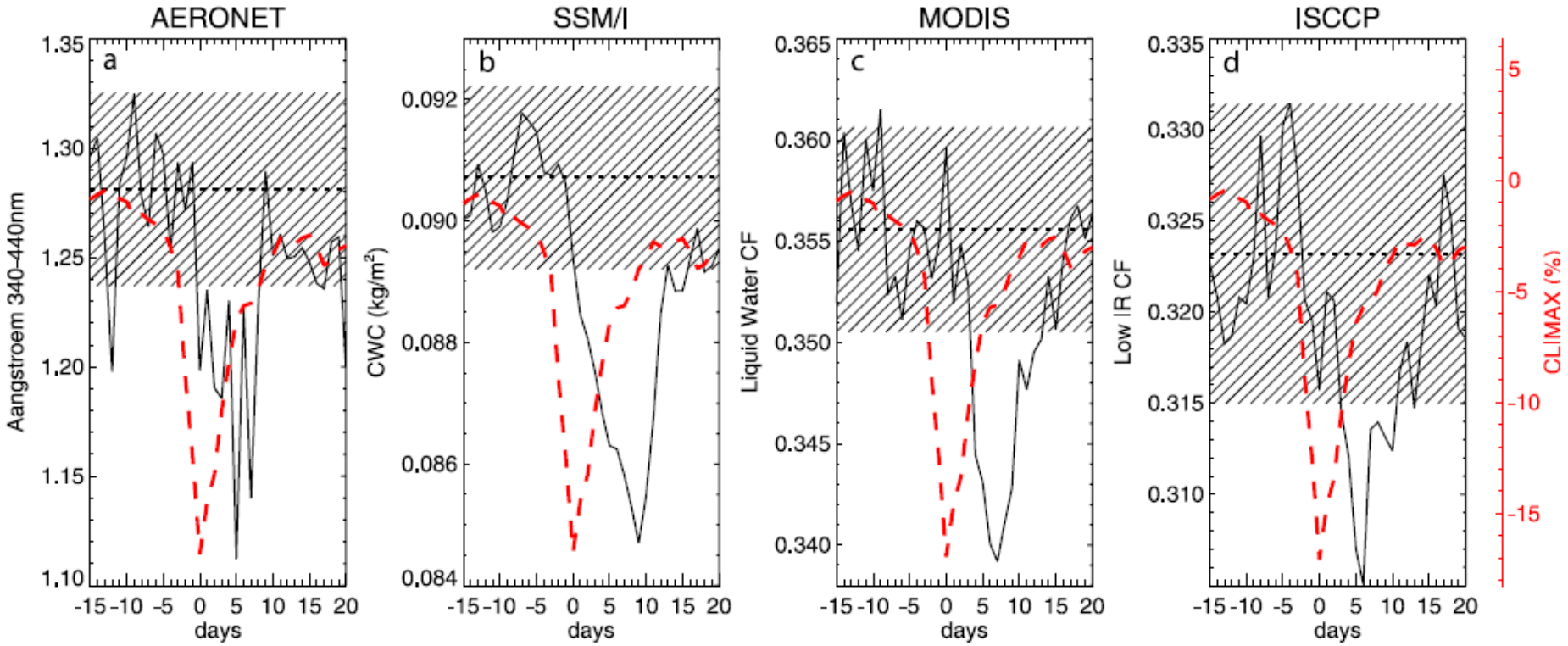


AERONET, SSM/I, MODIS og ISCCP data for the five strongest Forbush decreases

Aerosols

Clouds

Liquid water | Liquid cloud fraction | Low Clouds



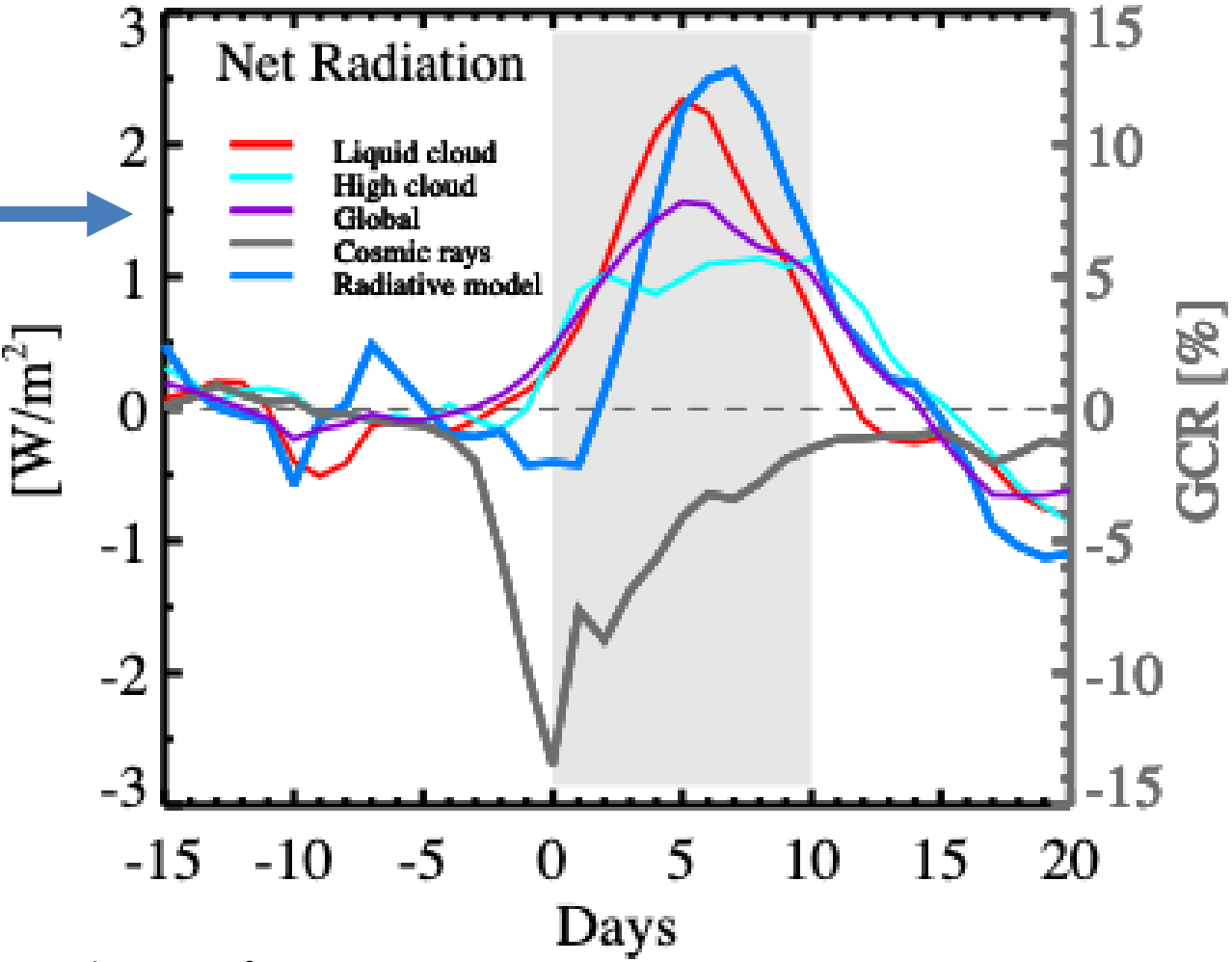
Svensmark, Bondo, Svensmark, Geo. Phys. Lett., 2009

Svensmark, Enghoff, Shaviv, Svensmark, J. Geophys Res., 2016

Observation from the CERES satellite of the energy balance due to a change in cosmic rays, followed by a change in cloud cover

Globally 1.5 W/m^2 Change in the radiative budget

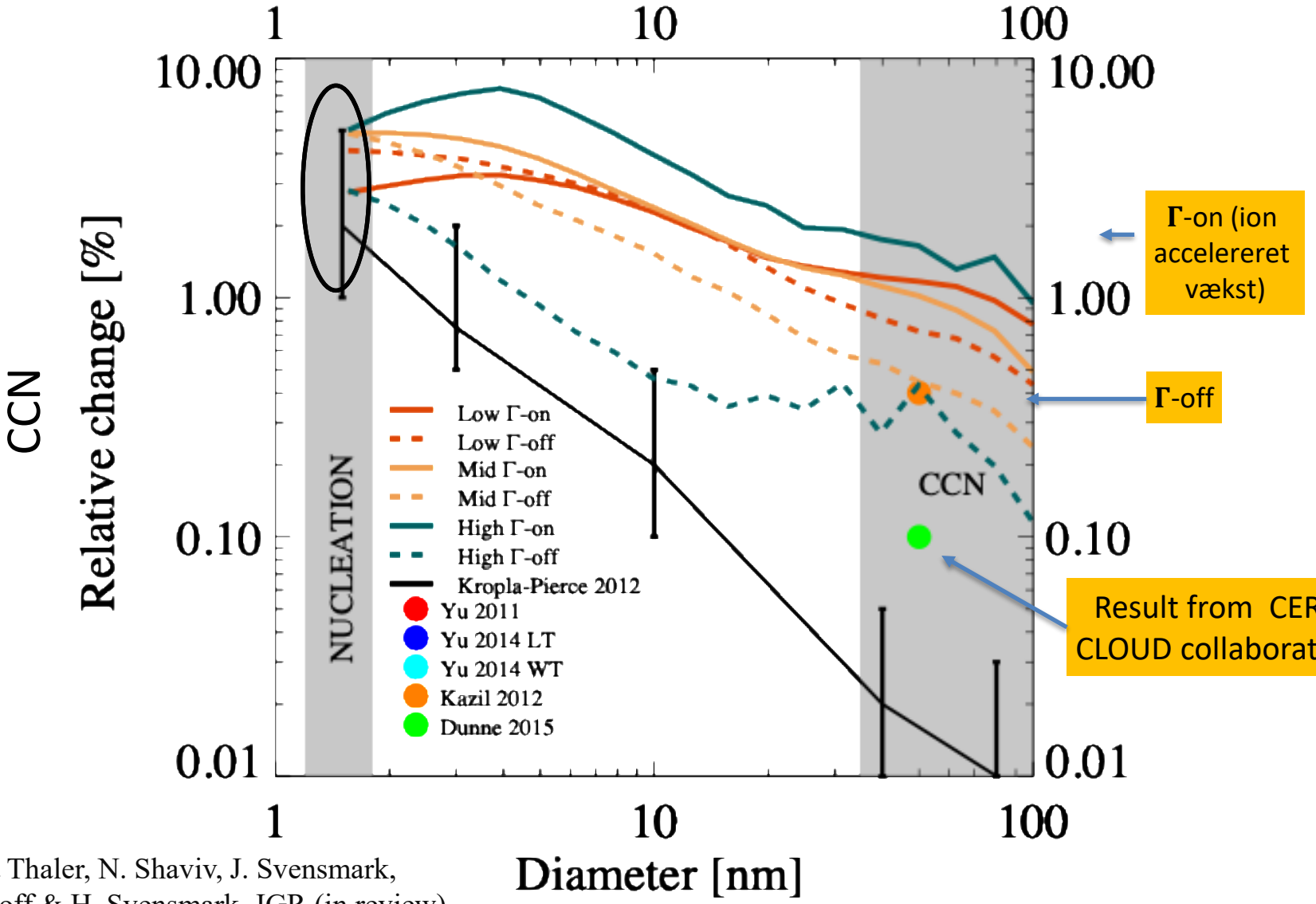
(For a change in cosmic rays corresponding to the 11 years solar cycle)



Svensmark, Enghoff, Shaviv, Svensmark, Scientific Reports 2021

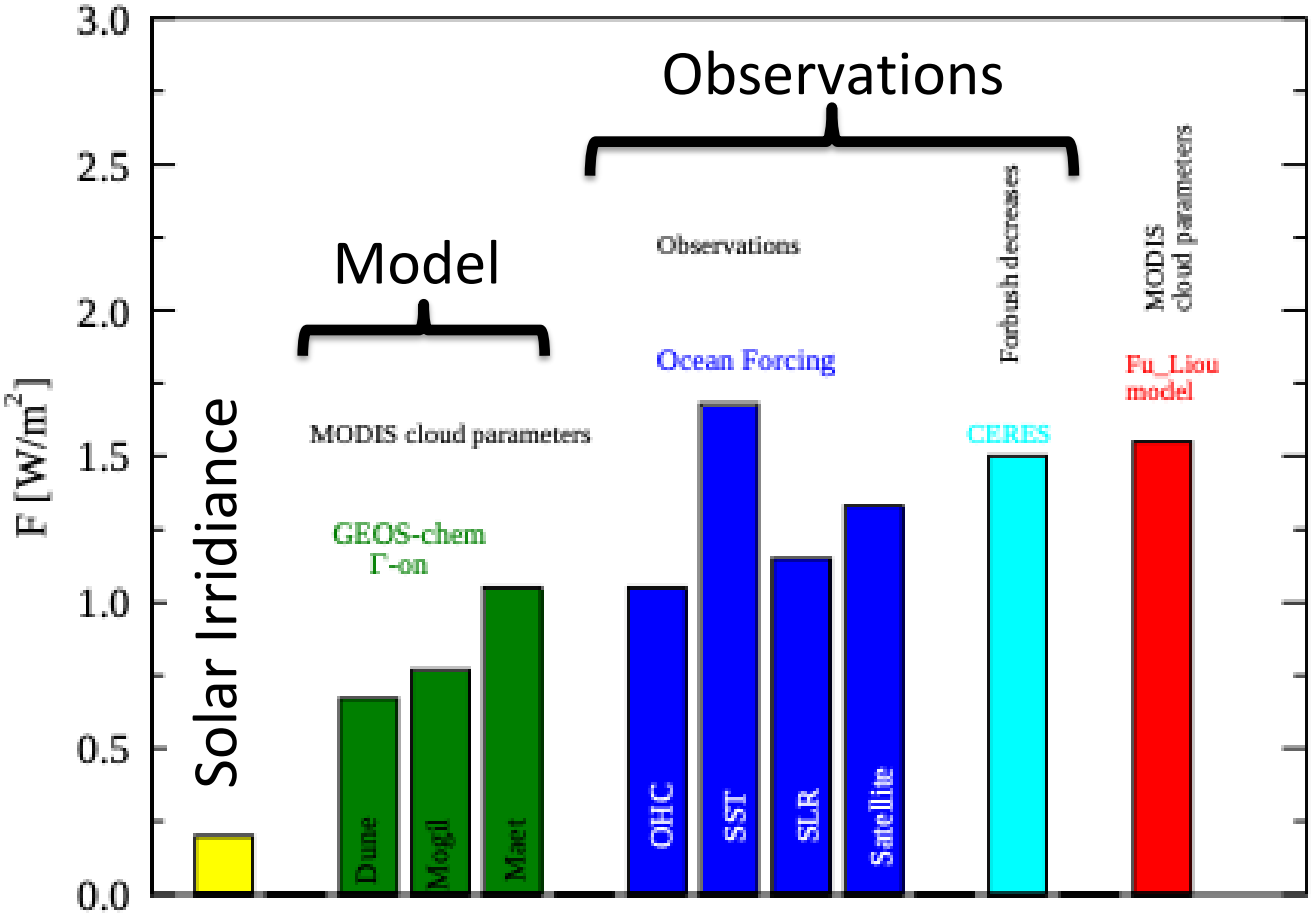
Modelling Solar cycle response (GEOS-Chem-TOMAS)

Including ion nucleation and ion accelerated growth



Irina Thaler, N. Shaviv, J. Svensmark,
M. Enghoff & H. Svensmark, JGR (in review)

Cosmic ray-cloud forcing over the 11-year solar cycle

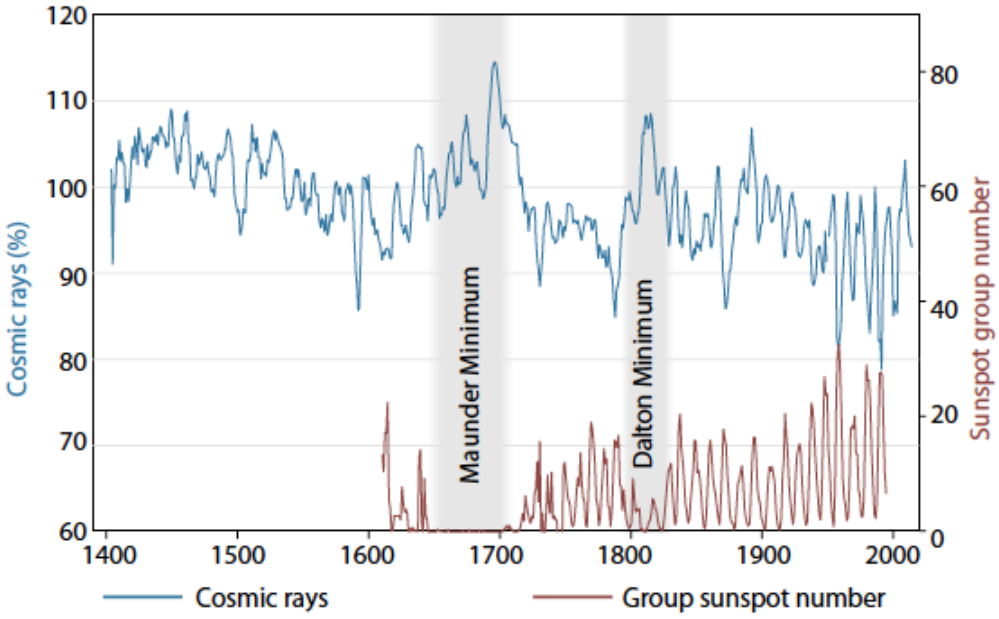


H. Svensmark, Irina Thaler, N. Shaviv,
J. Svensmark, M. Enghoff, (unpublished)

Summary

We now have evidence that changes in cosmic rays significantly influence clouds and, in turn, the Earth's energy balance.

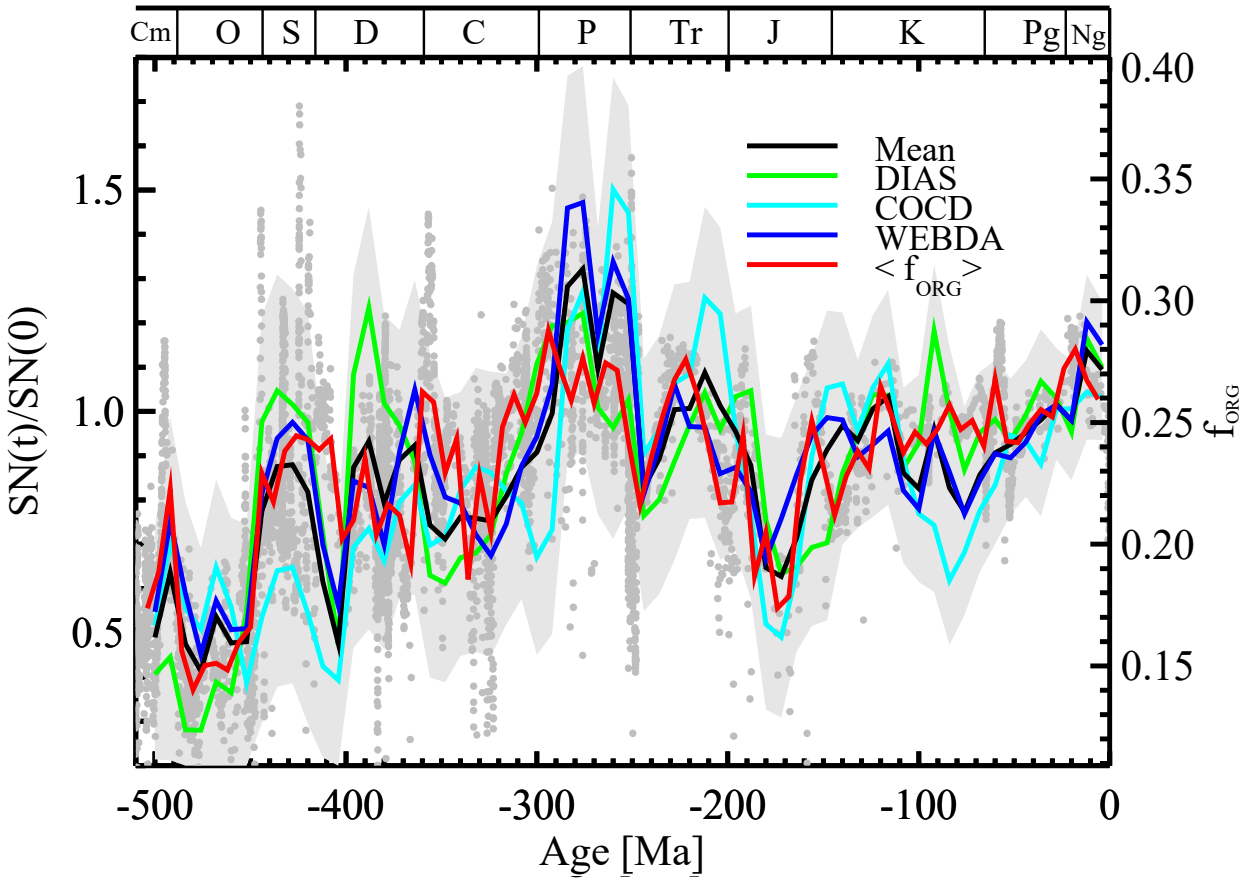
- Experimentes
- Observation
- Modelling



Hopefully we cant test the effect in a global climate model Including both cosmic rays and greenhouse gasses

Geological time scales

Fraction of organic material in sediments



Large bio-mass ➡ More organic material in sediments

⬆

High cosmic ray flux

Low cosmic ray flux

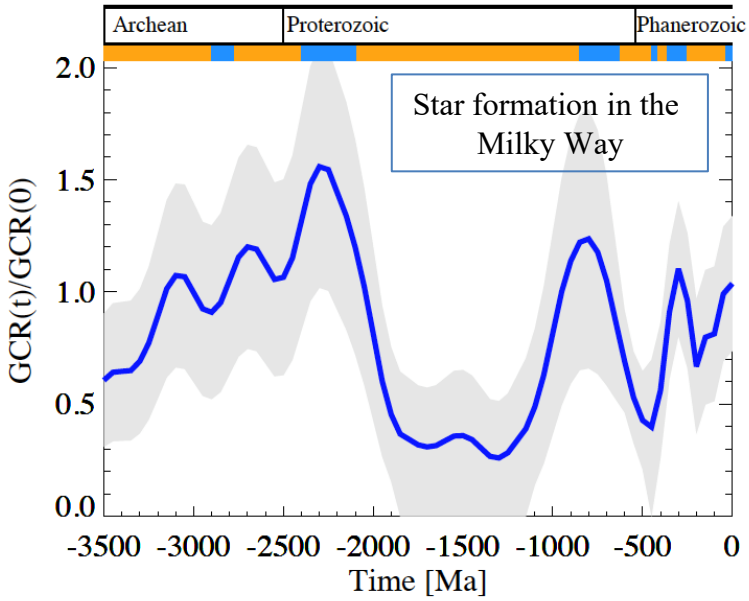
⬇

Smaller bio-mass ➡ Less organic material in sediments

Fraction of organic material in sediment

Svensmark, H. (2021). Supernova rates and burial of organic matter. Geophysical Research Letters, 48, e2021GL096376.

Cosmic rays throughout Earth's history and organic material in sediments



Cosmic rays and oxygen production

Oxygen

Photosynthesis

$6CO_2 + 6H_2O \leftrightarrow C_6H_{12}O6 + 6O_2$

Removal of organic material to sediments

Supernovae significantly influence the production of oxygen, which is essential for complex life.

Svensmark, H. (2021). Supernova rates and burial of organic matter. Geophysical Research Letters, 48, e2021GL096376.

Conclusions

A mechanism has been discovered that *connects cosmic-ray ionisation to cloud formation*, which seems to explain the significant climate changes observed throughout Earth's history.

This mechanism suggests that the Sun has had a substantial influence on both historical and present-day climates.

If the Sun played a crucial role in the climate changes of the 20th century, then climate sensitivity to CO_2 must be small; consequently, it is a lesser concern.

However, the IPCC does not assign any significance to the Sun's influence.

Additionally, the Milky Way plays a key role, with stellar processes being critically important not only for climate but also for the conditions necessary for life.

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Sun and climate in media