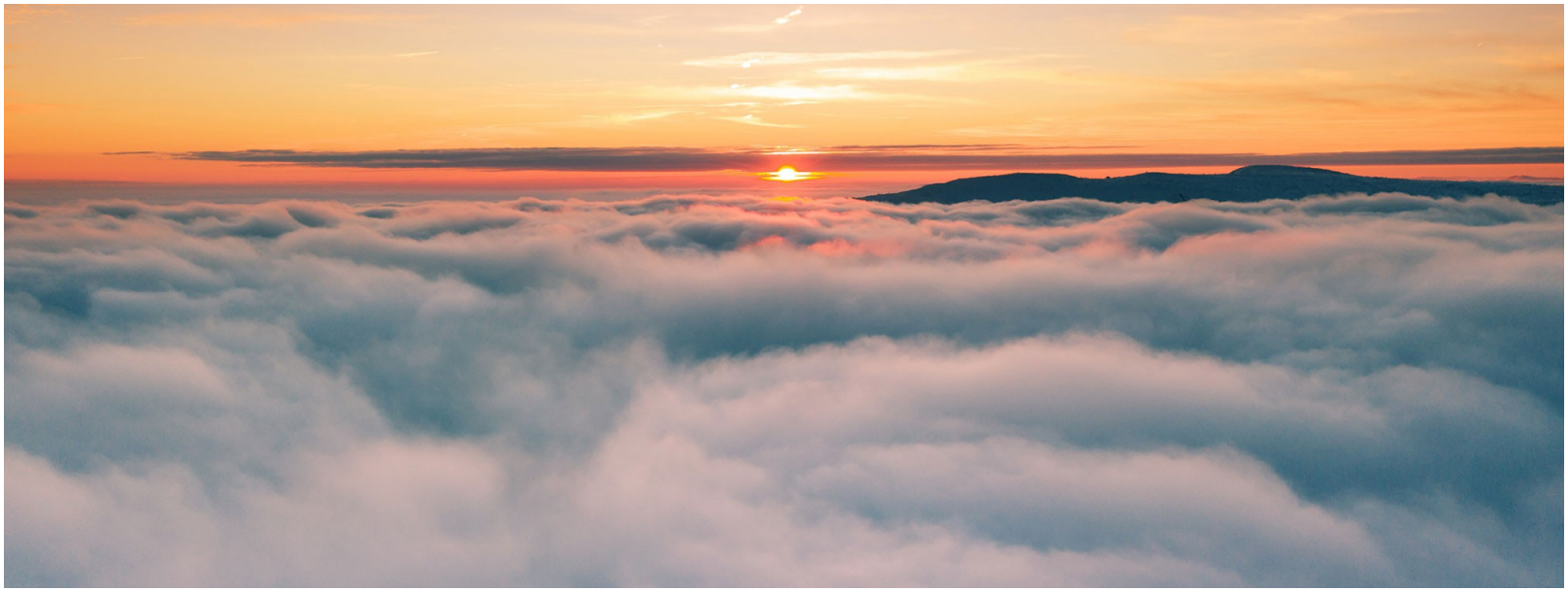
Understanding the cosmic ray climate link using experimental and empirical evidence



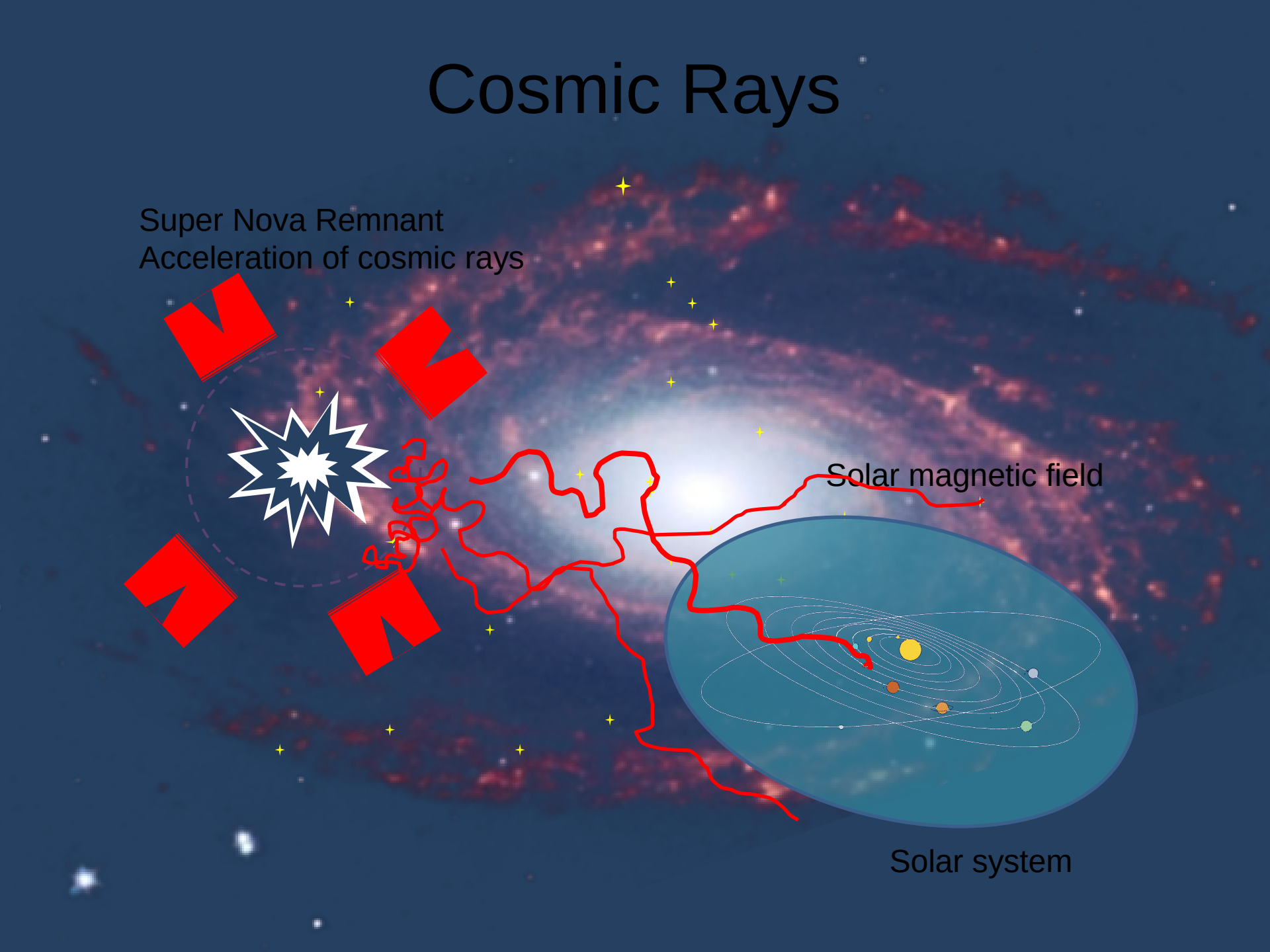
Henrik Svensmark, DTU Space
In collaboration with
Martin Enghoff, Nir Shaviv, Jacob Svensmark, and Irina Thaler

DTU/Lyngby-Oxford-Jerusalem

Understanding the cosmic ray climate link using experimental and empirical evidence

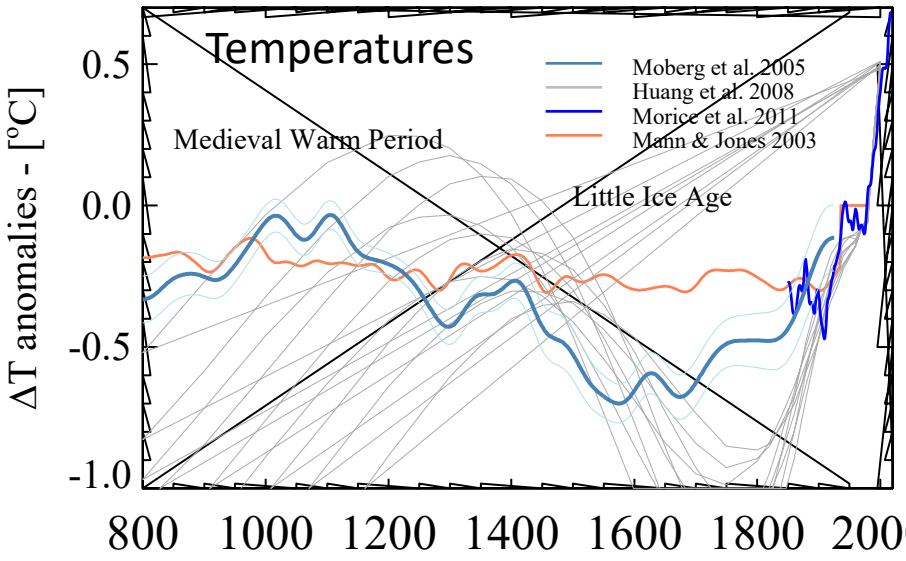
1. **The Cosmoclimatological Hypothesis**
   - Cosmic rays
   - Presentation of the hypothesis
   - The microphysical mechanism, theoretically and experimentally
2. **Starformation and Supernova**
   - Influence on life

Cosmic Rays


Super Nova Remnant
Acceleration of cosmic rays
Solar magnetic field
Solar system

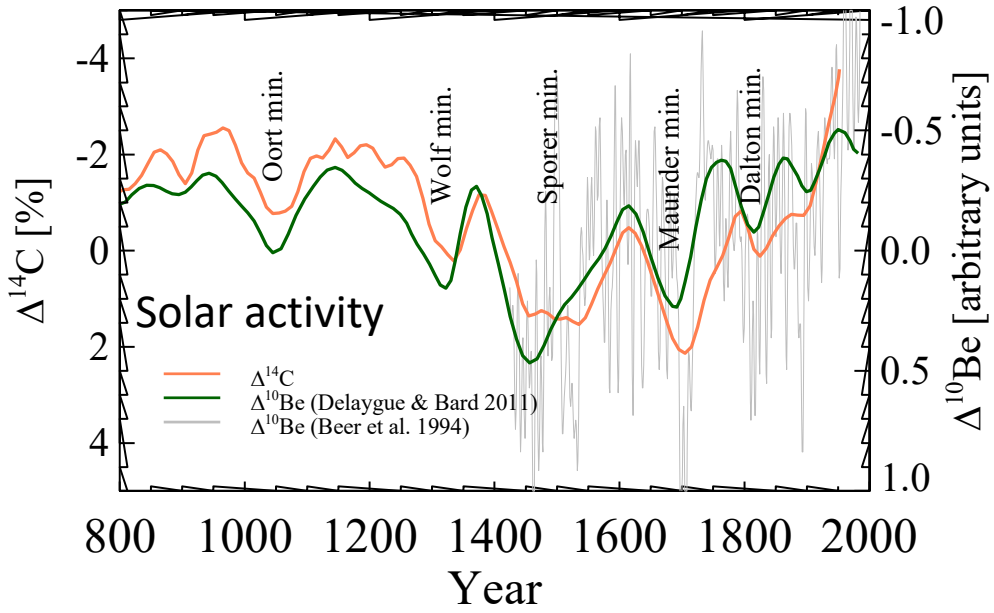
Cosmic rays in the atmosphere

Temperatures over the last 1000 years



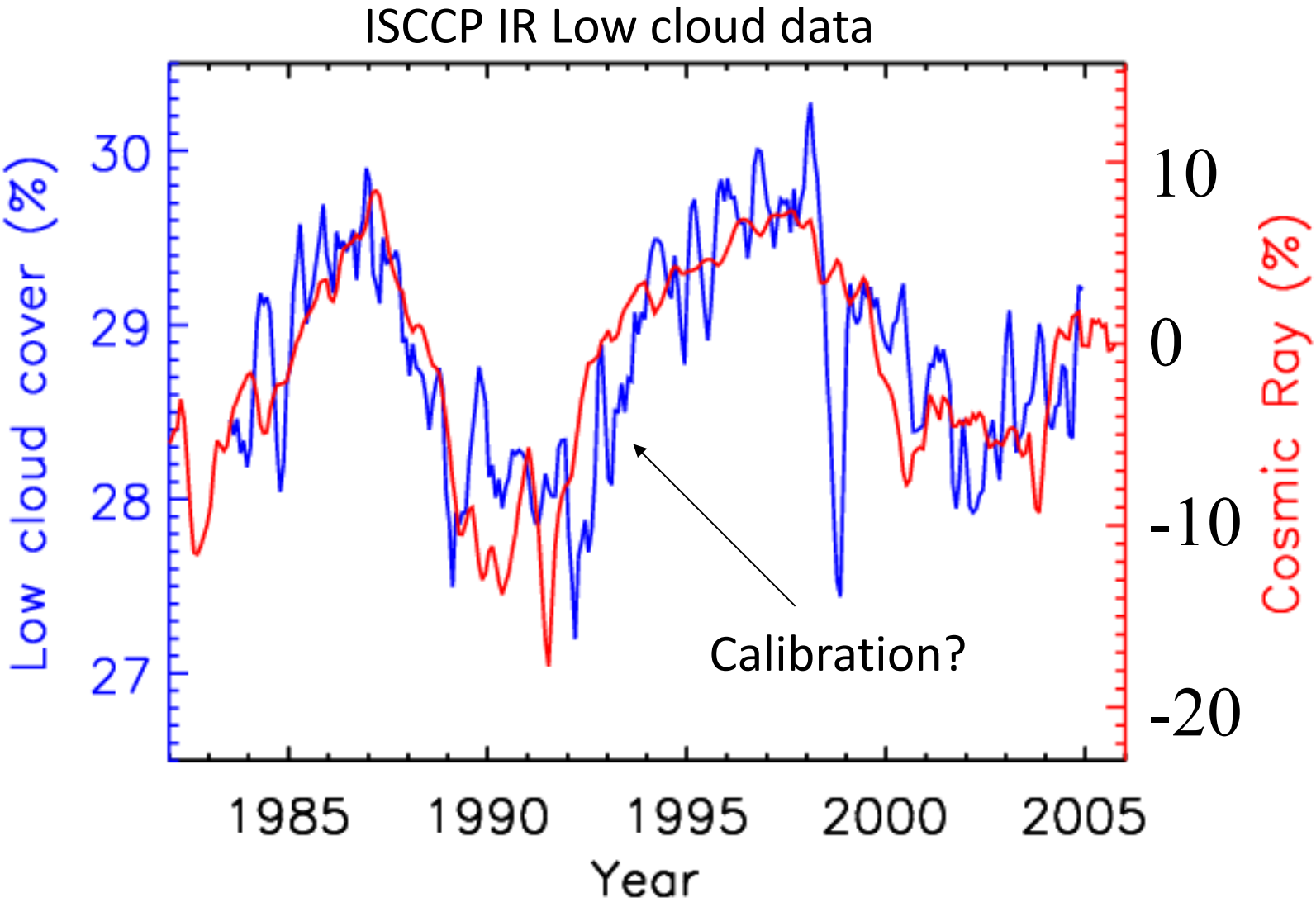
Cosmic rays

Solar activity



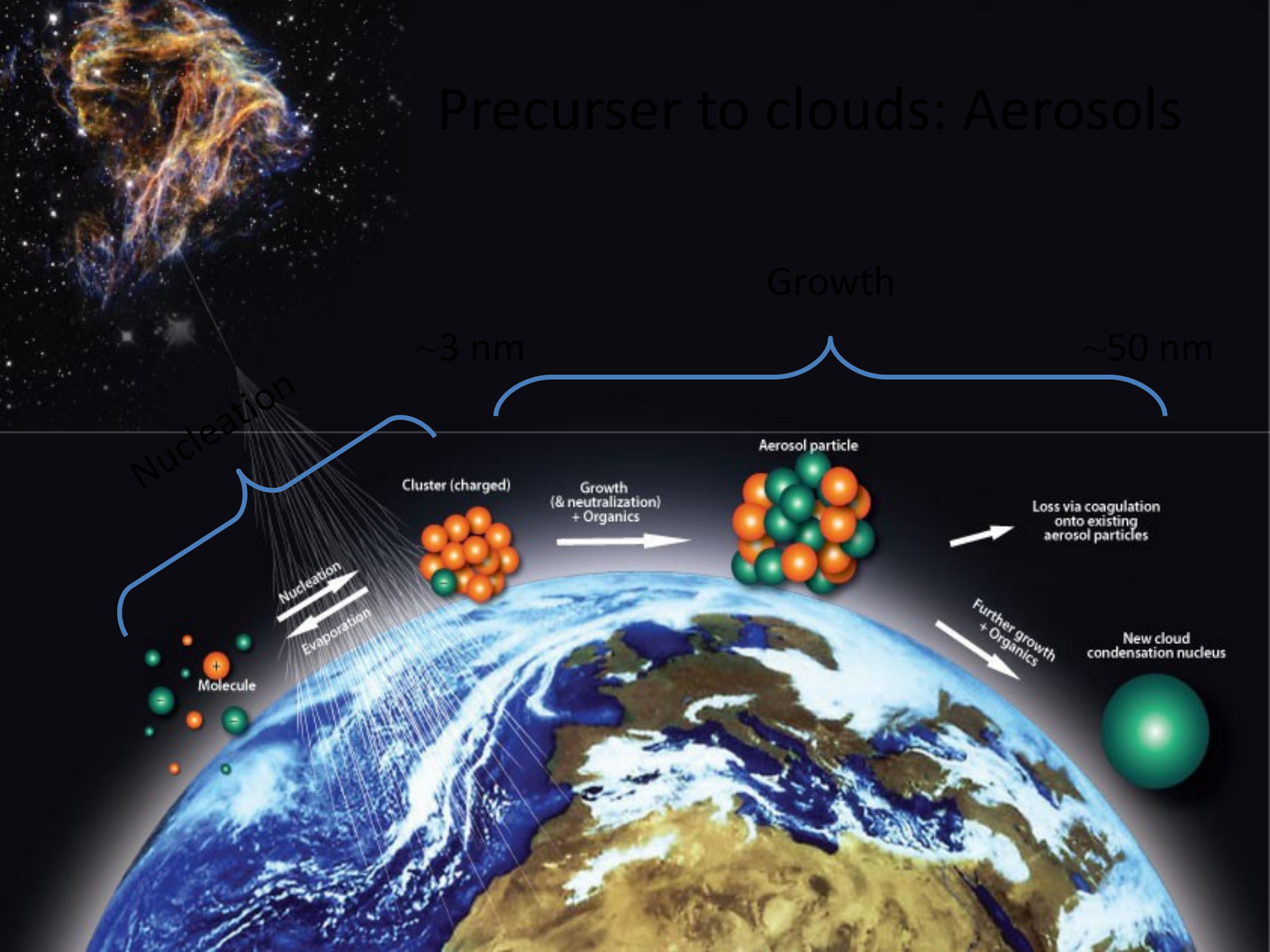

2019-11-01 00:00:00 UTC
www.digital-typhoon.org
Himawari-8 [RGB]
NII/NICT

Link between Low Cloud Cover and Galactic Cosmic Rays? Solar cycle variation



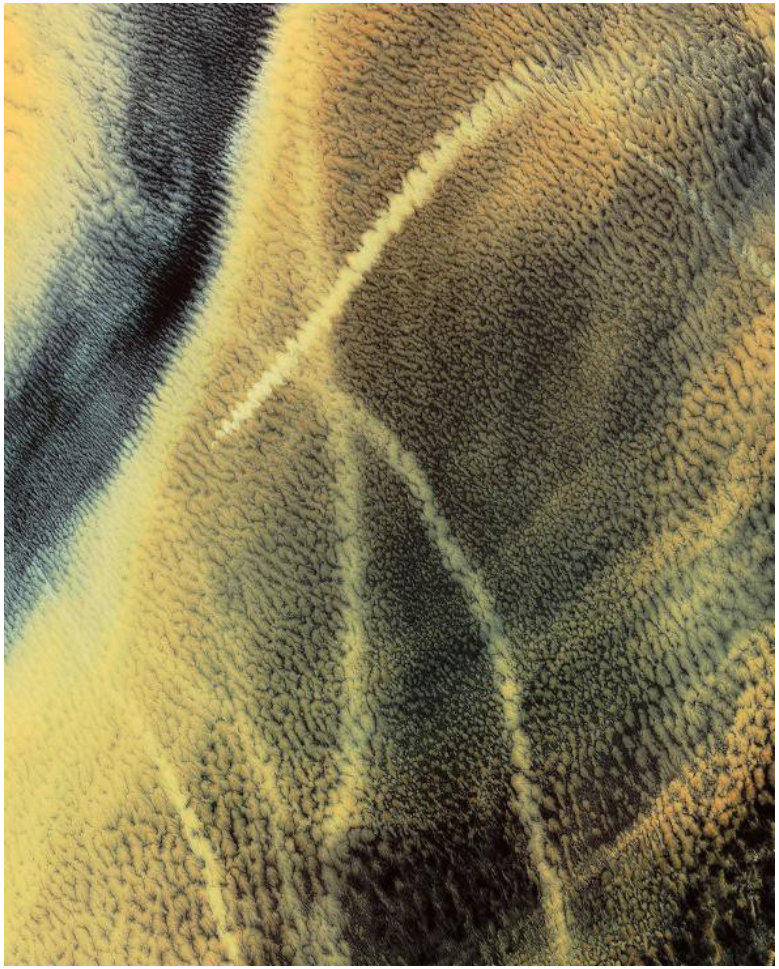
Svensmark & Friis-Christensen, JASTP 1997, Svensmark, PRL 1998, Marsh & Svensmark, PRL, 2000. (update 2005)

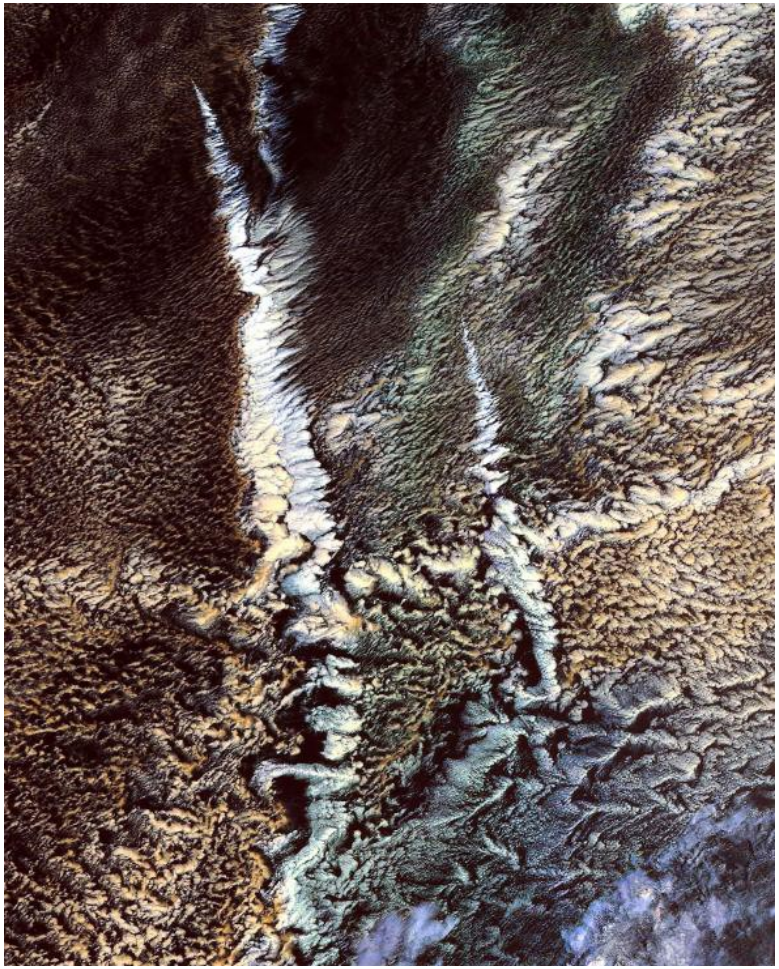
Precurser to clouds: Aerosols



Aerosols and microphysics of clouds

Satellite observations of ship tracks





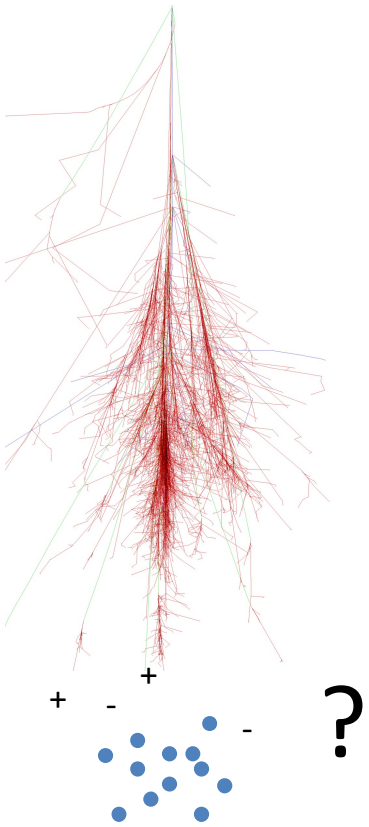
DTU, National Space Institute

ASTRID accelerator, Aarhus Universitet

CERN

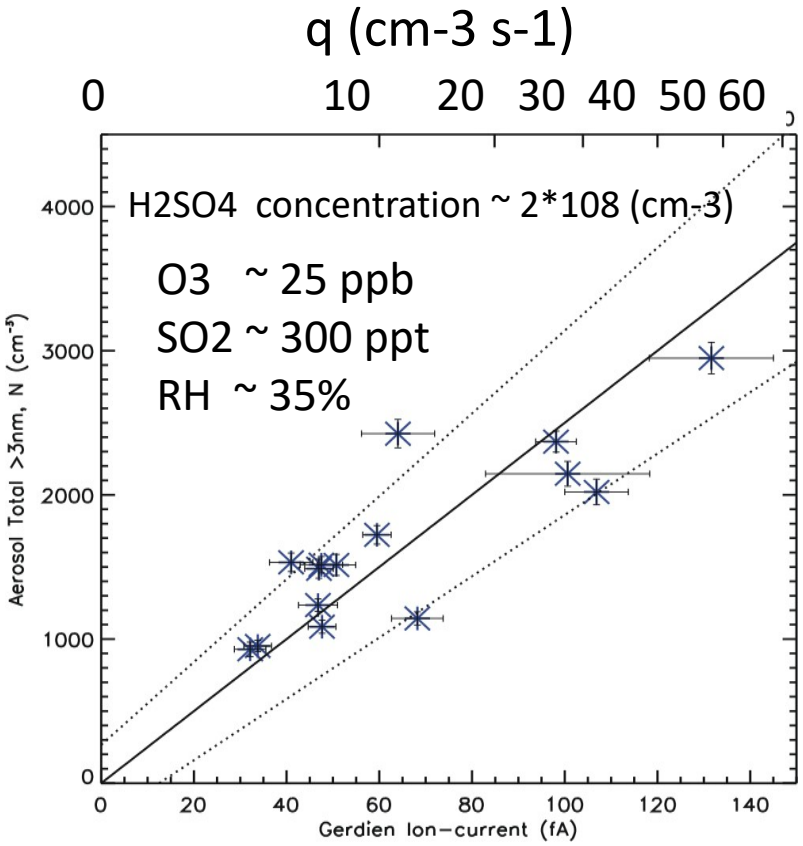
BOULBY Underground Laboratory (1.1 km underground)

Experimental challenges



1-2 nm stable aerosols

2004 - 2007



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

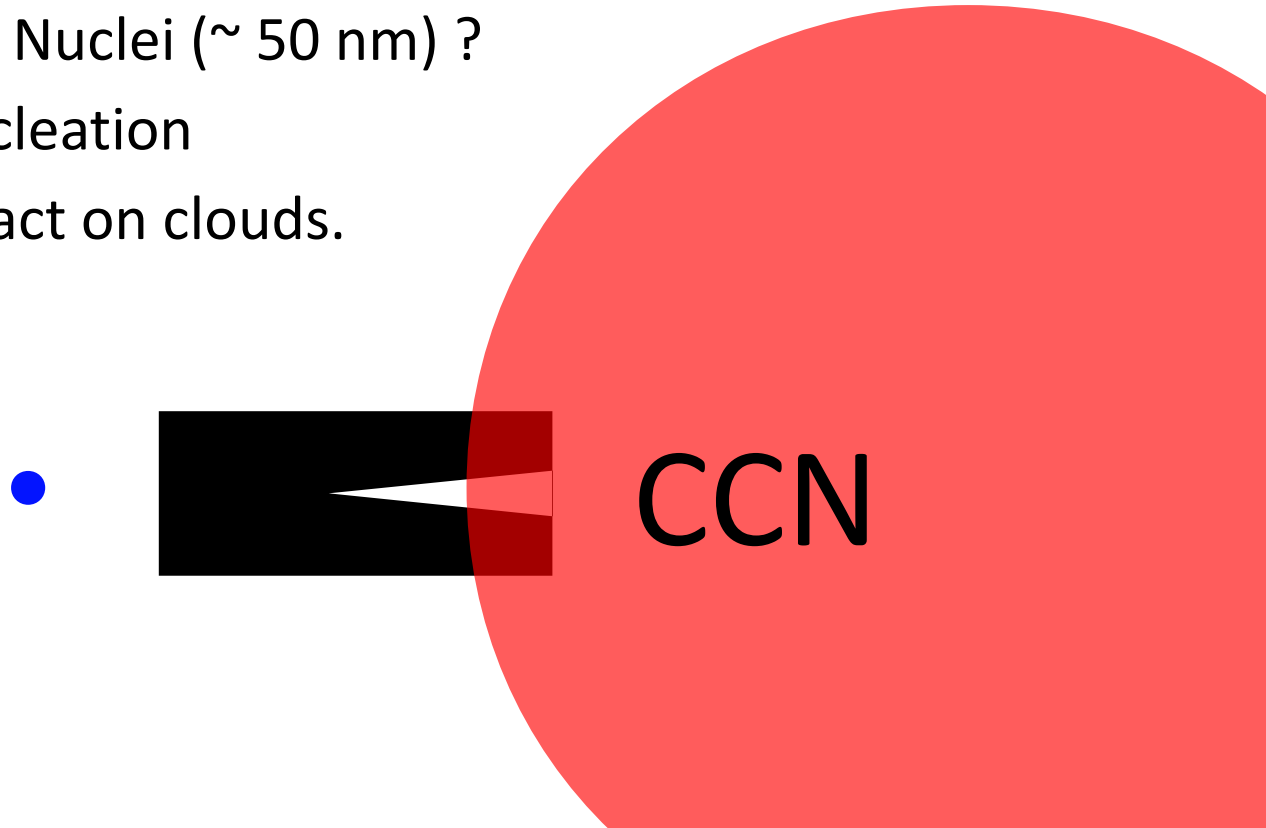
So experimentally there is good evidence for the generation of ultrafine aerosols by ions ~ 1-3 nm

- An important remaining question:

Will the small aerosols grow to Cloud Condensation Nuclei (~ 50 nm) ?

Nucleation

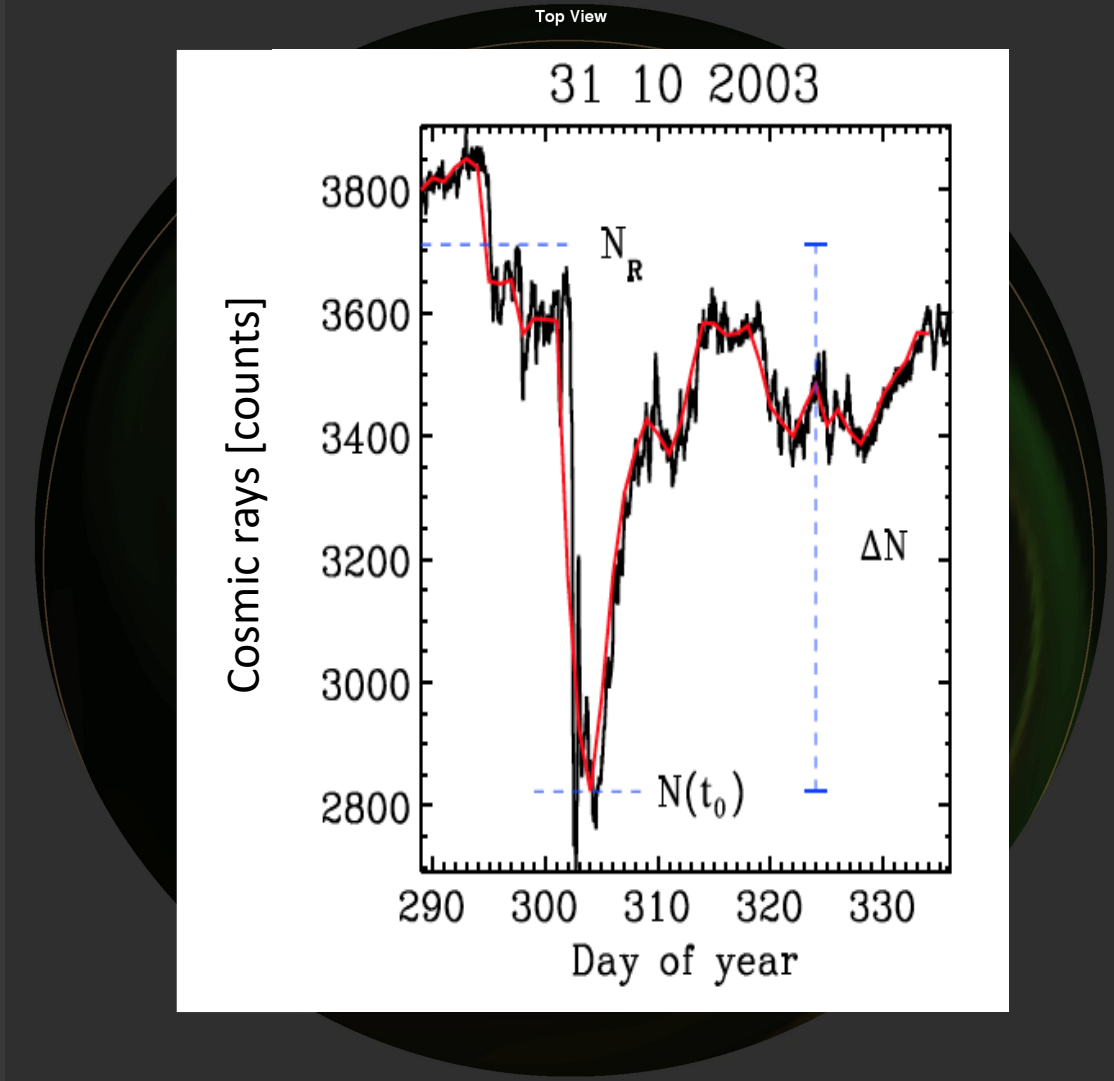
If not no impact on clouds.



RESULTS FROM Global Circulation Models (2009 – present)
(No ion-effects on growth)

Coronal Mass Ejections

Natural experiments for testing the GCR-atmosphere link

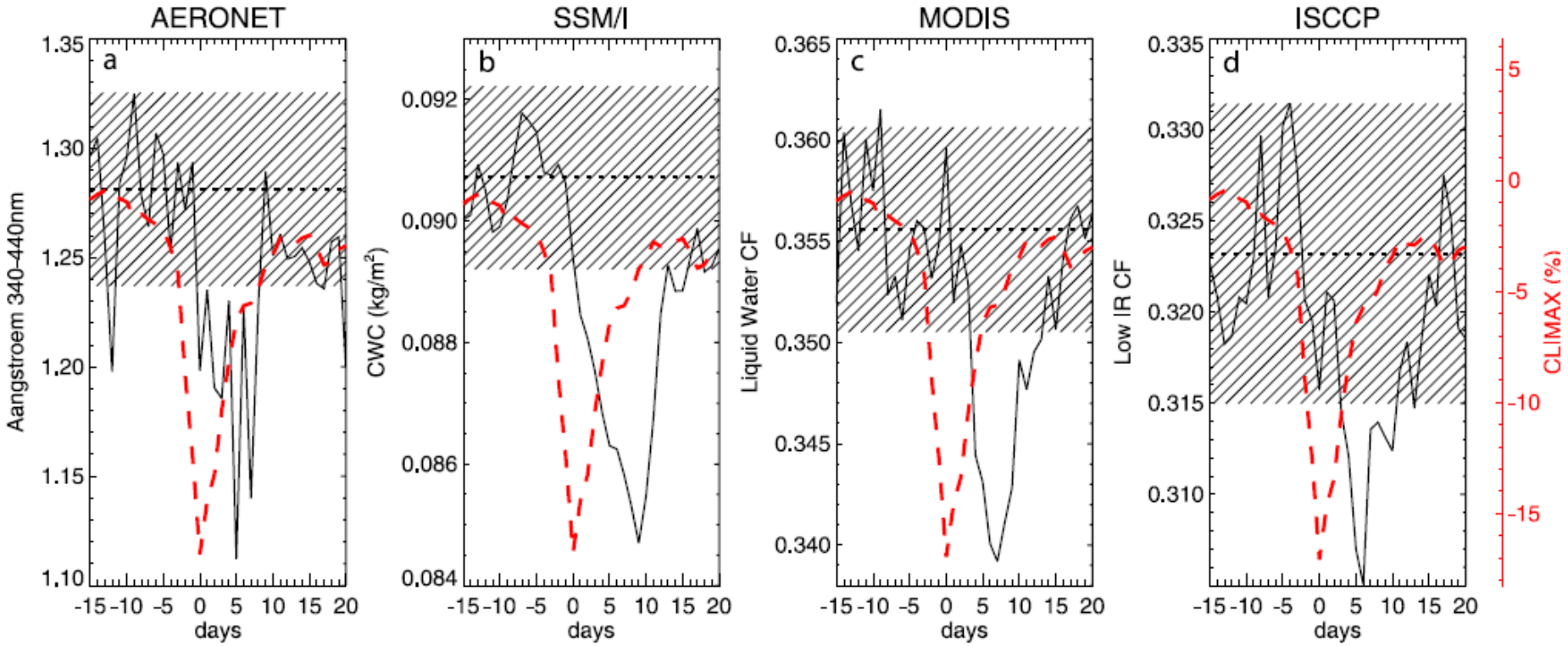


AERONET, SSM/I, MODIS and ISCCP data for 5 strongest Forbush decreases

Aerosols

Clouds

Liquid water Liquid cloud fraction Low Clouds



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

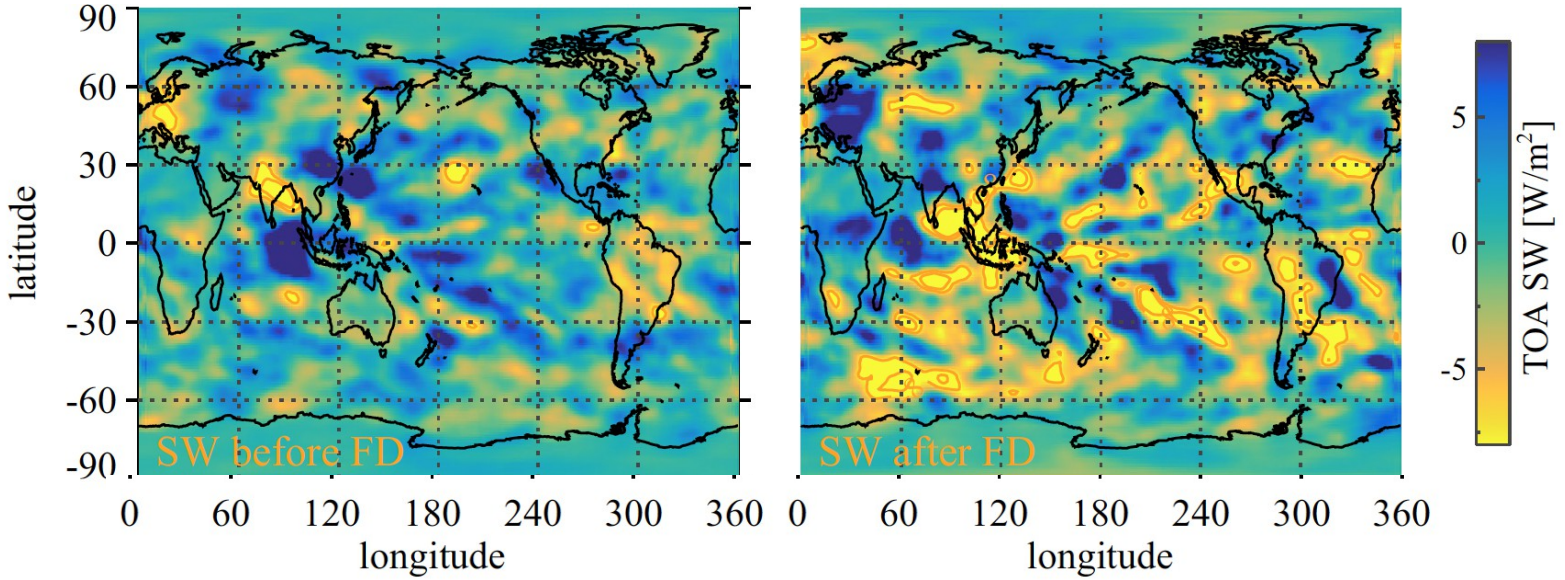
Svensmark, Enghoff, Shaviv, Svensmark, J. Geophys Res., 2016

CERES instrument: The effect on the energy balance

Shortwave

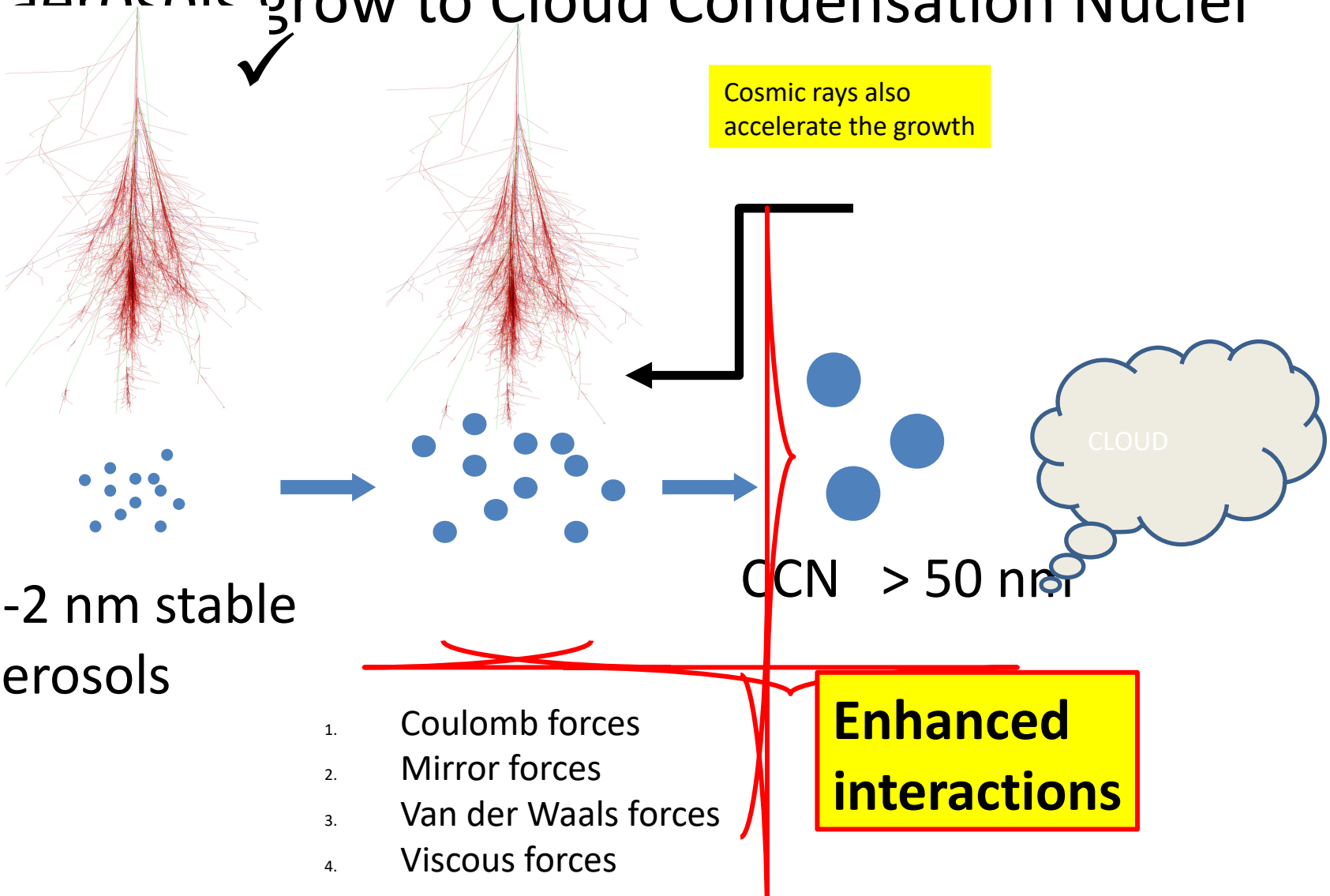
Before cosmic ray change
(One week average)

After cosmic ray change
(One week average)



Svensmark, H., Svensmark, J., Enghoff, M.B., Shaviv, J. N., *Sci Rep* **11,** 19668 (2021)

Experiments and observations suggest that aerosols grow to Cloud Condensation Nuclei

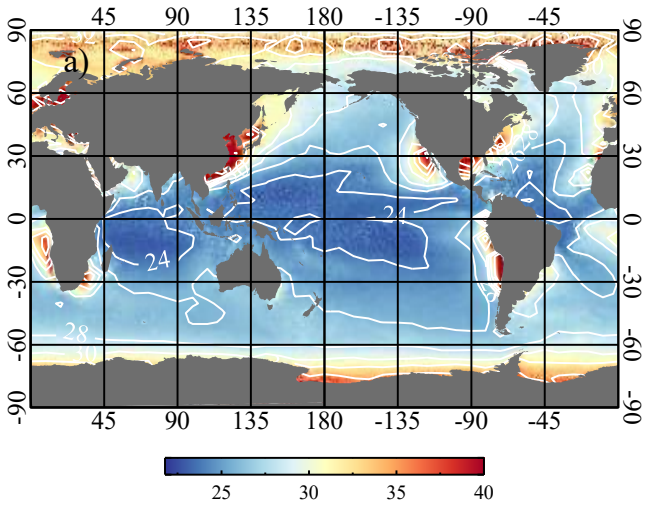


Low Liquid clouds over the oceans are more sensitive to small aerosols

Svensmark, H., Enghoff, M. B., Svensmark, J., Thaler, I., & Shaviv, N. J. (2024).
Supersaturation and critical size of cloud condensation nuclei in marine stratus clouds.
Geophysical Research Letters, 51, e2024GL108140

Critical CCN size

Much smaller than generally thought

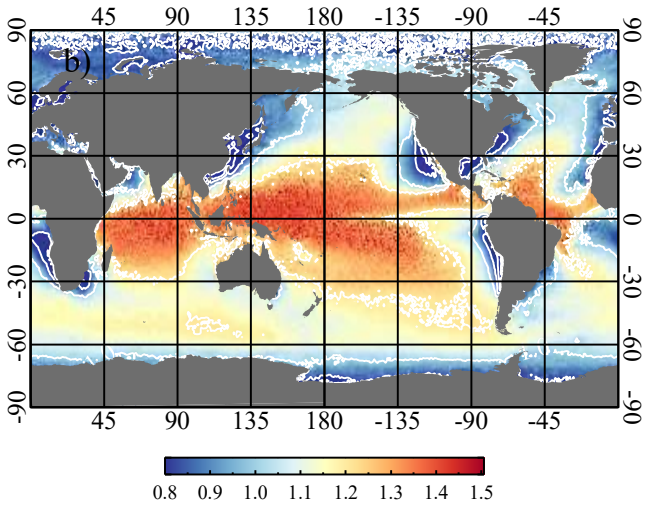


Critical size of CCN ~ 30 nm

Supersaturation ~ 1%
and not 0.2-0.3%

Supersaturation

Much larger than generally thought



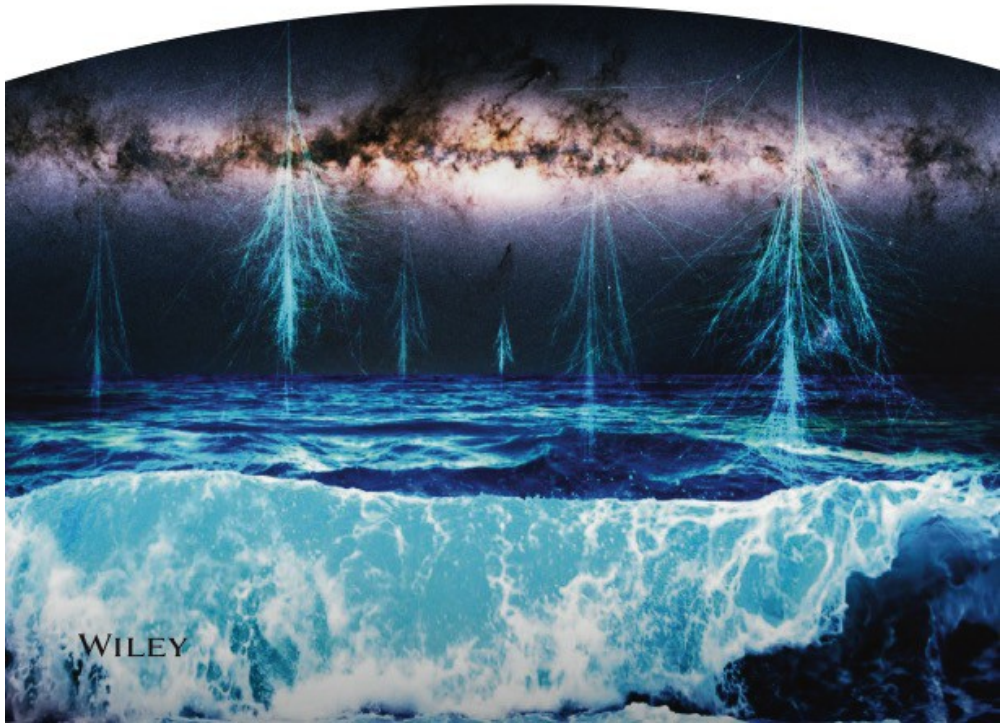
Cosmic rays have been present in Earth's atmosphere at all times, i.e., over billion of years

With consequenses for climate and life in general

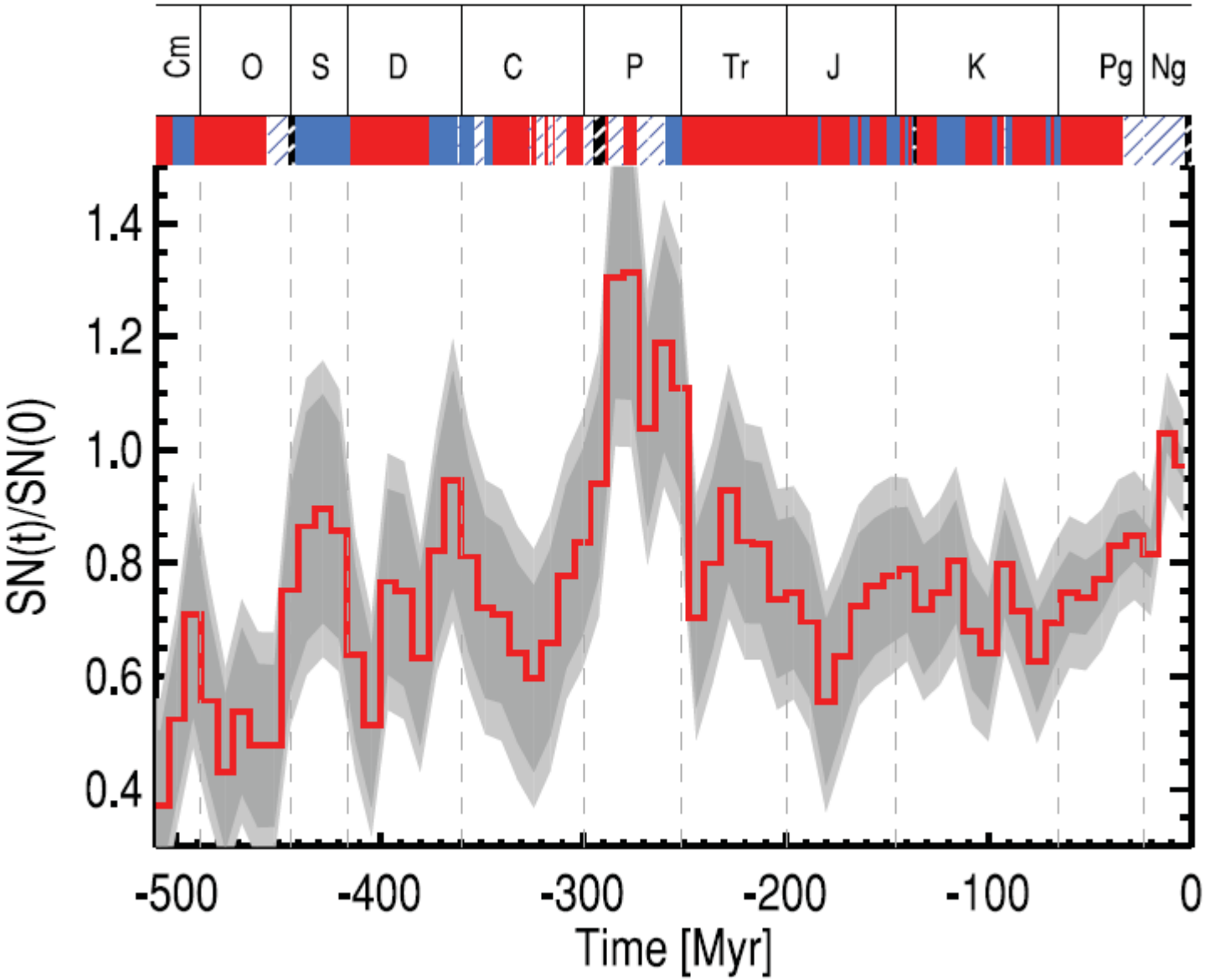
AGU ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters®

16 January 2022 · Volume 49 · Issue 1

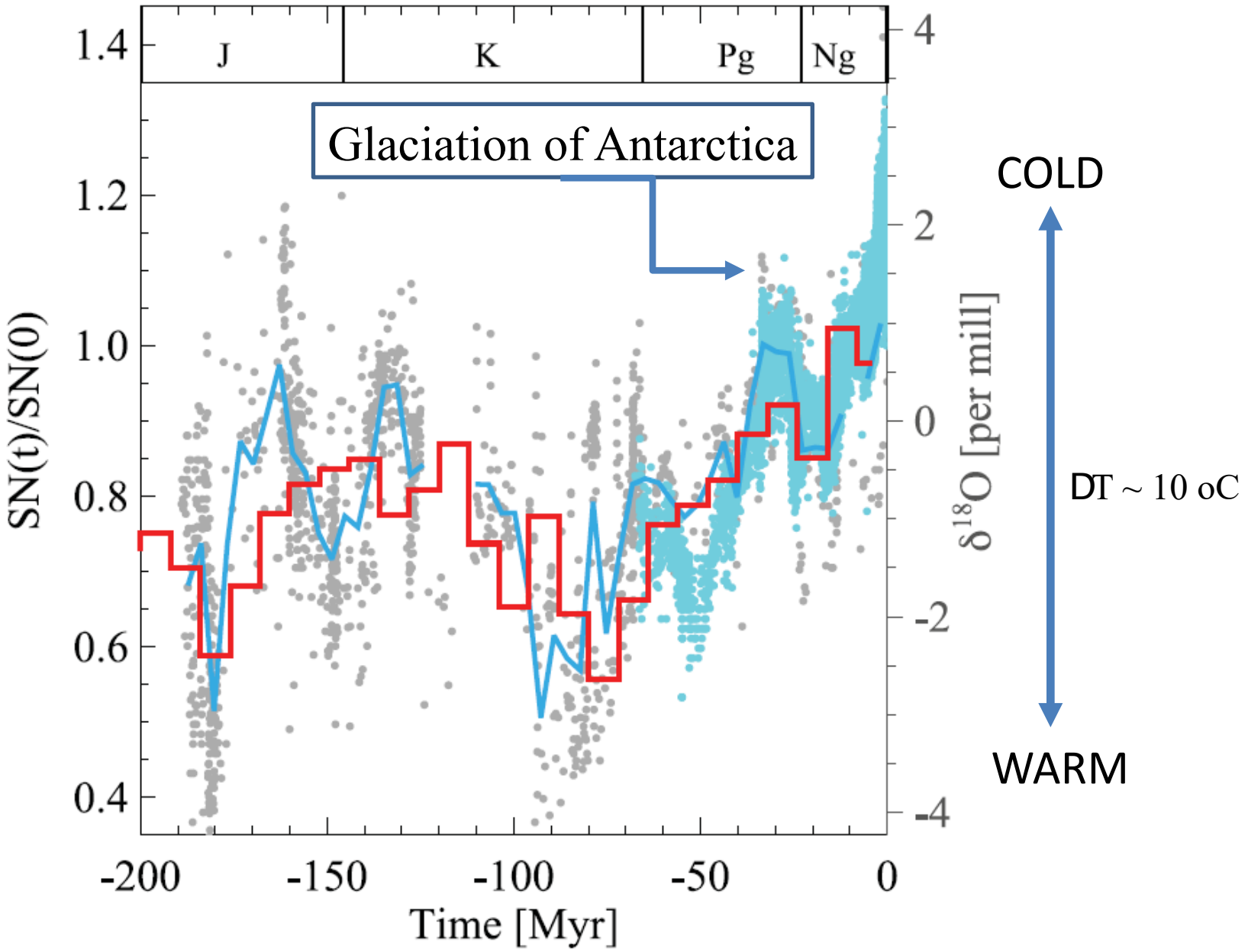


SN activity and glaciations during the last 500 Myr



Svensmark, Mon. Not. R. Astron. Soc., 423, 1234-1253 (2012)

Proxy temperature and supernova activity during 200 Myr

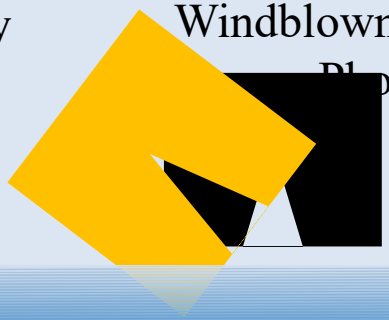


Svensmark, Mon. Not. R. Astron. Soc., 423, 1234-1253 (2012)

Biological Pump

Solar energy

Windblown and river runoff nutrients
Phosphor, Fe, Nitrogen



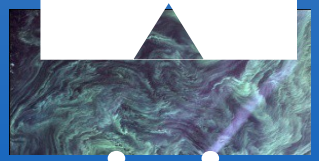
Bio production

+ Nutrients

Bio production

13C/12C

De-composion



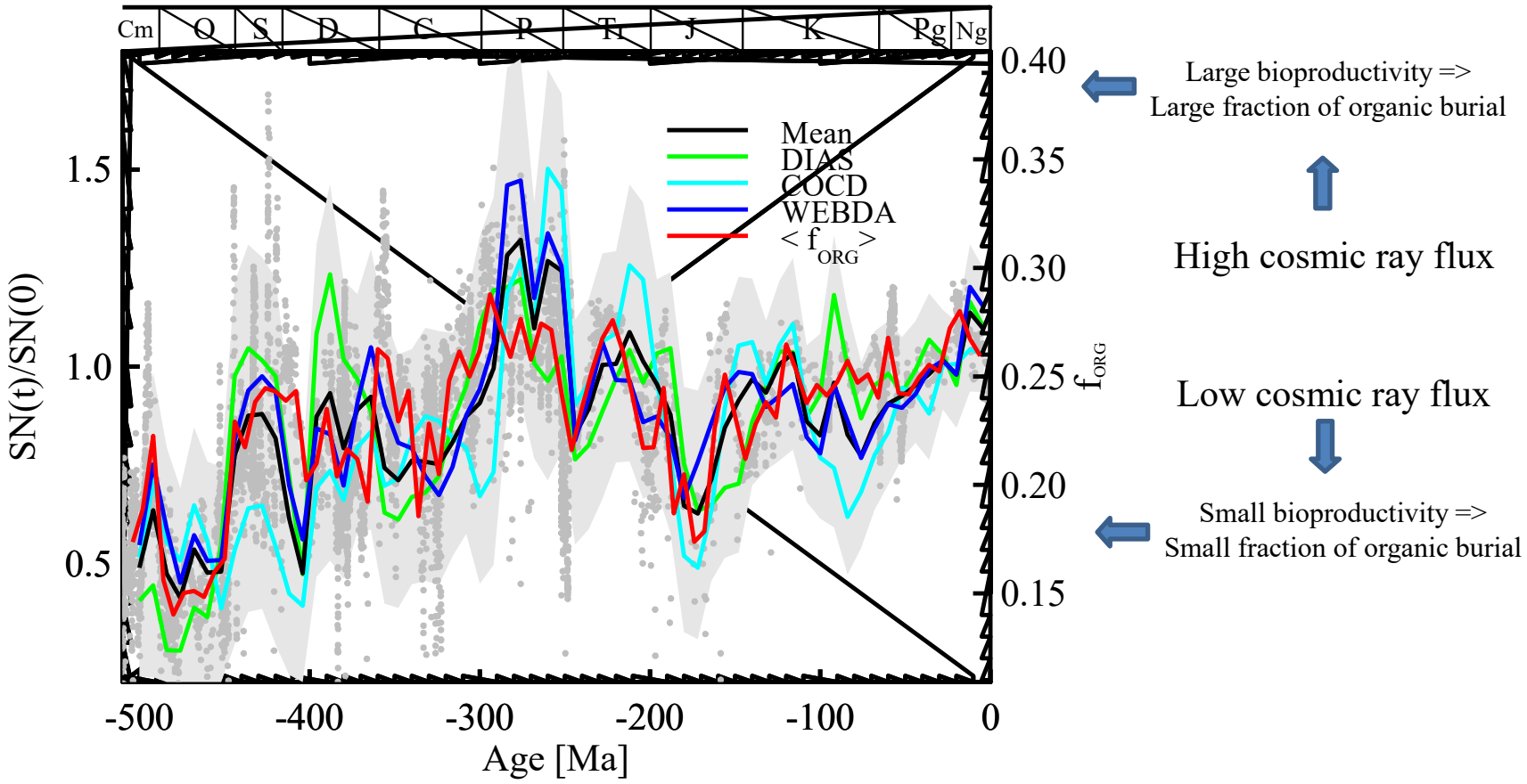
Inorganic Carbonate
Sediments

Organic Sediments

Sedimentary mountains (Grand Canyon)

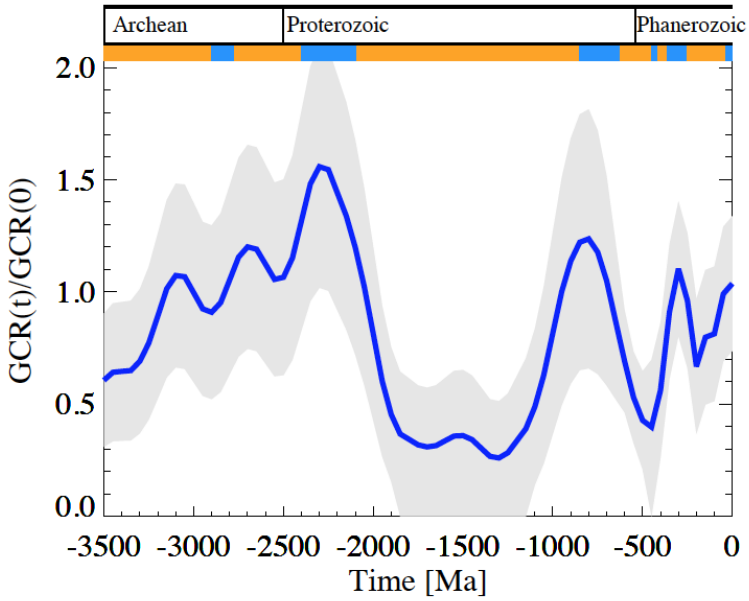
One can estimate the fraction of organic material buried as sediments

Organic burial in sediments and supernova activity



Galactic cosmic rays and burial of organic matter during the history of Earth

Star-formation in the Milky Way



Galactic cosmic rays and burial of organic matter
The source of oxygen

Galactic cosmic rays and the source of oxygen

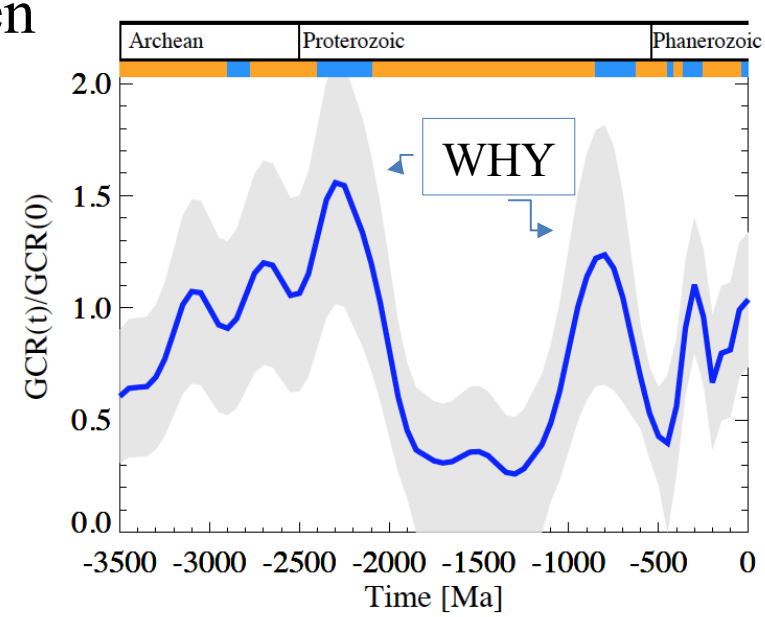
Oxygen

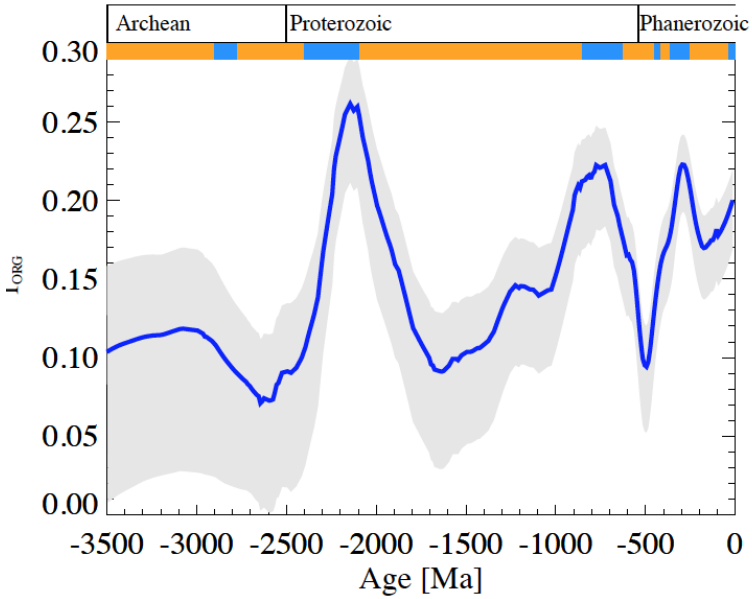
Photosynthesis

$$6CO_2 + 6H_2O \leftrightarrow C_6H_{12}O_6(glucose) + 6O_2$$

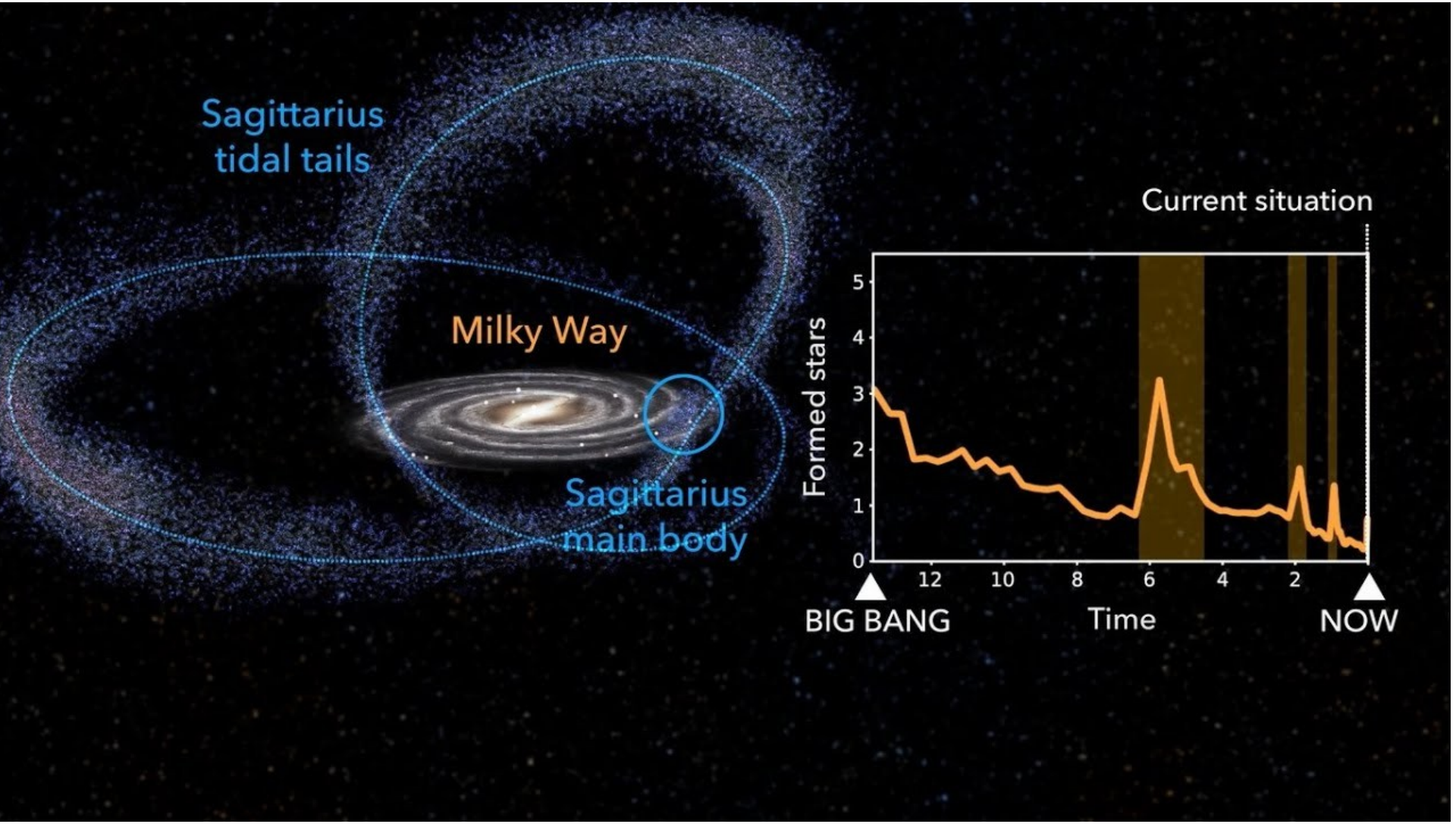
Burial of organic matter in sediments

Supernovae have helped the production of oxygen.
Oxygen is needed for the evolution of complex life





Sagittarius dwarf galaxy



Tomás Ruiz-Lara et al. "The recurrent impact of the Sagittarius dwarf on the Milky Way star formation history", Nature Astronomy, 2020

Gaia Data Release 2 (DR2) data

Supernovae and macroevolution

Ammonites

(100 Myr)

Trilobites

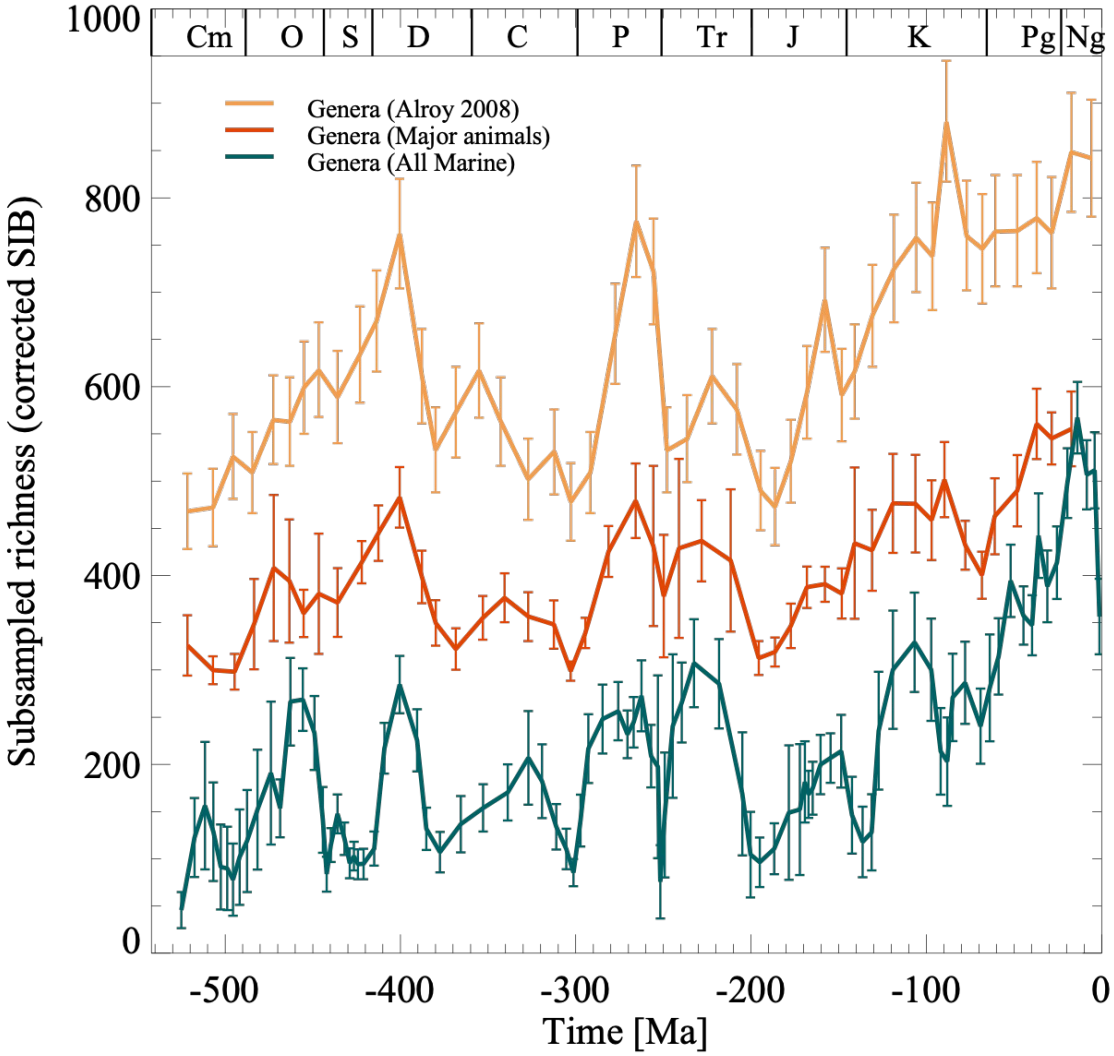
(250 Myr)

Dickinsonia

(541 Myr)

Supernovae and macroevolution

Diversity curves



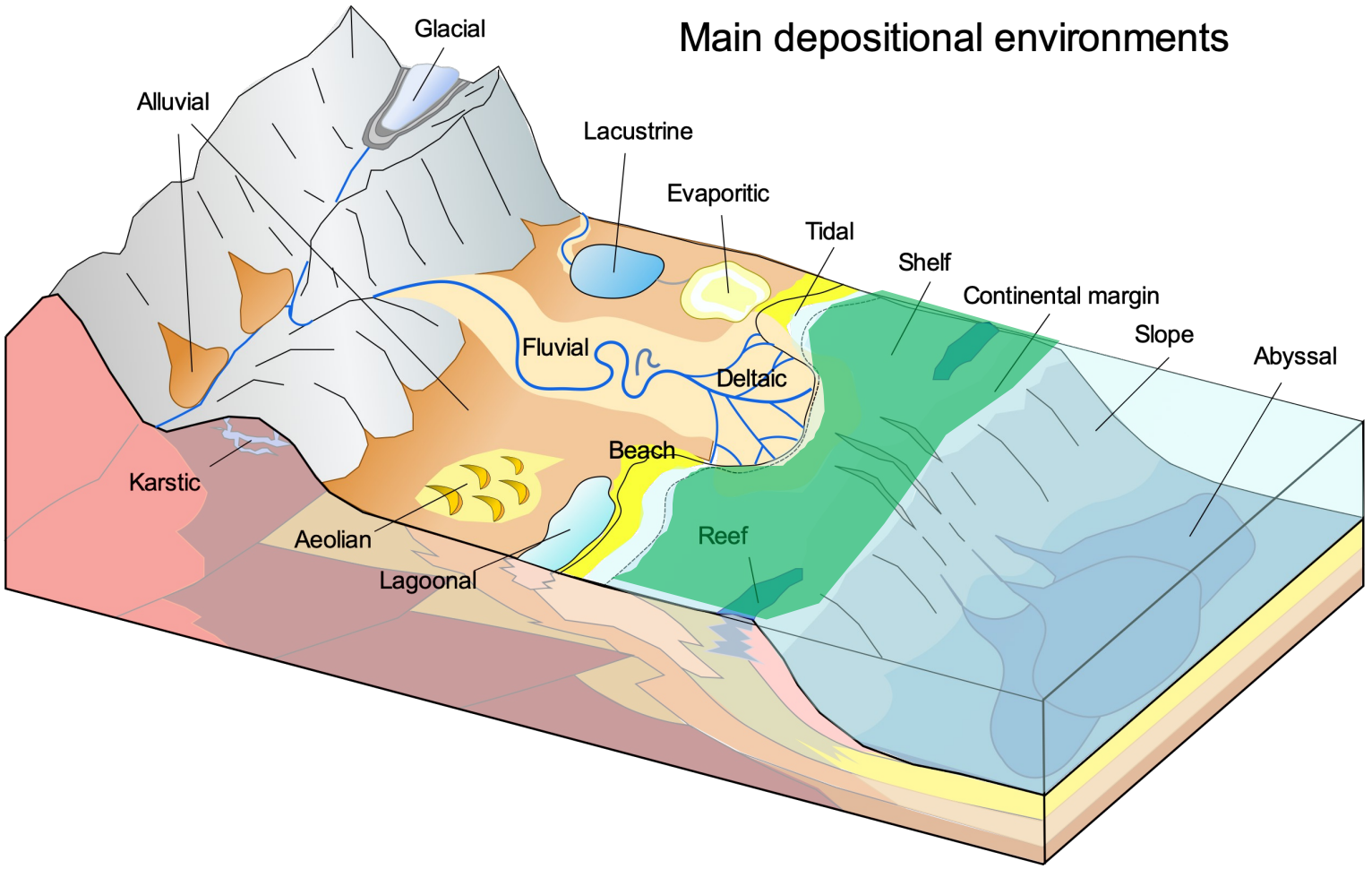
Marine invertebrate

Major marine animals
(~300.000 specimens)

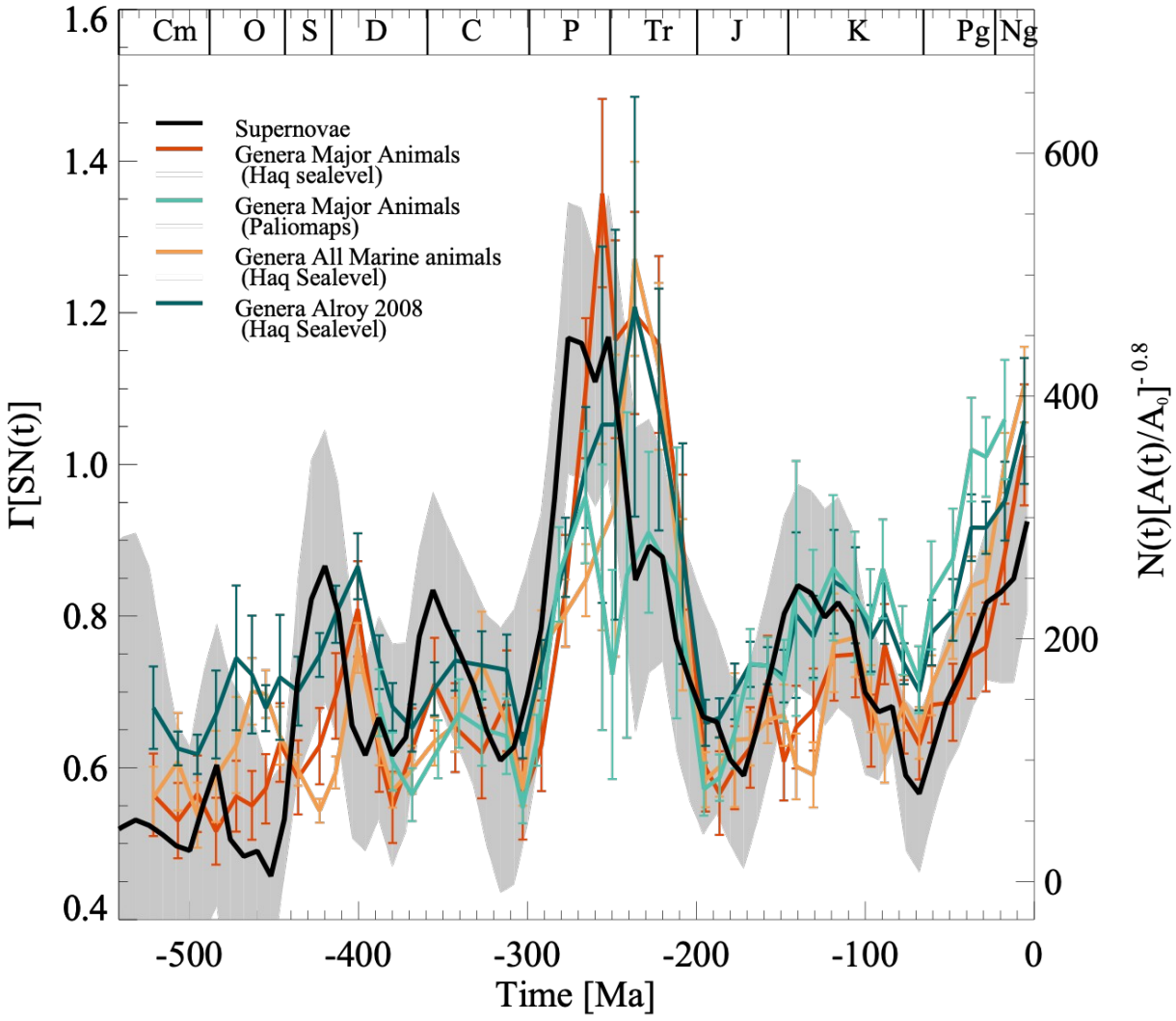
All marine animals
(~1.000.000 specimens)

Svensmark submitted 2022

Most marine life is on the continental shelf's
Diversity $\propto$ Area

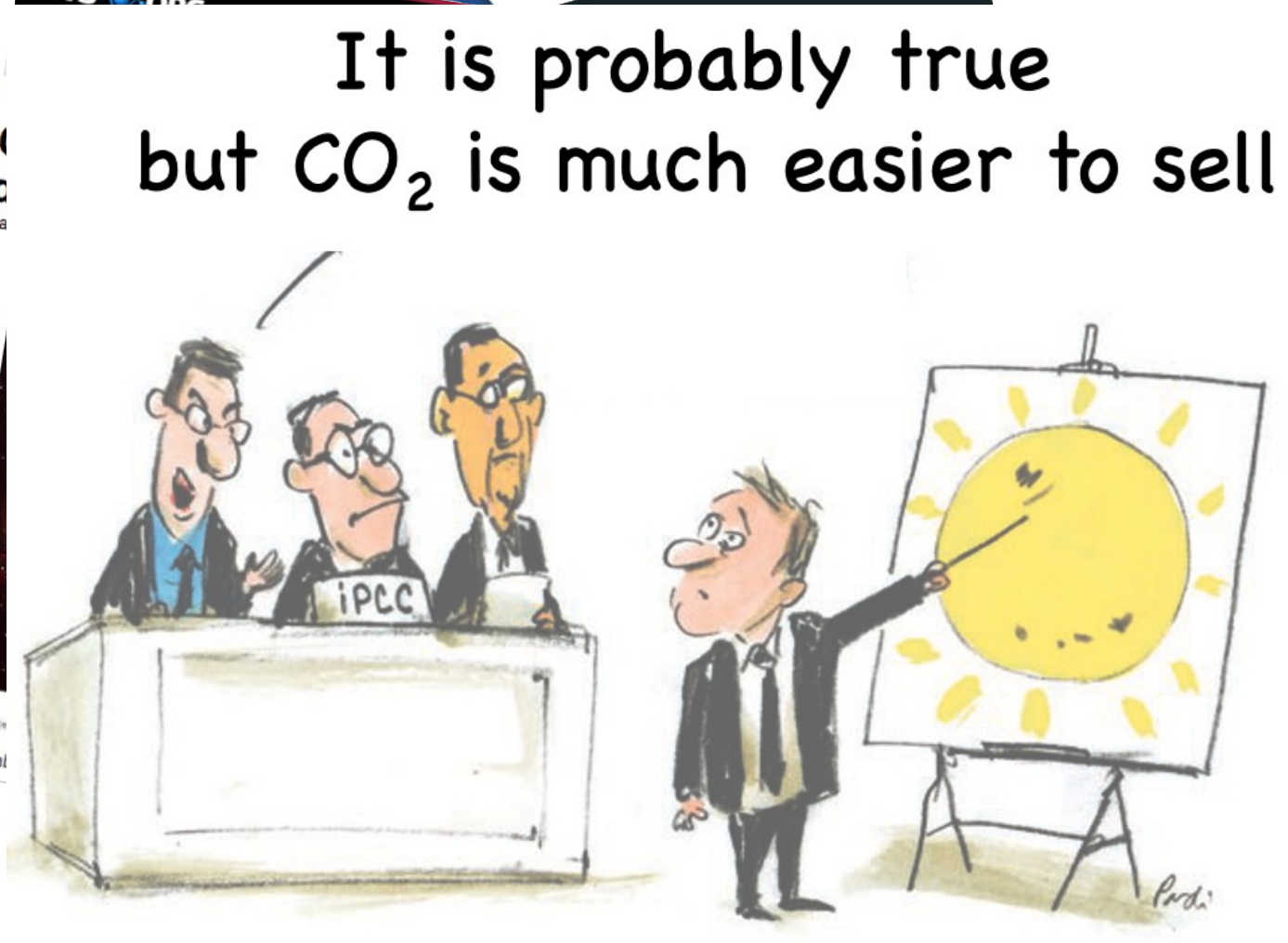


Supernovae and macroevolution



Svensmark submitted 2022

Is the theory dead again?



Conclusions

Variations in cosmic rays are associated with changes in Earth's climate. Strong empirical evidence on all time scales

Evidence suggests that clouds link to cosmic ray variations

- **Solar activity affects the climate (days to 10.000 years)**
- **Supernova activity affects climate (million of years)**
- **Burial of organic matter follows variations in supernovae history. Which is the source of oxygen and therefore fundamental for the evolution of complex life**