The Milky Way and Earths Climate

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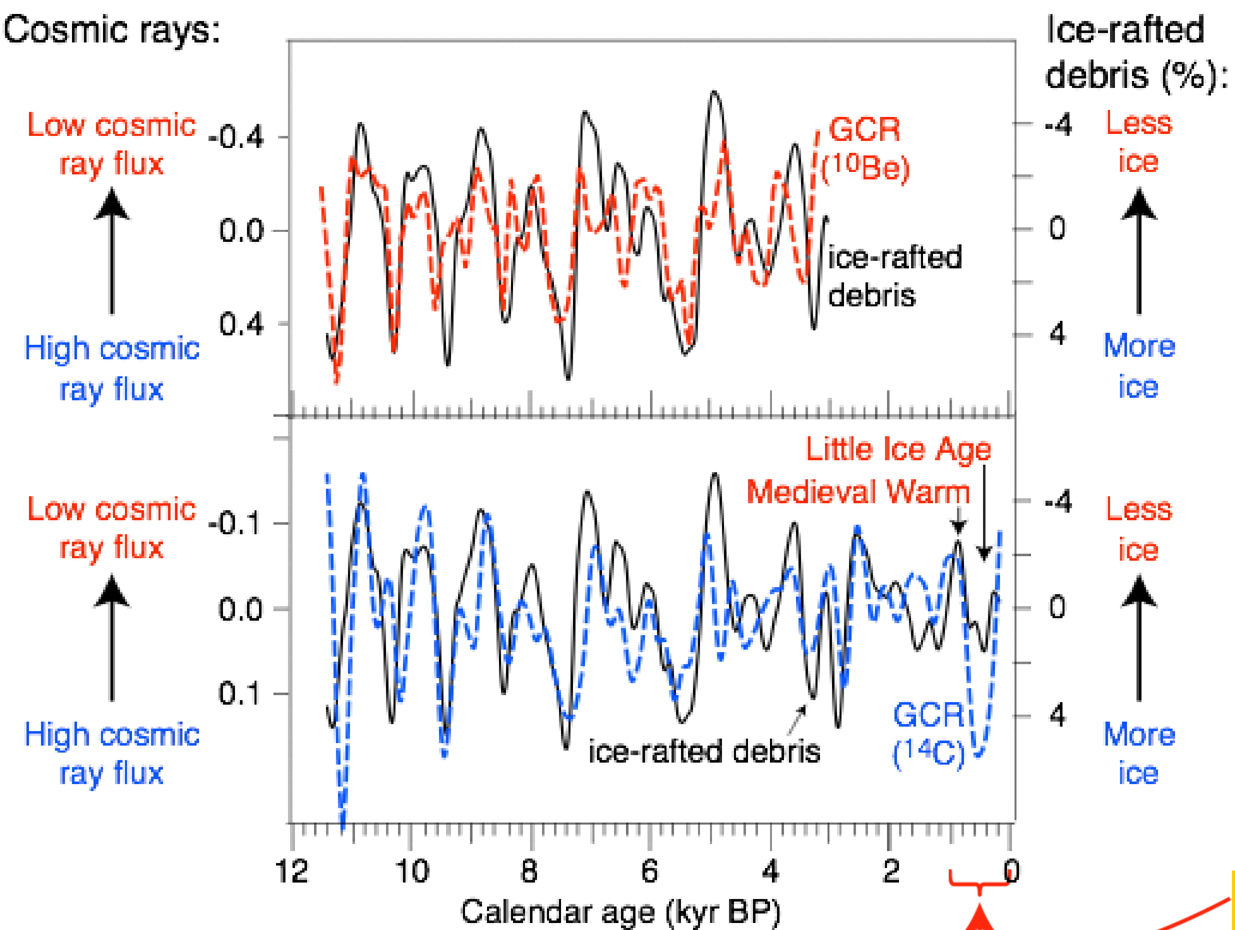
The Milky Way and Earths Climate

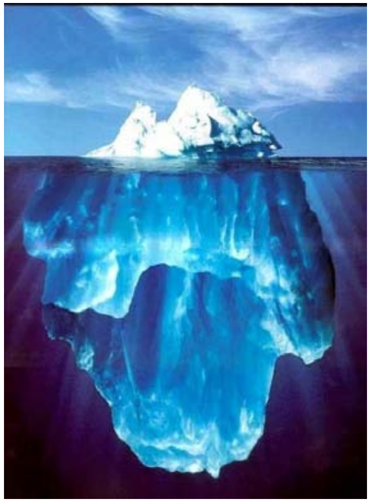
Major problems needs to be addressed

1. The link between solar activity and climate. Emprically data
2. Understanding of the microphysical link. Cosmic rays, clouds and climate
3. Implications on the conditions on Earth and in particular life

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

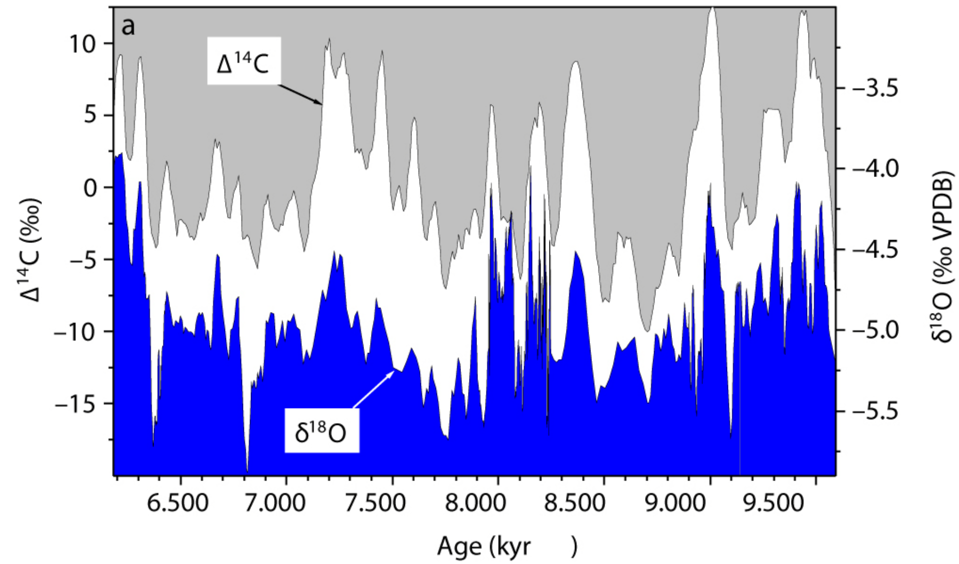
Last 1000 years
Little Ice Age

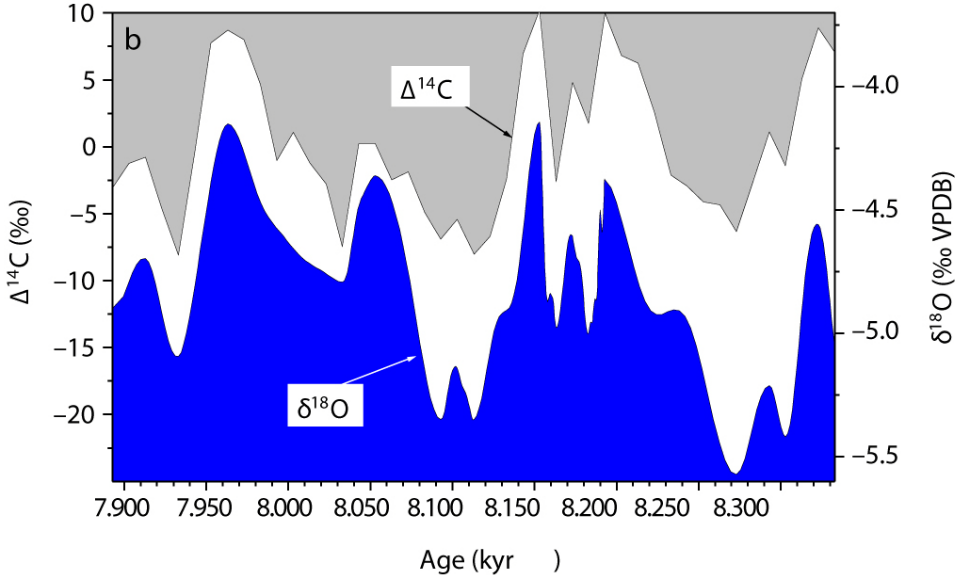
- Little Ice Age is merely the most recent of a dozen such events during the last 10.000 years

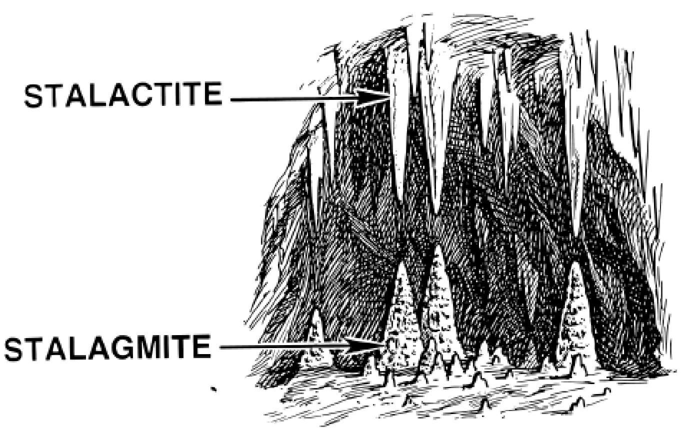
Adapted from Kirkby

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

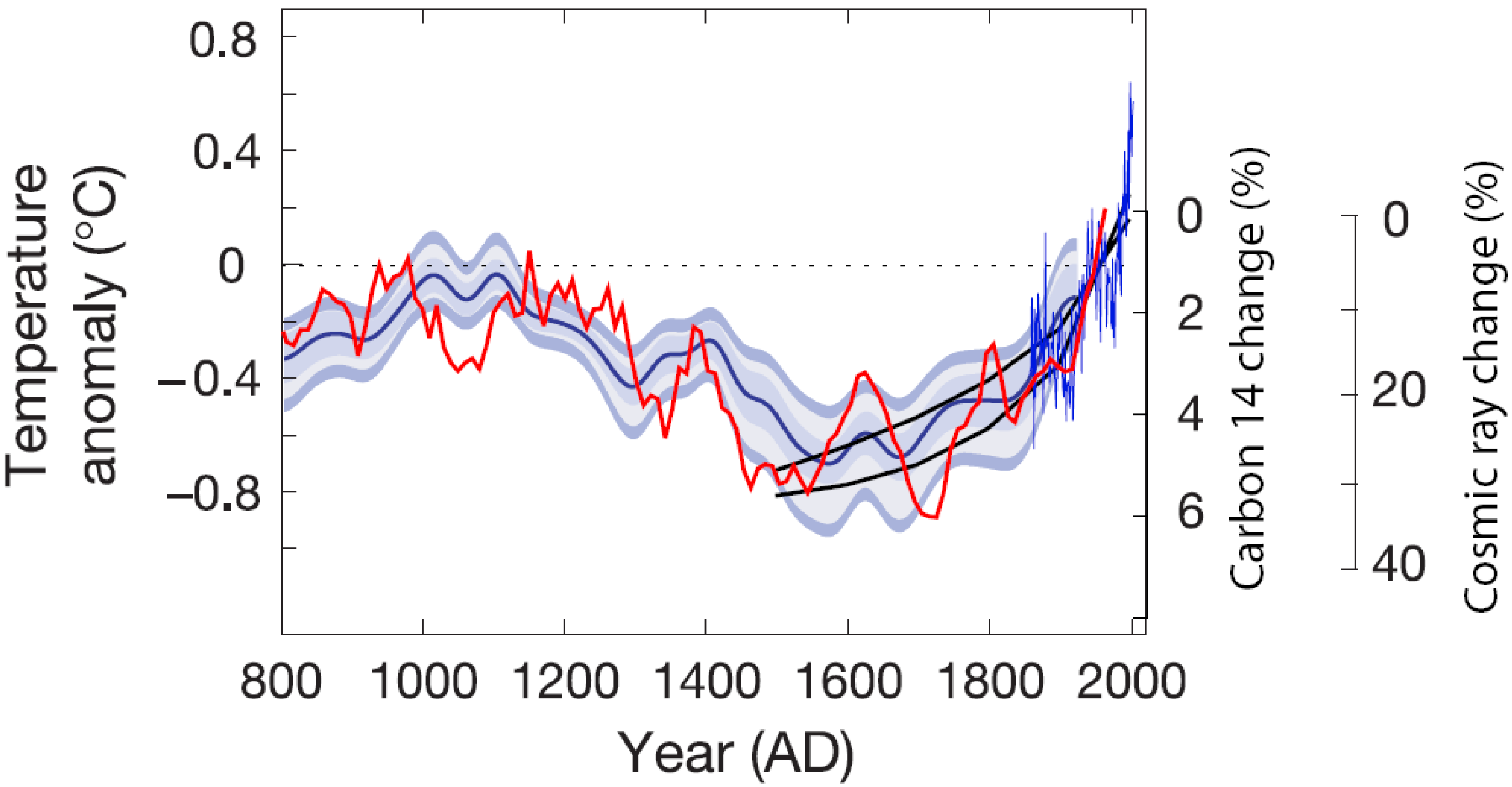






U. Neff et al., Nature 411, 290 - 293 (2001)

Cosmic rays and climate over the last millennium

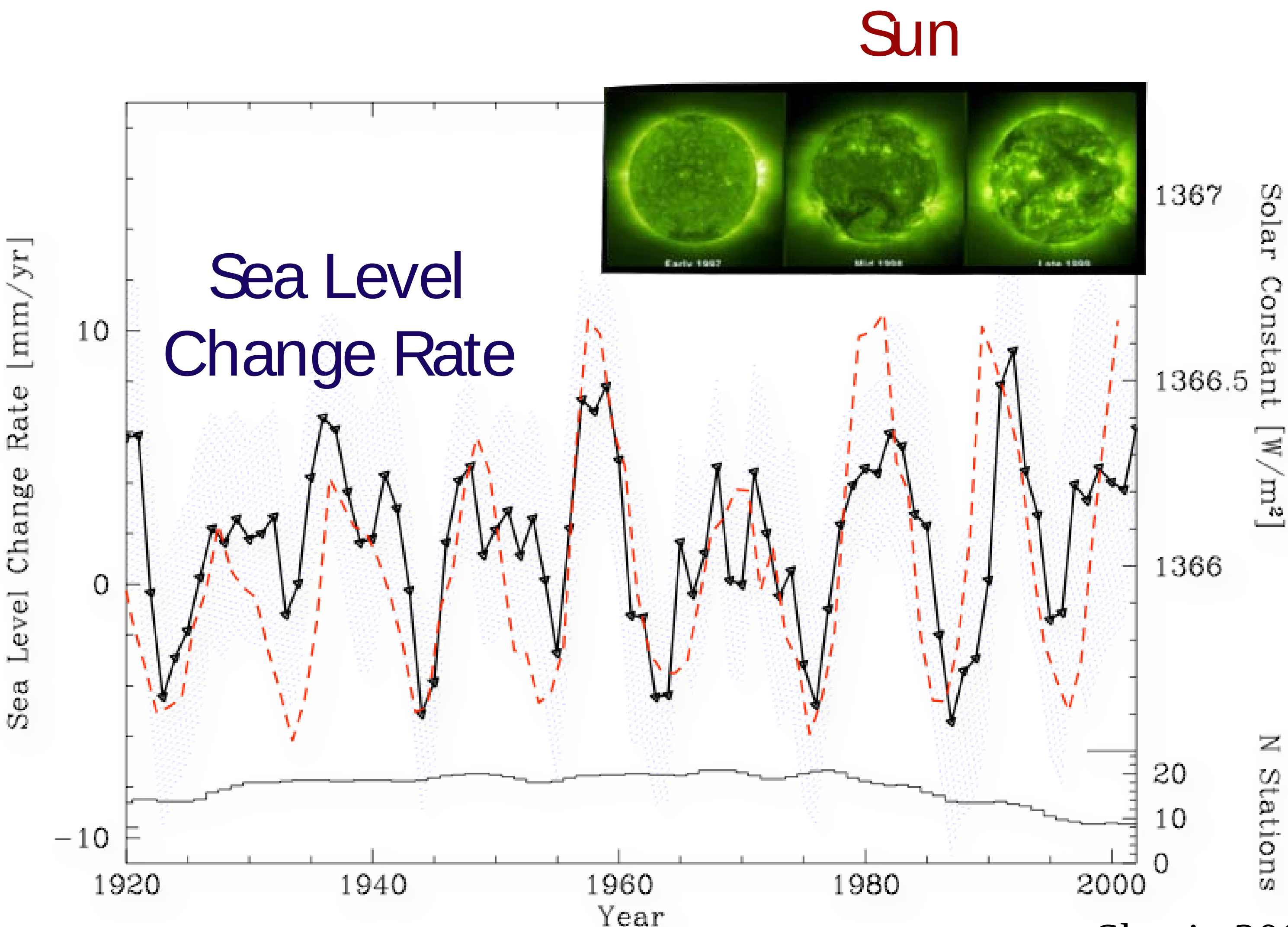


Quantifying solar impact on climate

The Earth is mainly ocean

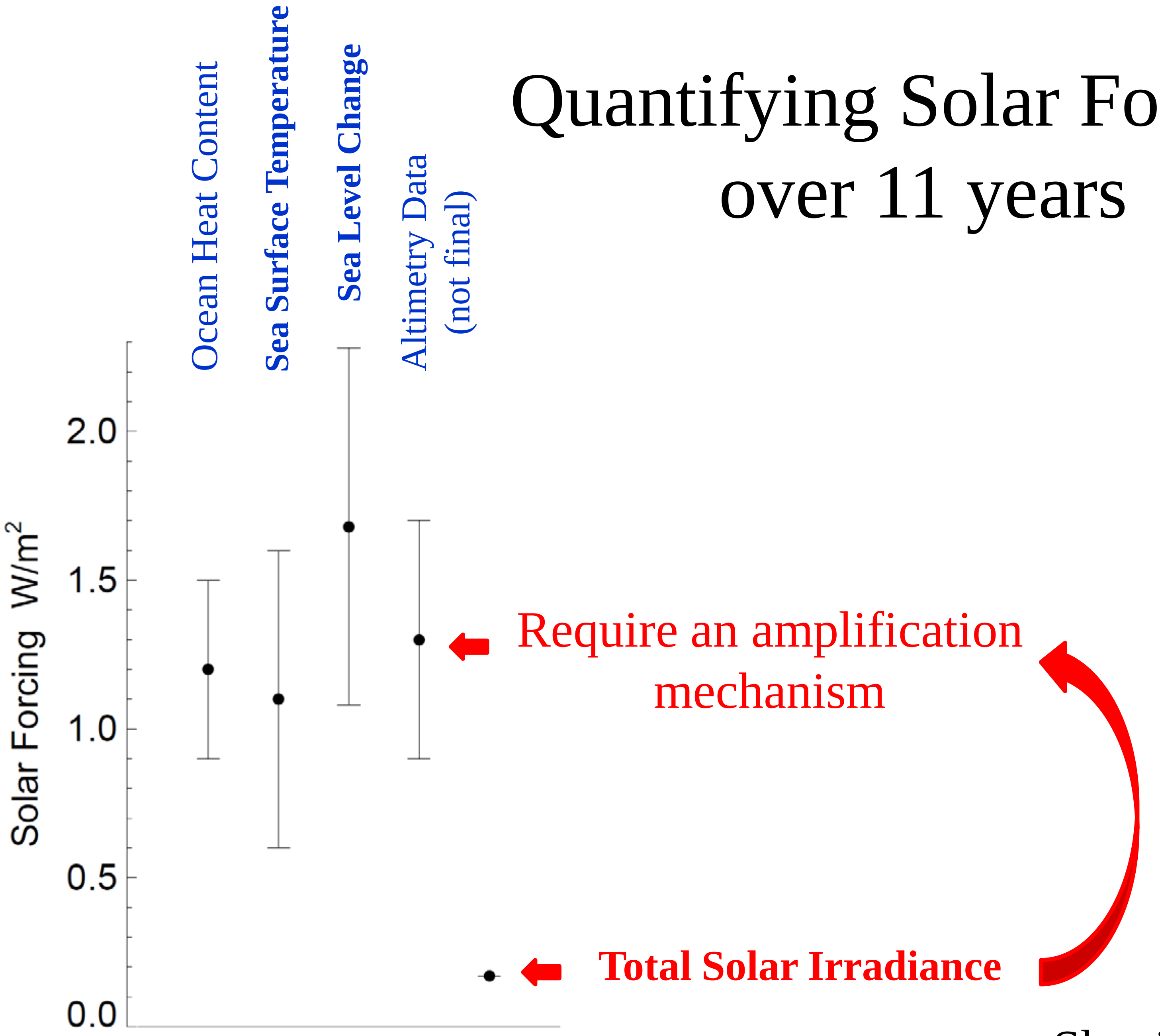
- **Ocean Heat Content**
- **Ocean temperature**
- **Sea level**

Quantifying the Solar impact:



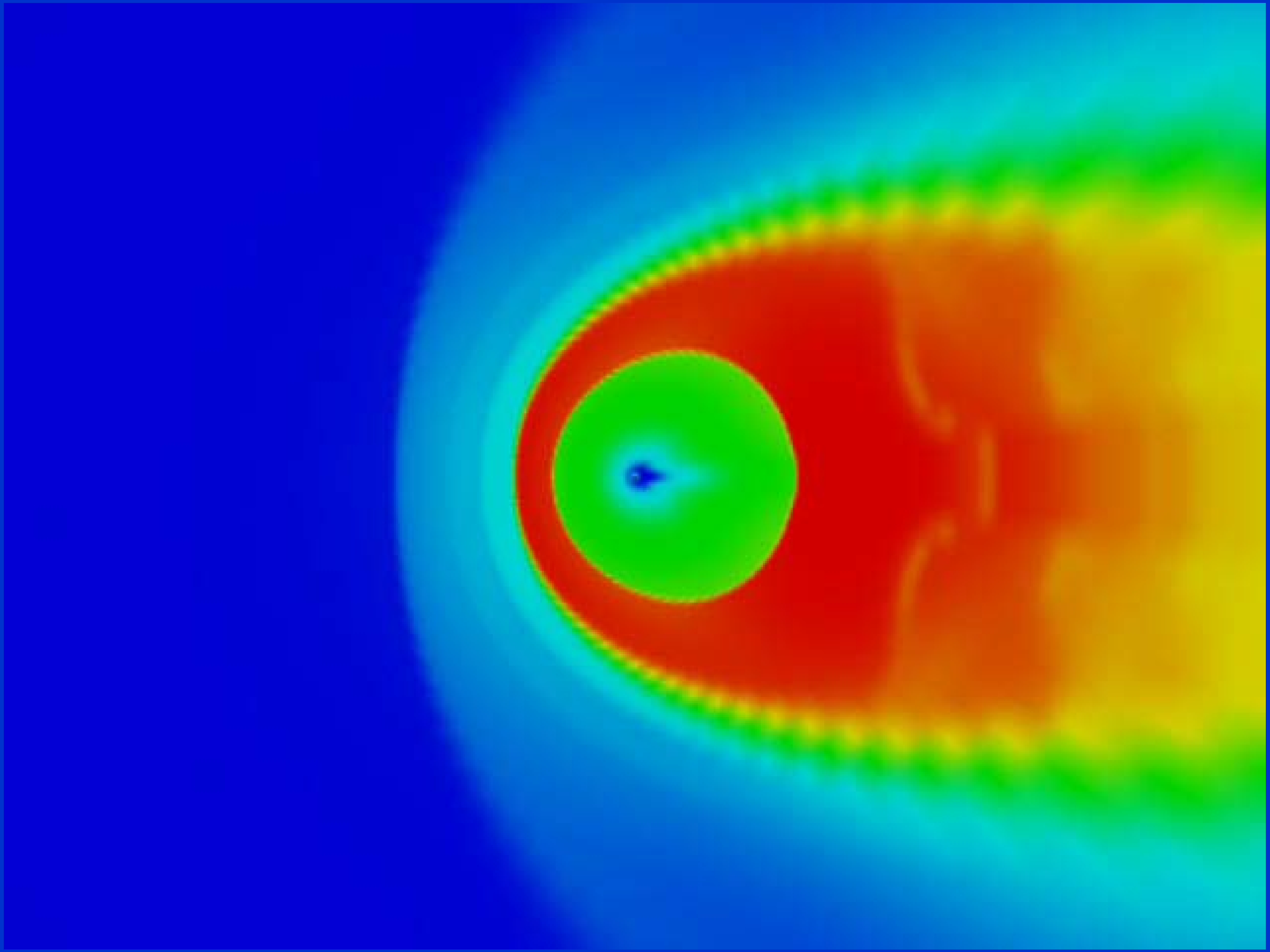
Shaviv 2008

Quantifying Solar Forcing over 11 years

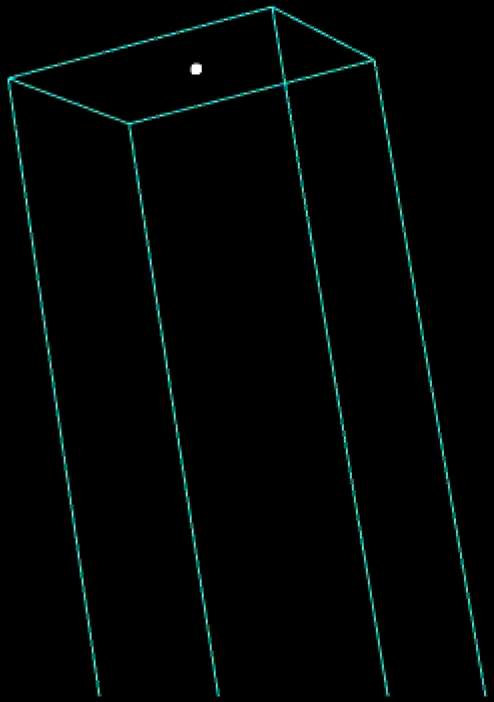


Shaviv, 2008

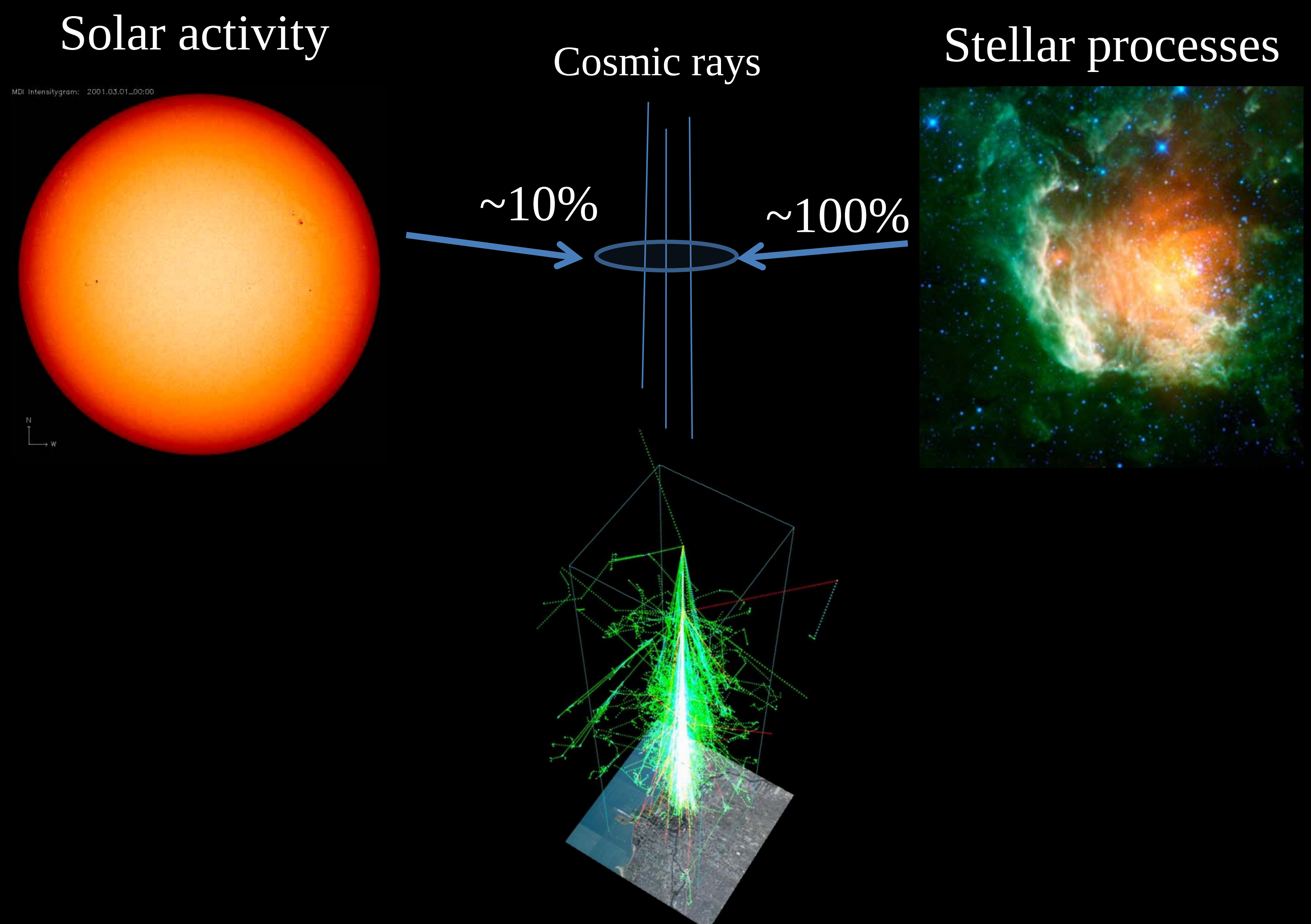
Heliosphere



Cosmic ray shower (Movie)

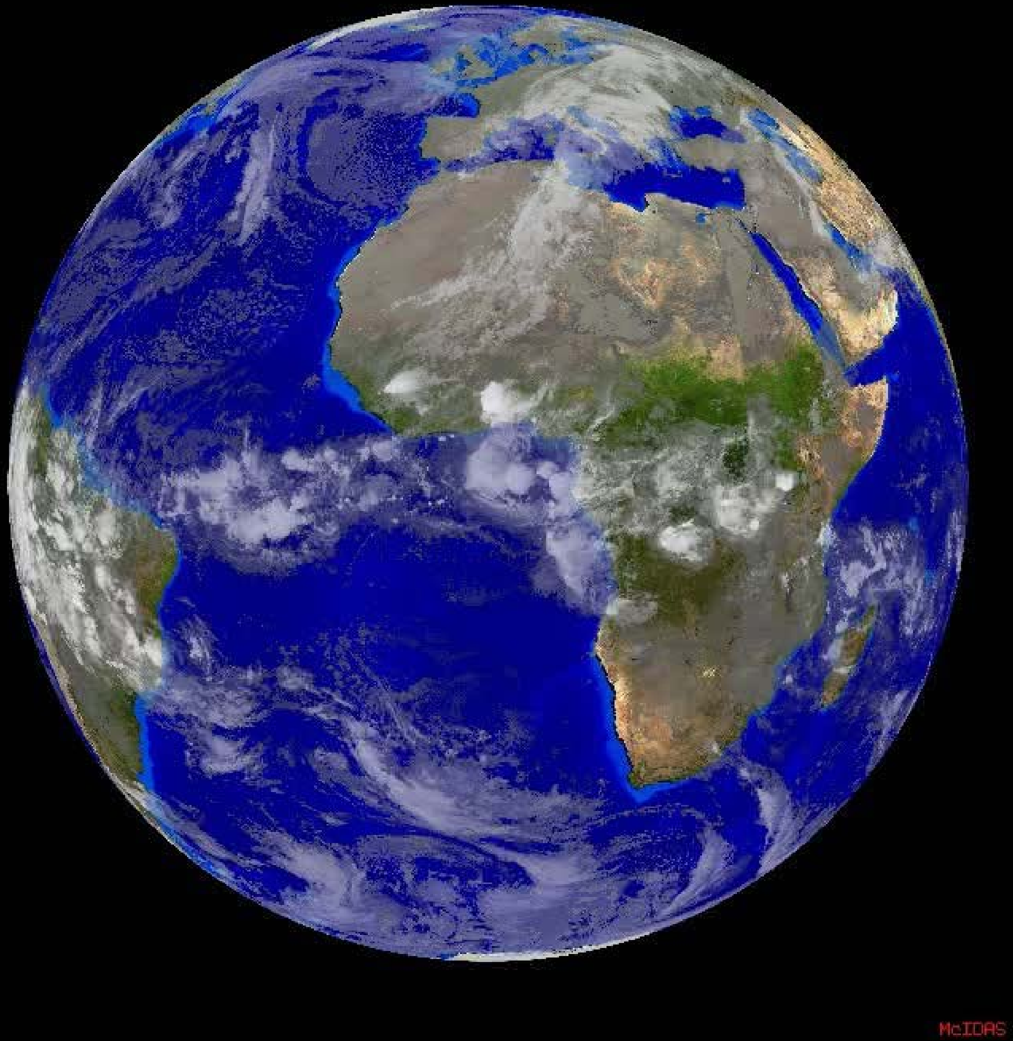


About 70 muons/s /m^2 at the Earths surface
In 24 hours about 12 million muons goes through a human body



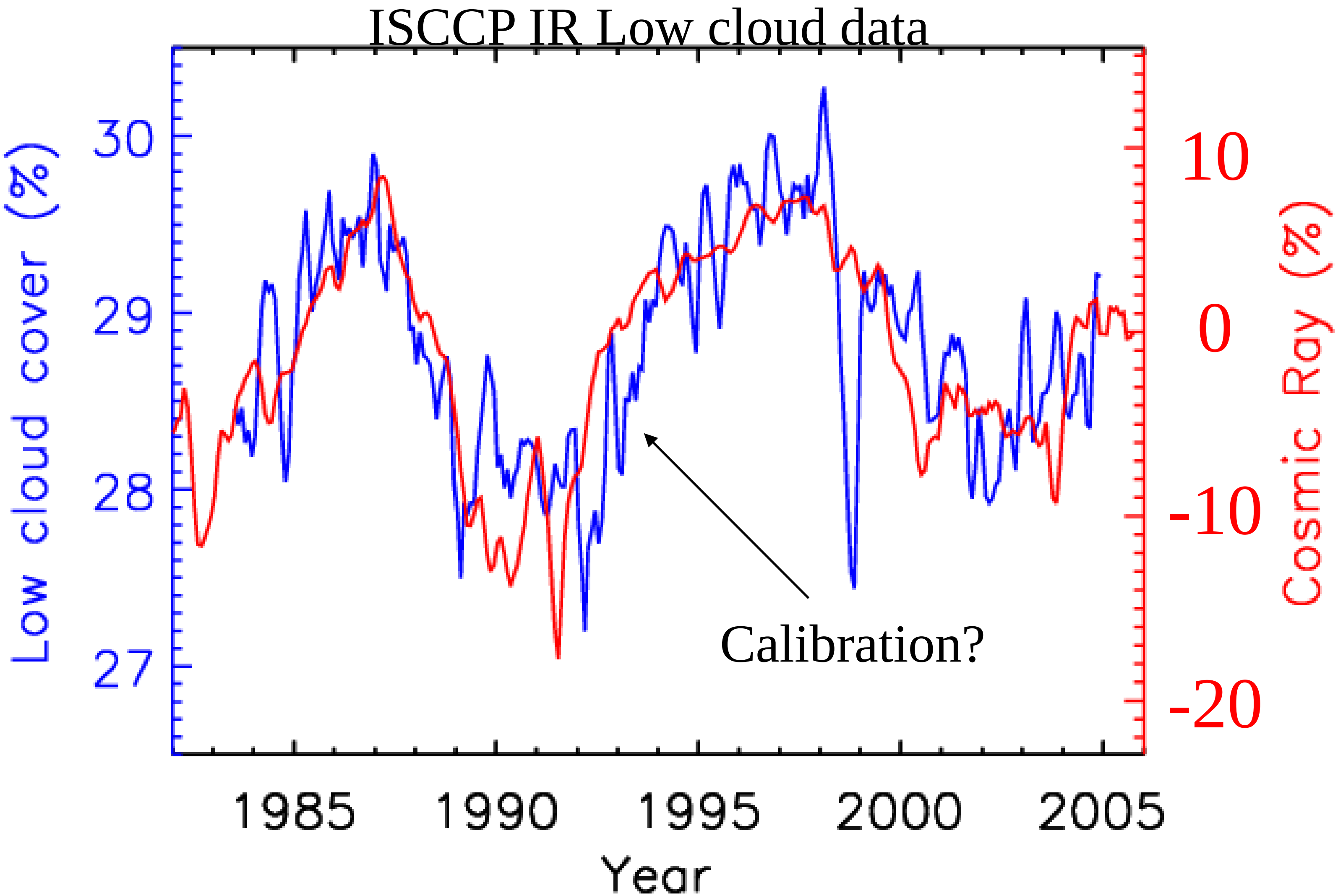
Solar activity
MDI Intensitygram: 2001.03.01_00:00
Cosmic rays
Stellar processes
~10%
~100%

How can STARS influence Climate?



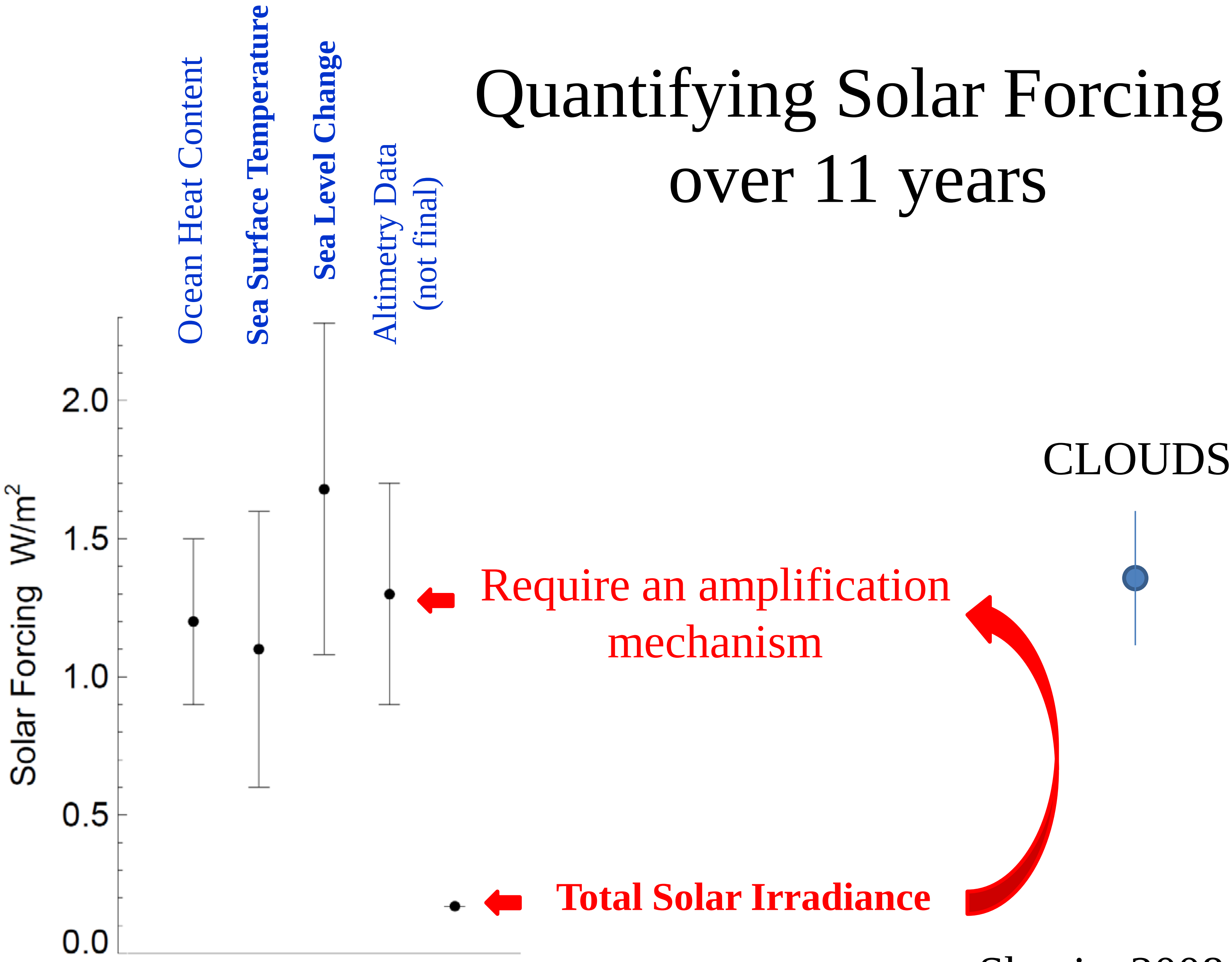
Net effect of clouds is to cool the Earth by about 30 W/m^2

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

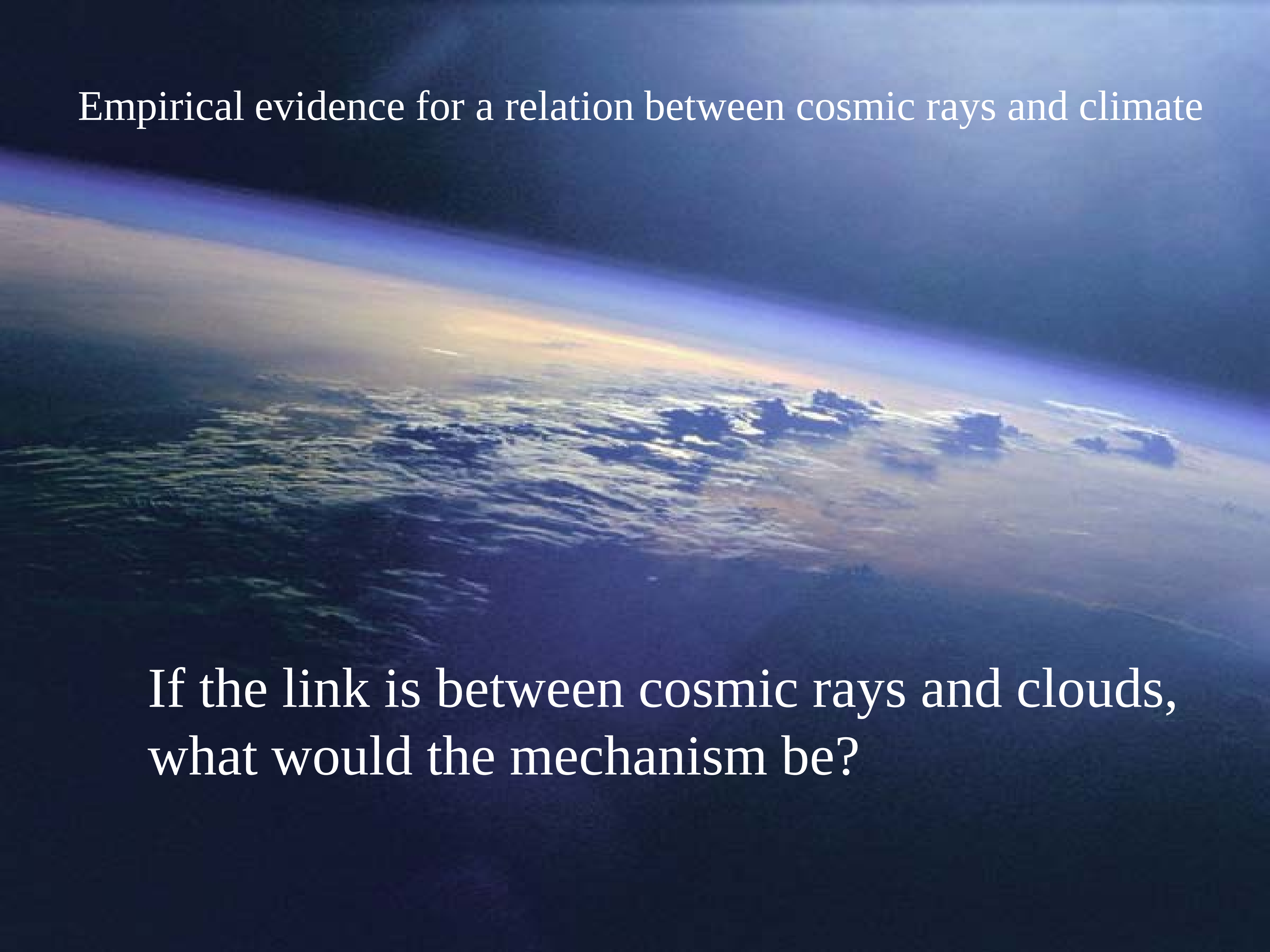


Svensmark & Friis-Christensen, JASTP 1997, Svensmark, PRL 1998, Marsh & Svensmark, PRL, 2000. (update 2005)

Quantifying Solar Forcing over 11 years



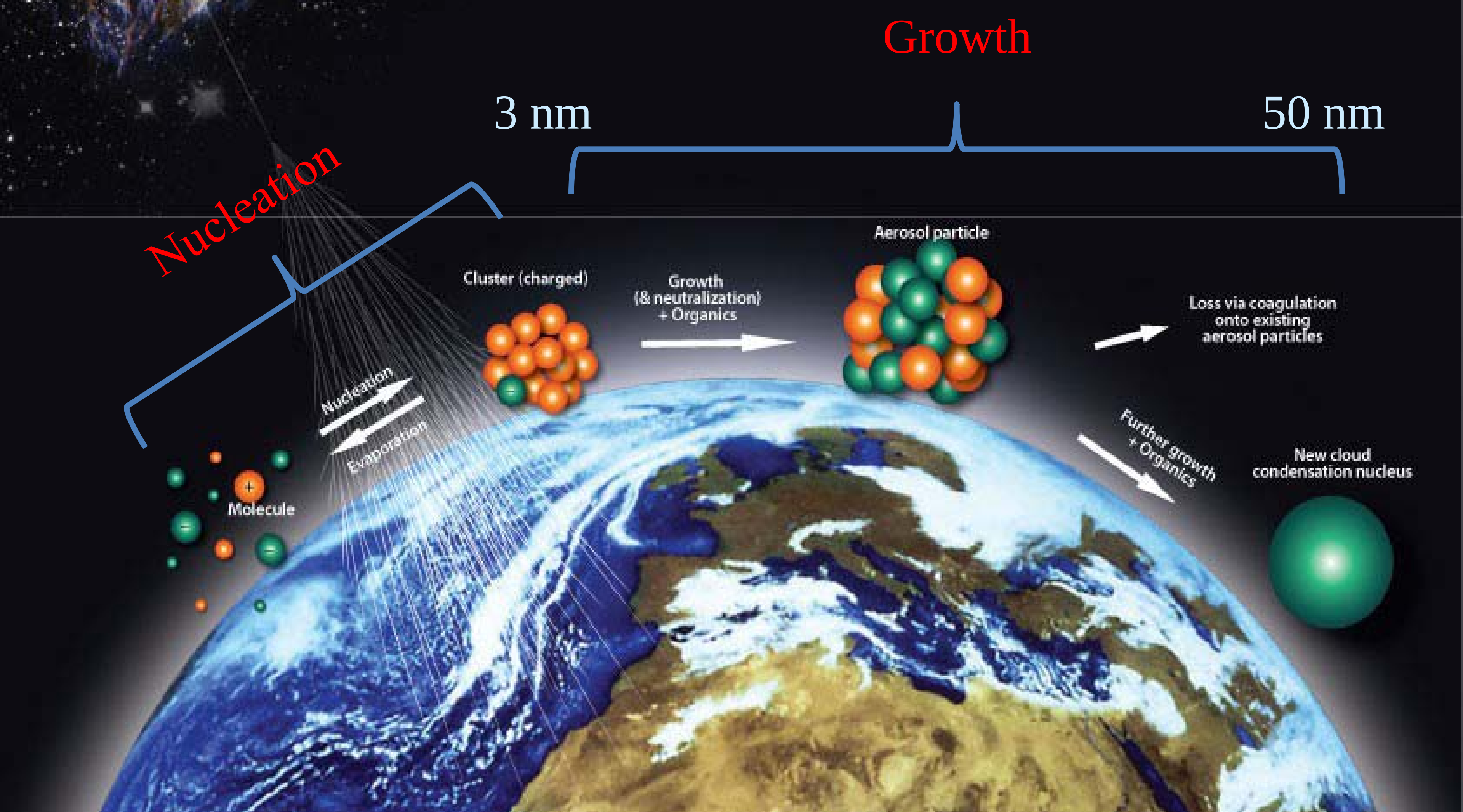
Shaviv, 2008



Empirical evidence for a relation between cosmic rays and climate

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

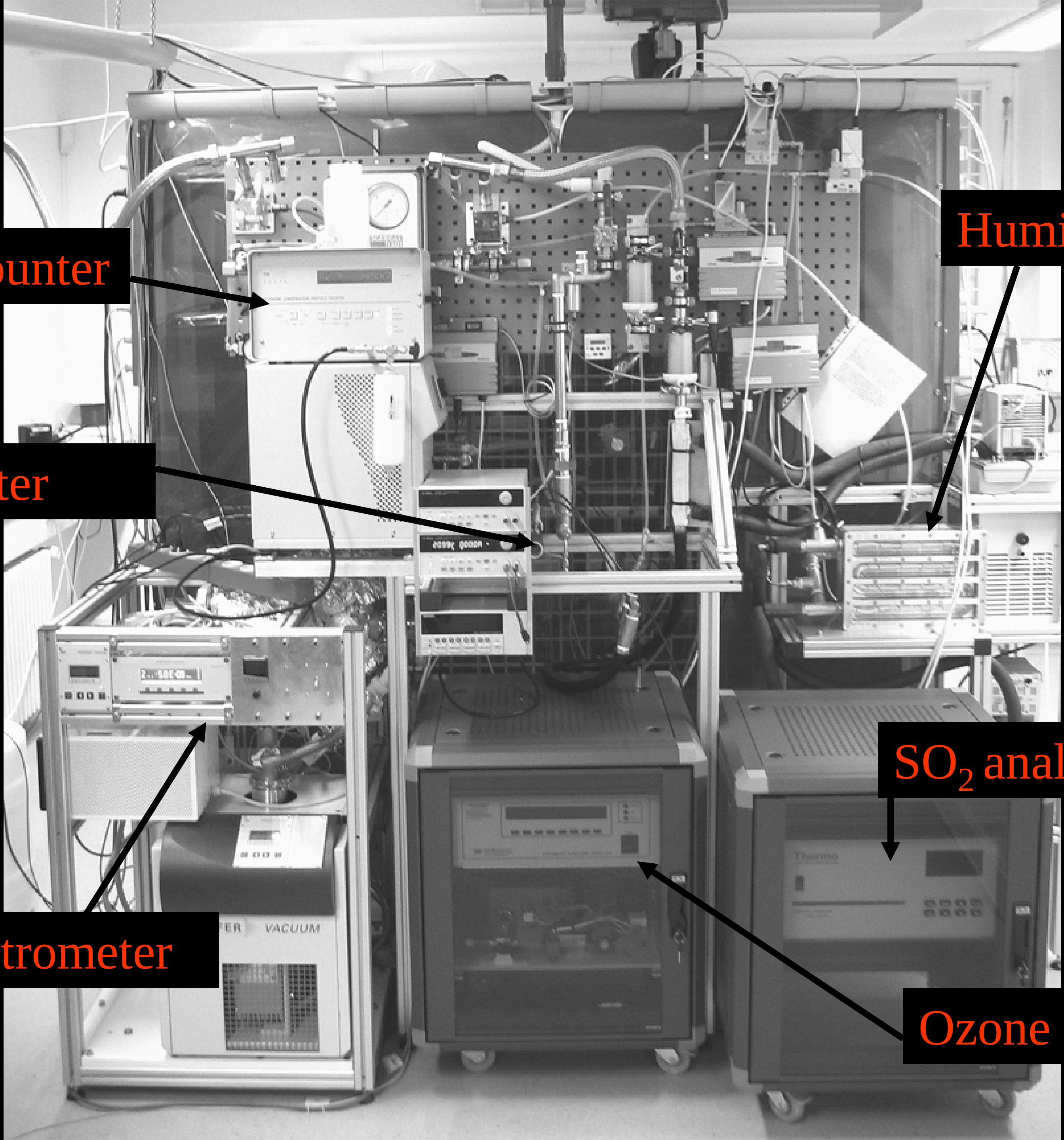
Precurser to clouds: Aerosols



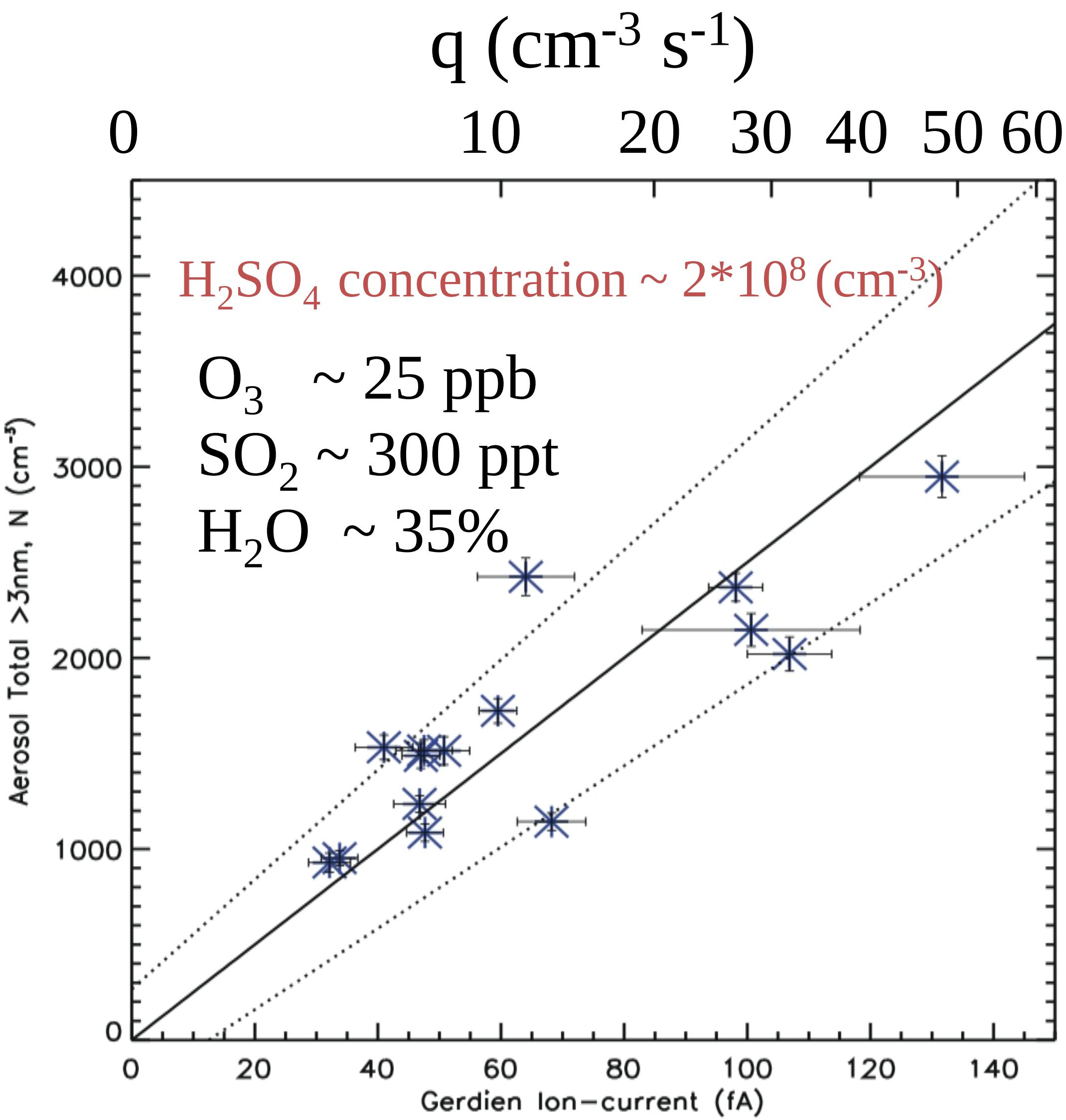
Aerosols and microphysics of clouds

Satellite observations of ship tracks

Visible: 0.9 mm


Particle counter
Ion counter
Mass spectrometer
Humidifier
SO_2 analyzer
Ozone analyzer

Steady state experiment



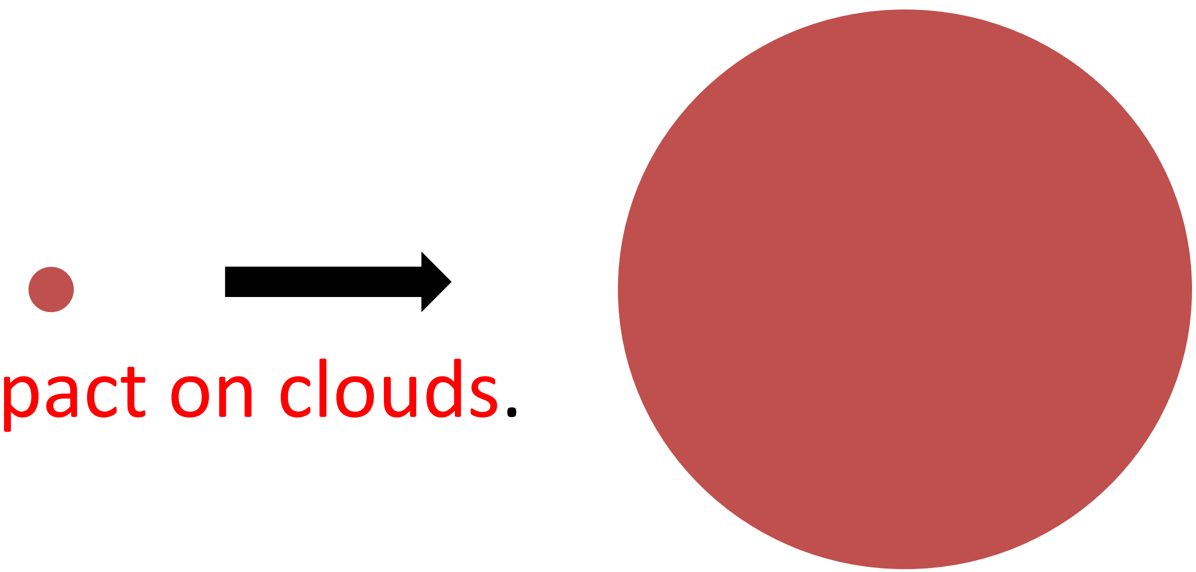
Svensmark et al. Proc. R. Soc. A (2007) 463, 385–396

CLOUD at CERN 2011

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

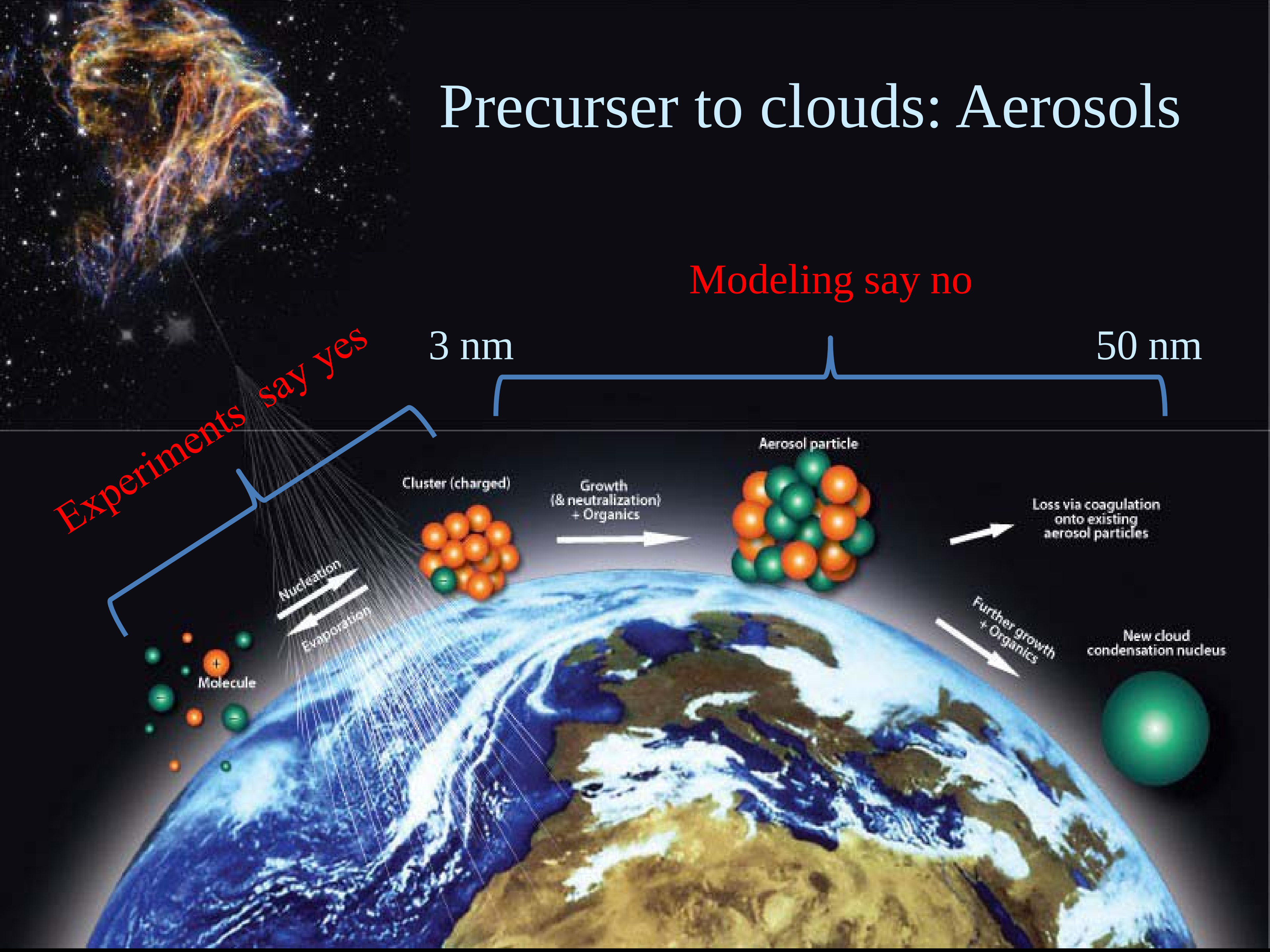
- An important remaining question:

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



If not no impact on clouds.

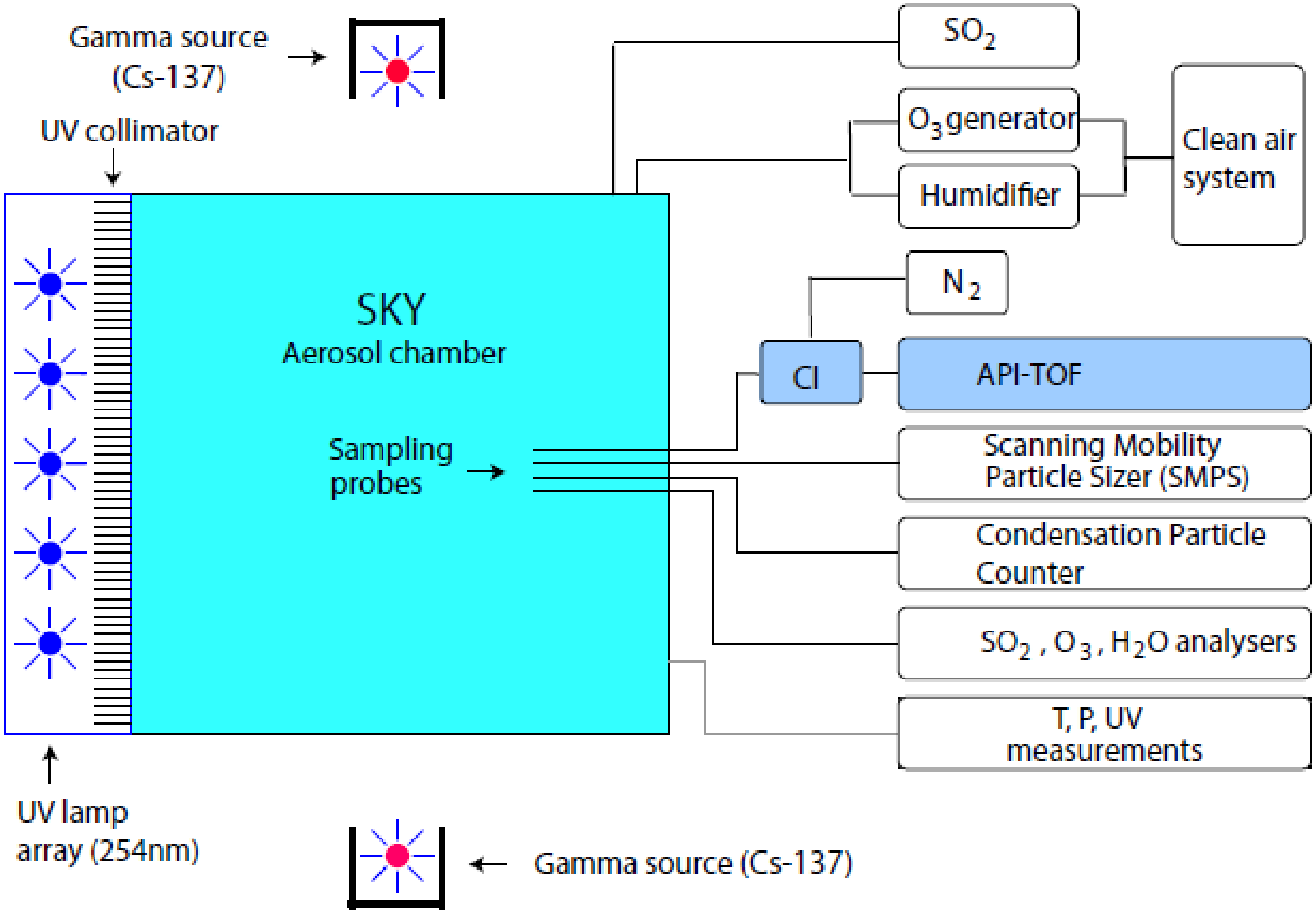
Precurser to clouds: Aerosols



Modeling says NO
to an effect of ions on CCN
(and therefore clouds and climate)

Fortunately the problem can also be addressed in the laboratory

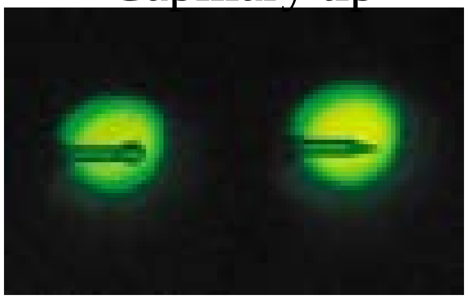
Experimental Setup

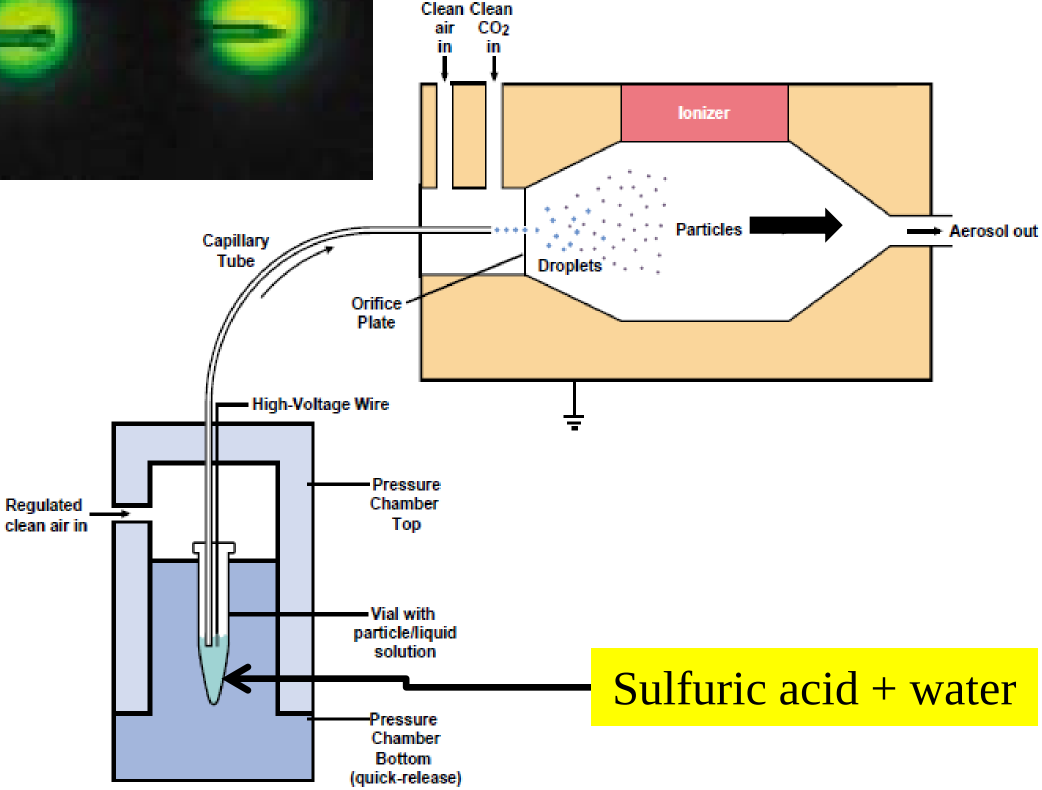


Production of aerosols

Not by UV or ionization

Capillary tip

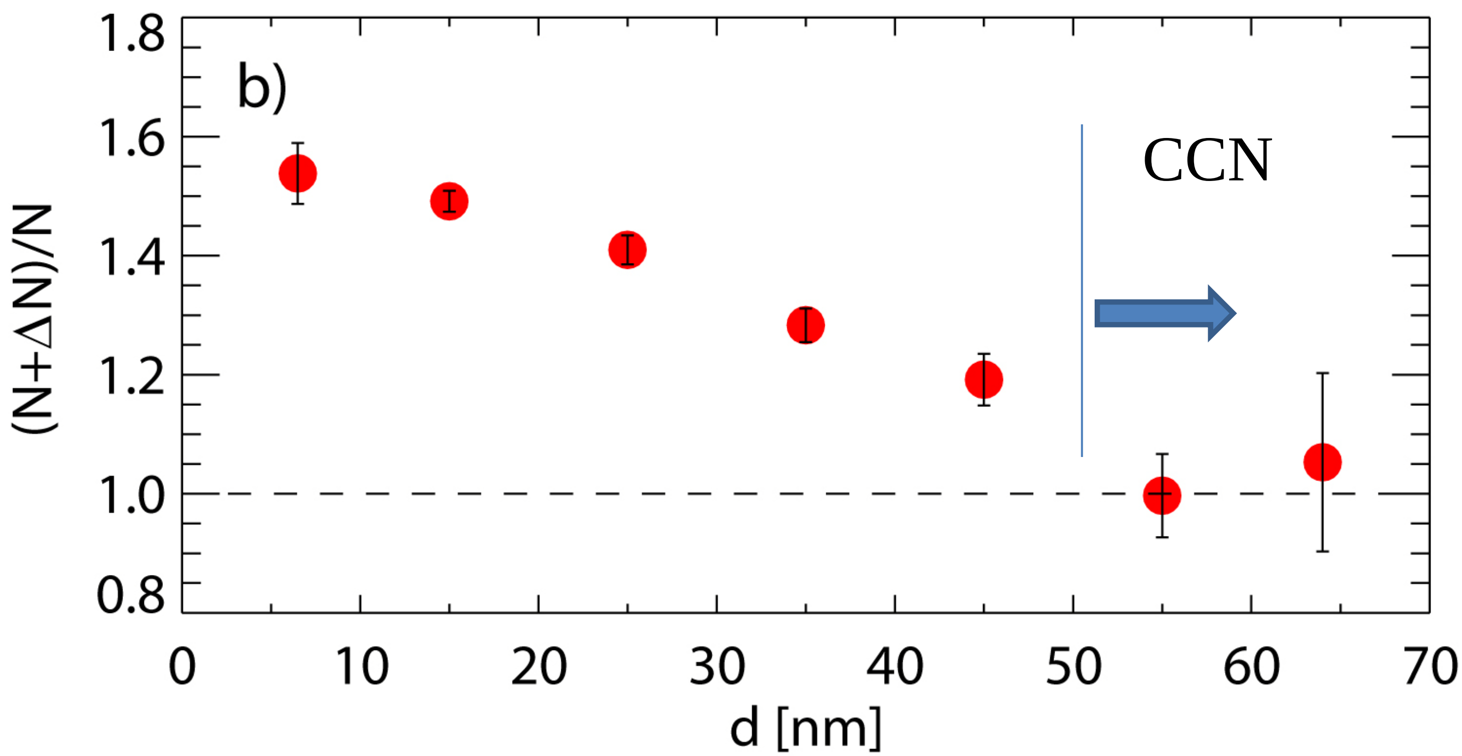




Sulfuric acid + water

Monodisperse sulfur acid aerosols

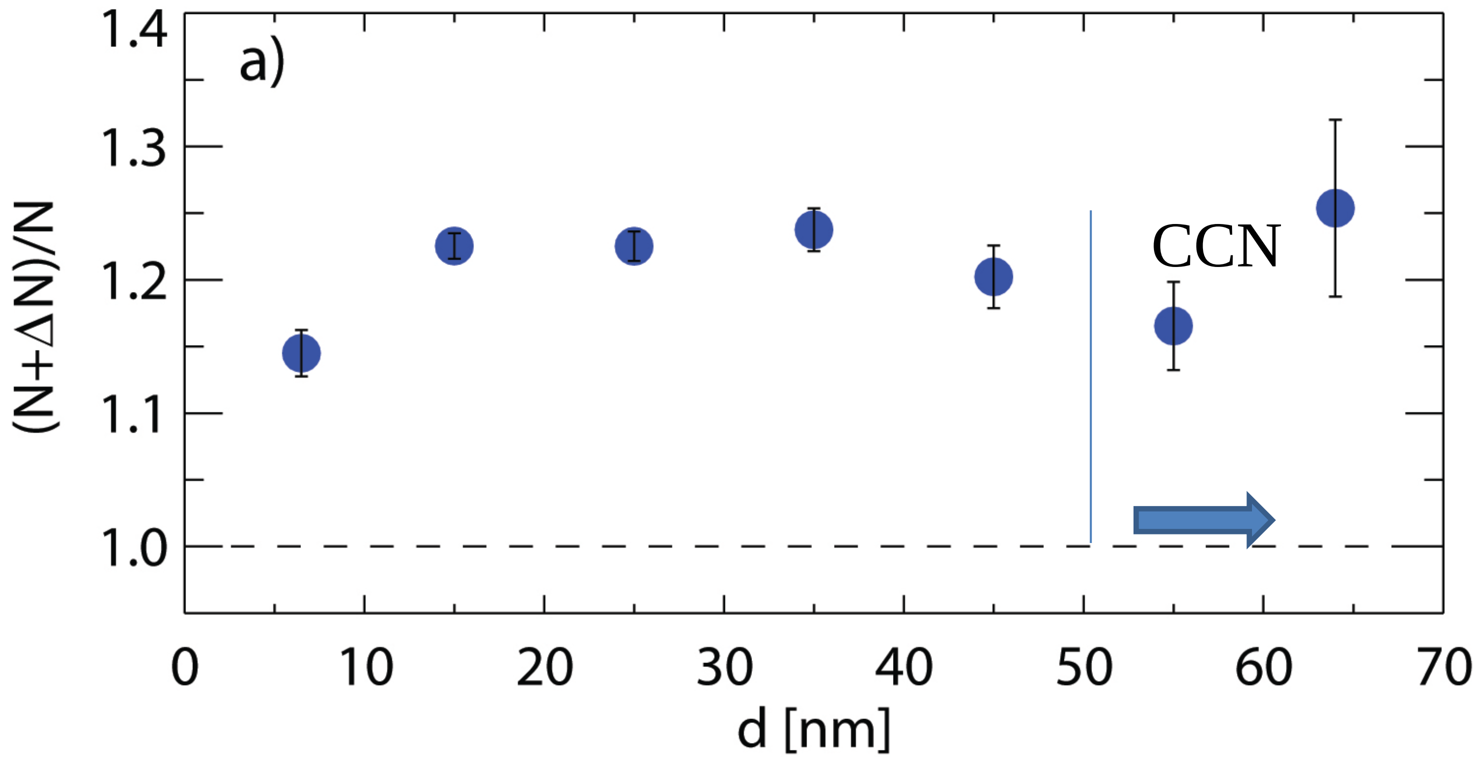
Addition of ”neutral” aerosols



More particles compeating for the same gas, therefore slower growth and larger losses, as also seen in model results.

Svensmark, Enghoff, Pepke Pedersen, 2012

Additional aerosols using iones



Contradicts all the modeling results

Svensmark, Enghoff, Pepke Pedersen, 2012

What is going on?

The explanation is simple. The ions are produsing additionally H_2SO_4 , that compensates for the extra particles.

How do we know this?

From resent experiments and *ab initio* calculations which suggest that ions assist in a catalytic production of H_2SO_4

If true any aerosol will be assisted in growth

Two channels of making sulphur acid

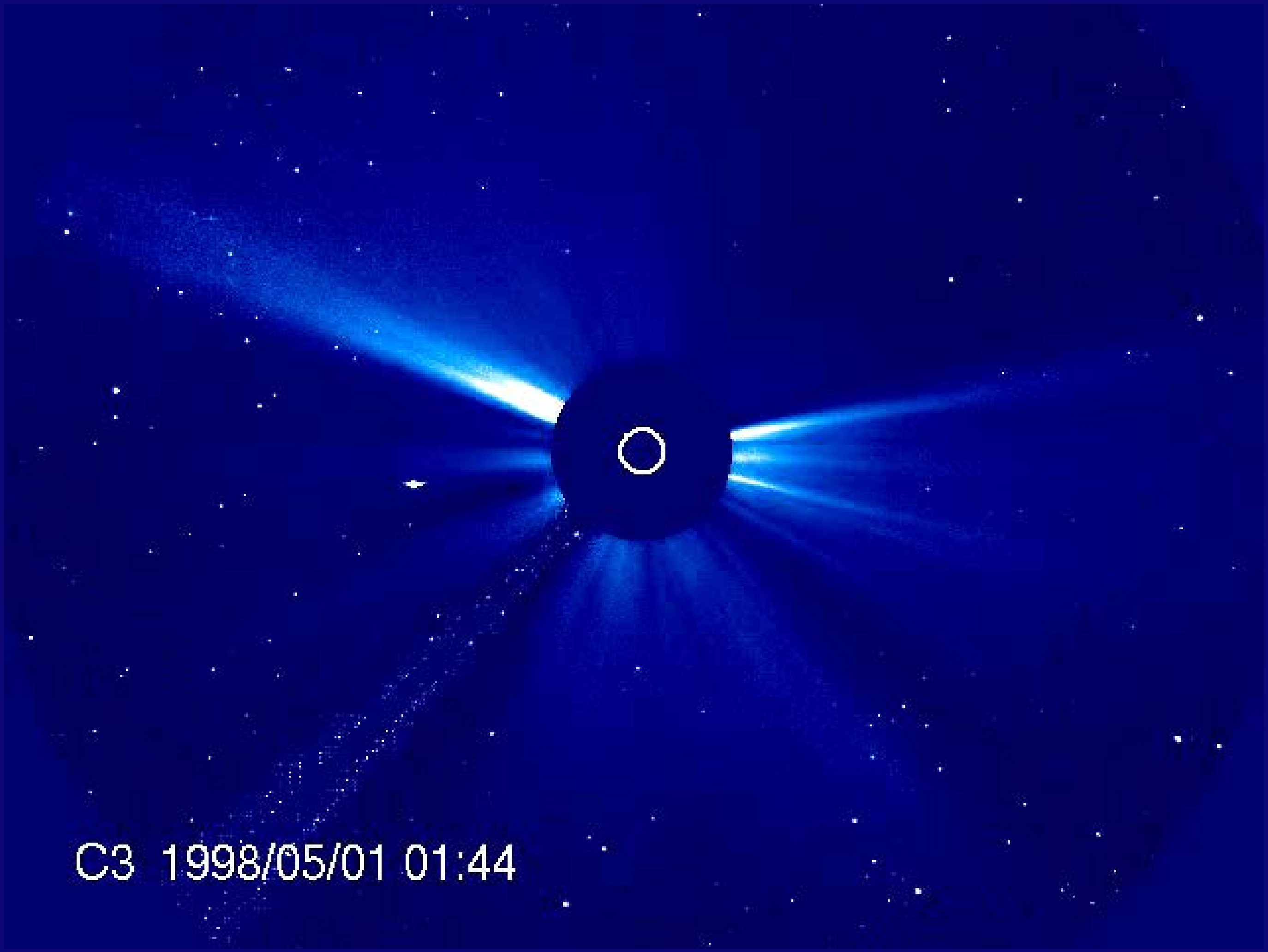
UV photo chemistry → }
(Cosmic ray) Ion-chemistry → } H_2SO_4

In 2006 we in fact suggested catalytic reactions involving, O3, SO2, H2O, and negative ions leading to (H2SO4,water) clusters (Svensmark et al. 2006 RSPA).

These ideas has been explored with *ab initio* density functional theory (quantum chemistry).

Coronal Mass Ejections

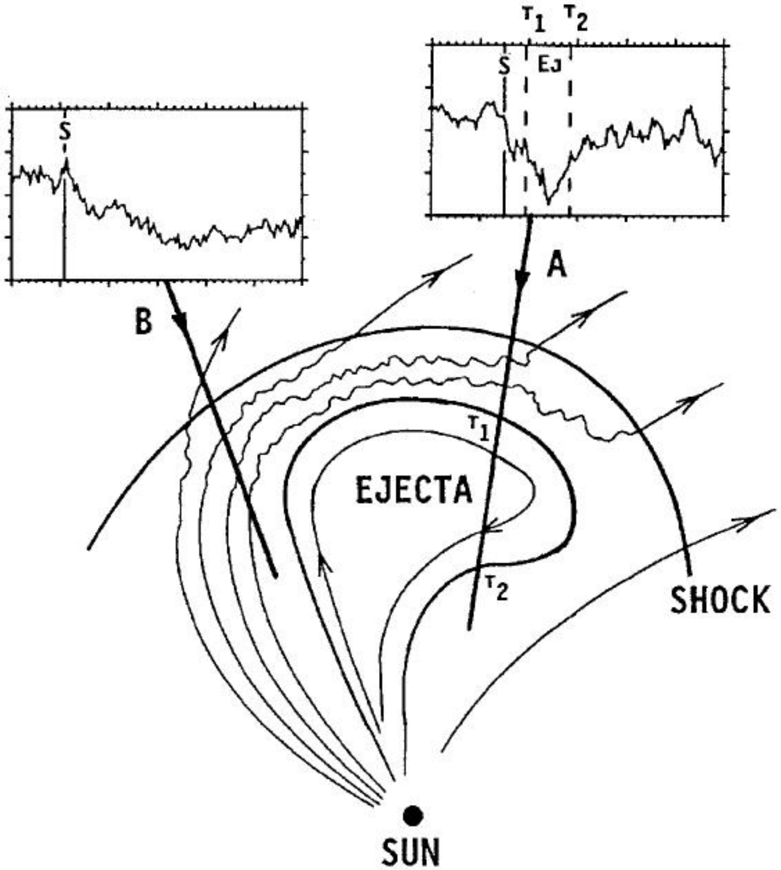
Natural experiments for testing the GCR-atmosphere link



SOHO satellite, one month of observation

Coronal Mass Ejections

Natural experiments for testing the GCR-atmosphere link

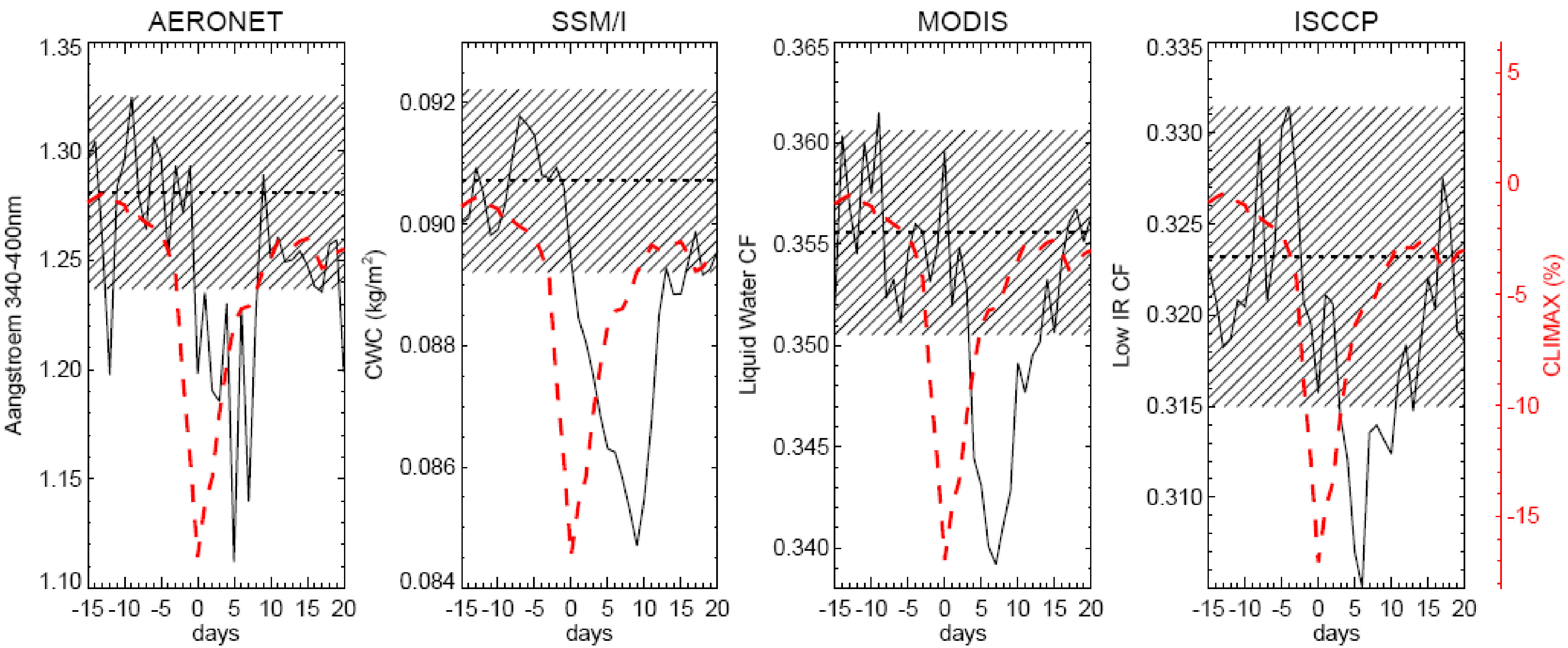


AERONET, SSM/I, MODIS and ISCCP data for 5 strongest Forbush decreases

Aerosols

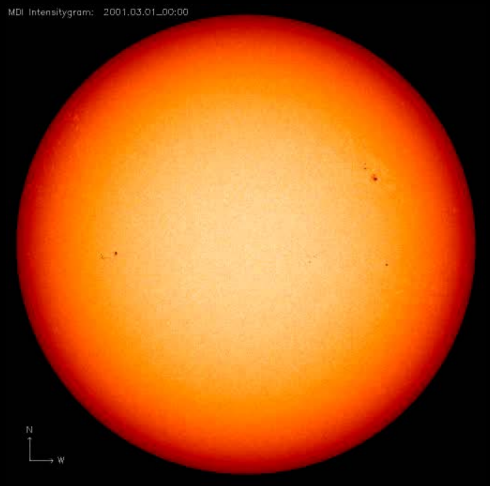
Clouds

Liquid water | Liquid cloud fraction | Low Clouds



Evidence of nearby supernovae affecting life on Earth
Last 500 myr

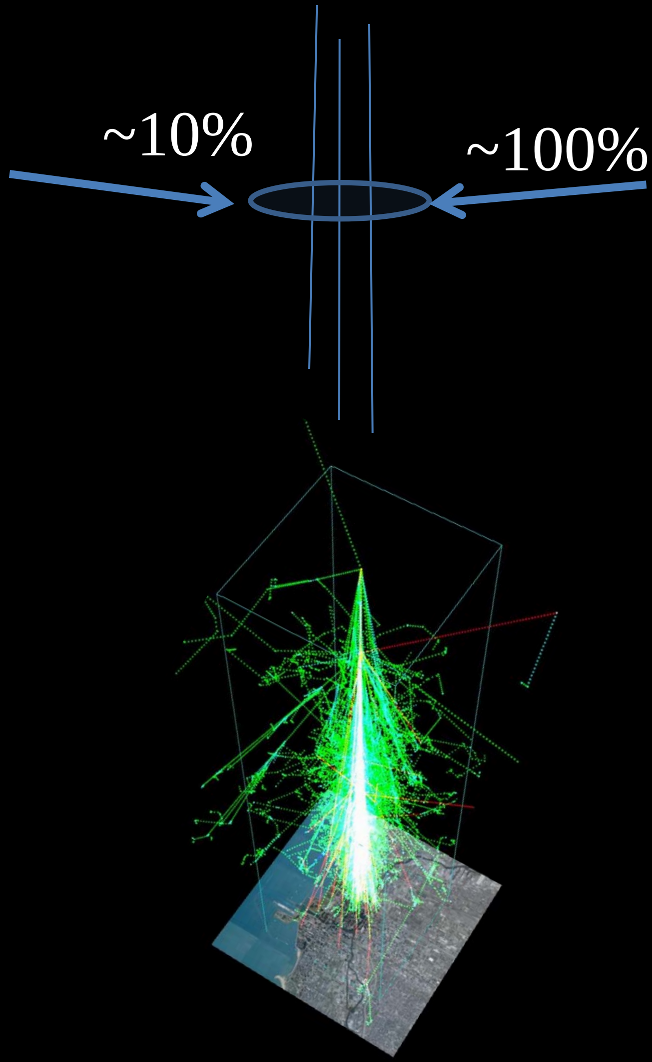
Solar activity



Cosmic rays

~10%

~100%



Stellar processes

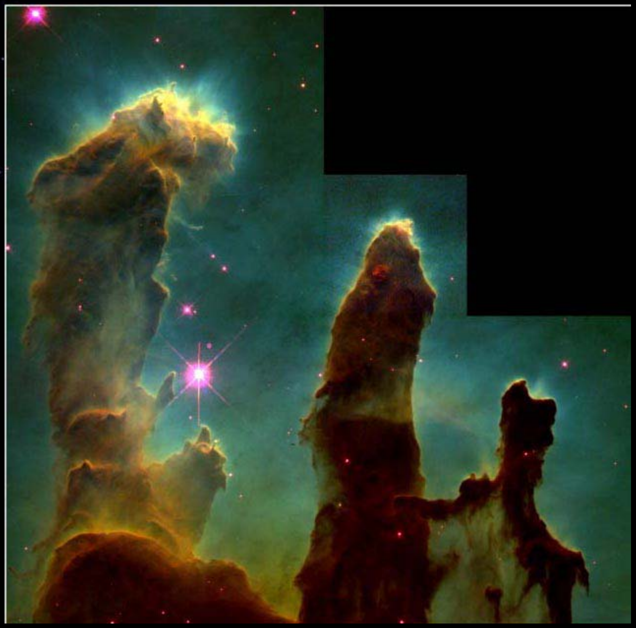
Super nova and star formation

Open Stellar Clusters

NGC 2516, 150 million old

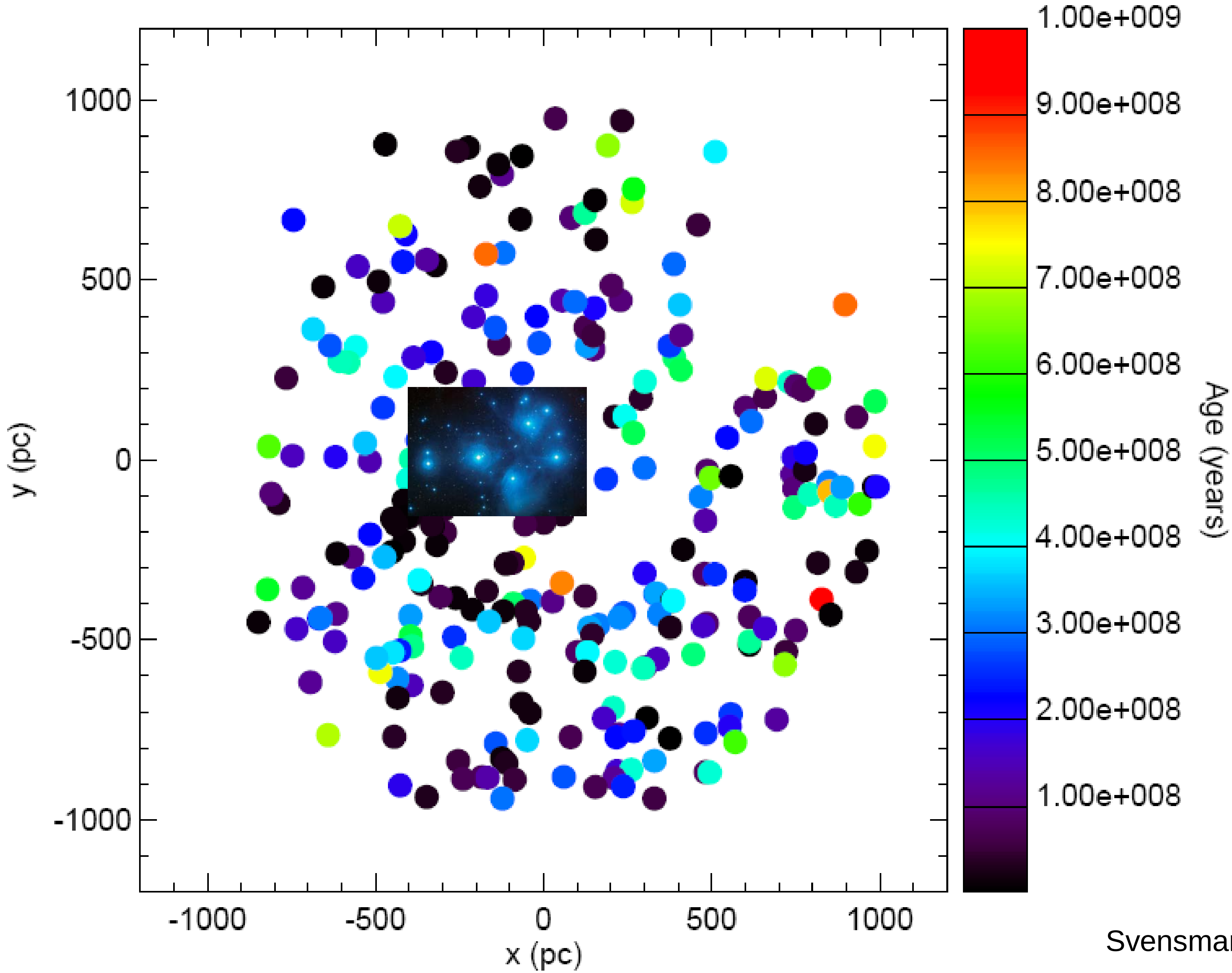
Pleiades 200 myr old ~ 1000 stars
Distance from solar system ~150 pc

Star formation



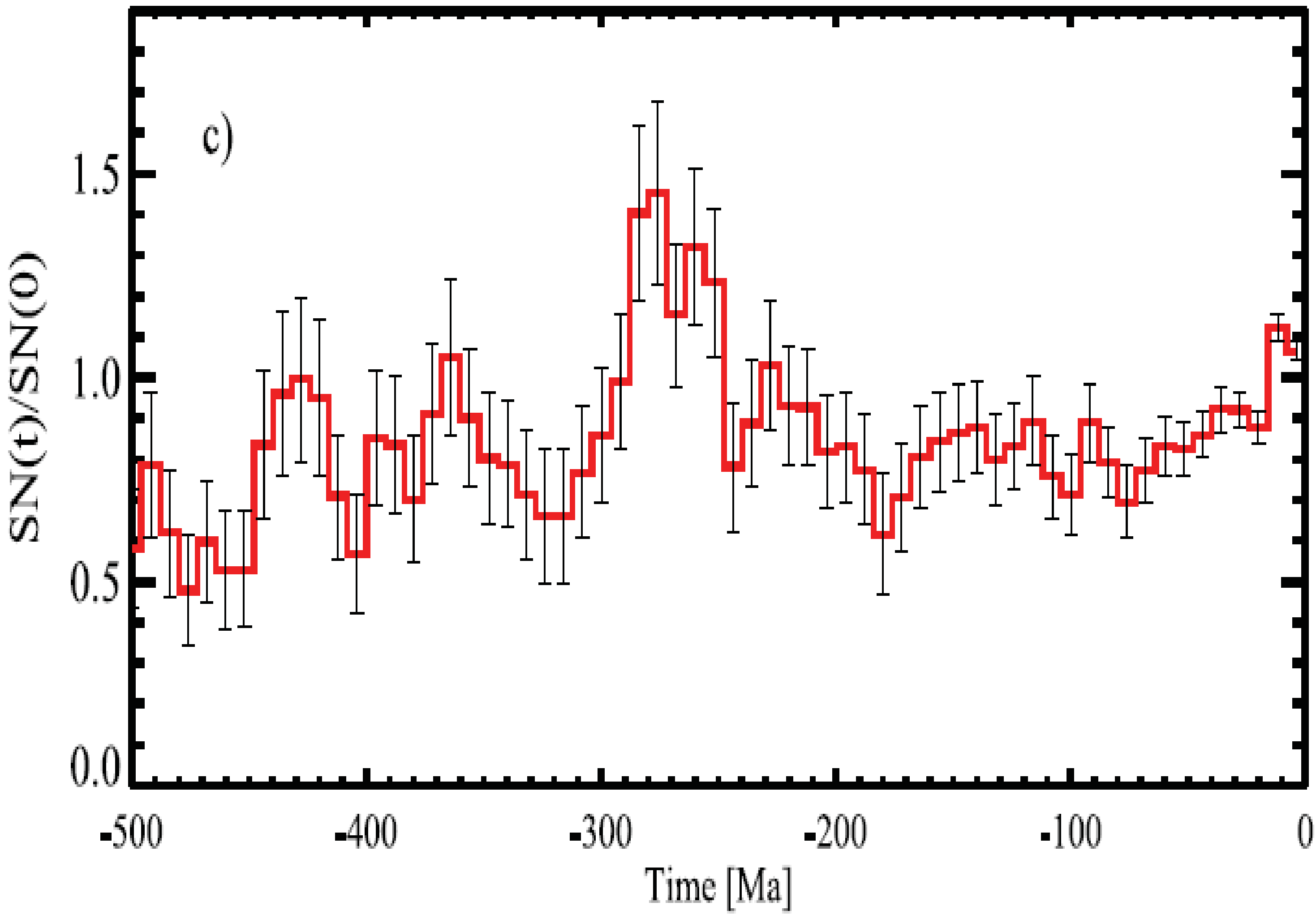
Star formation from a cloud of hydrogen gas

Observations of open clusters in the Solar neighborhood (WEBDA)



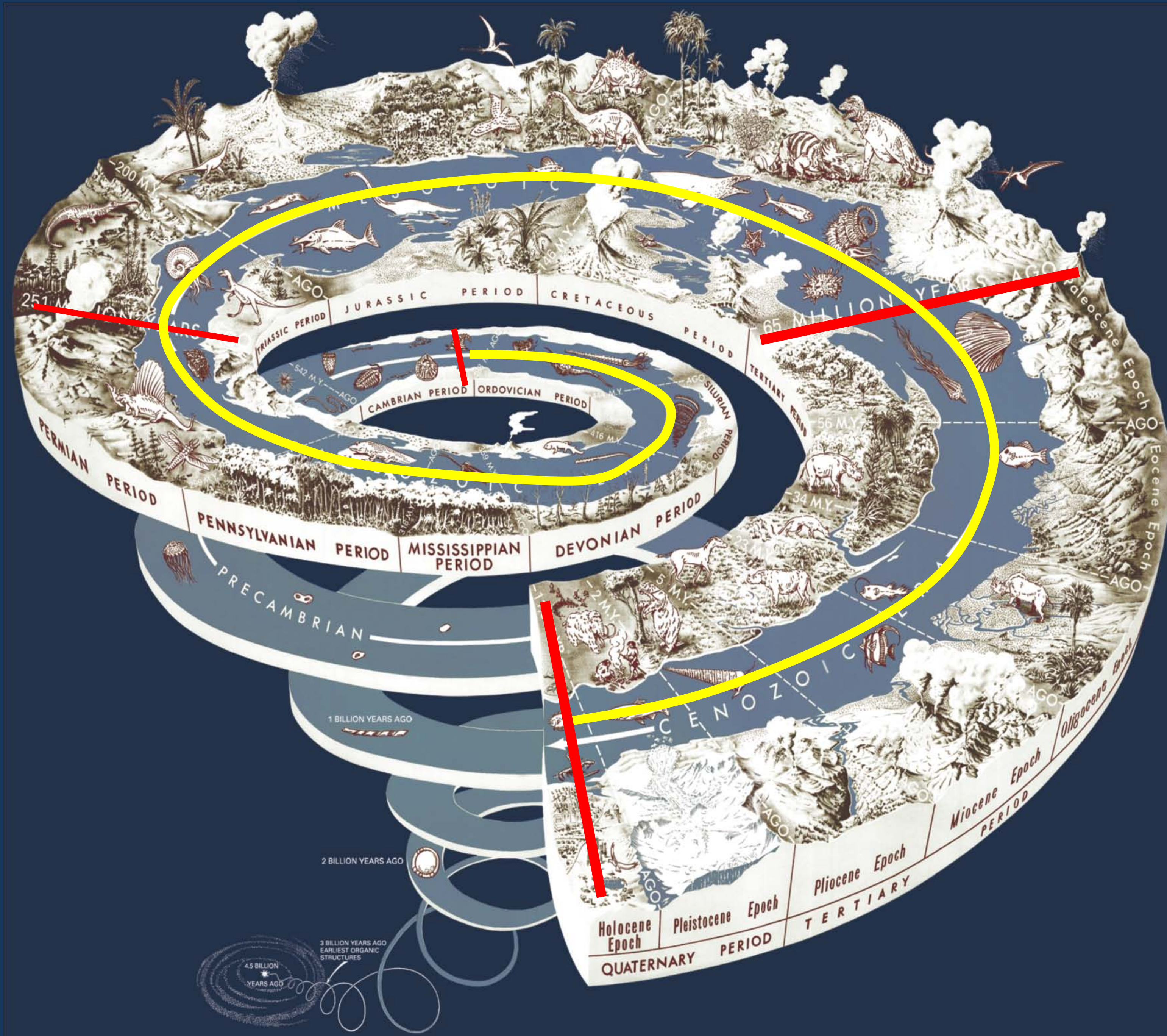
Svensmark 2012

Super nova history in the Solar neighborhood

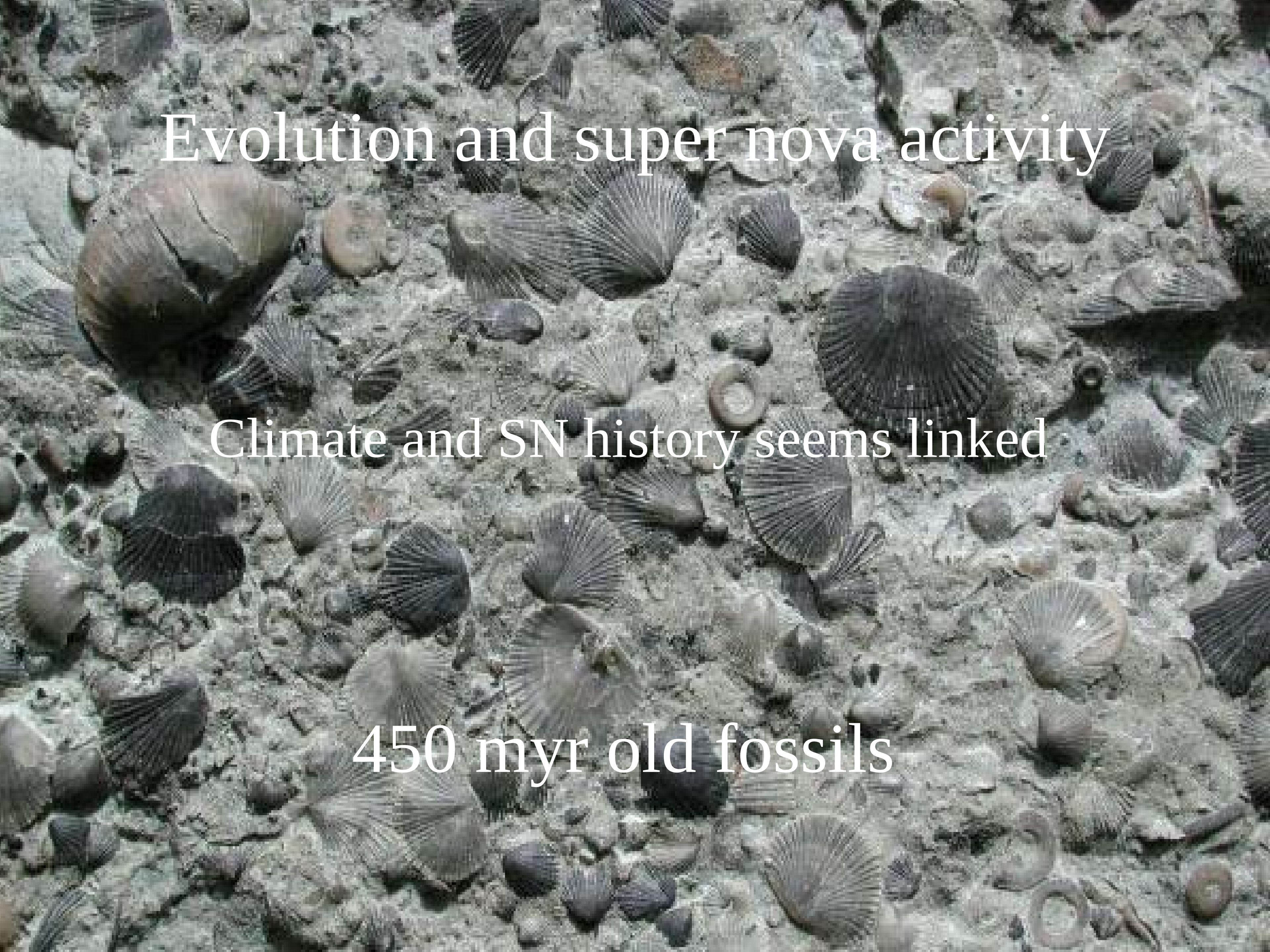


Svensmark, Mon. Not. R. Astron. Soc., 423, 1234-1253 (2012)

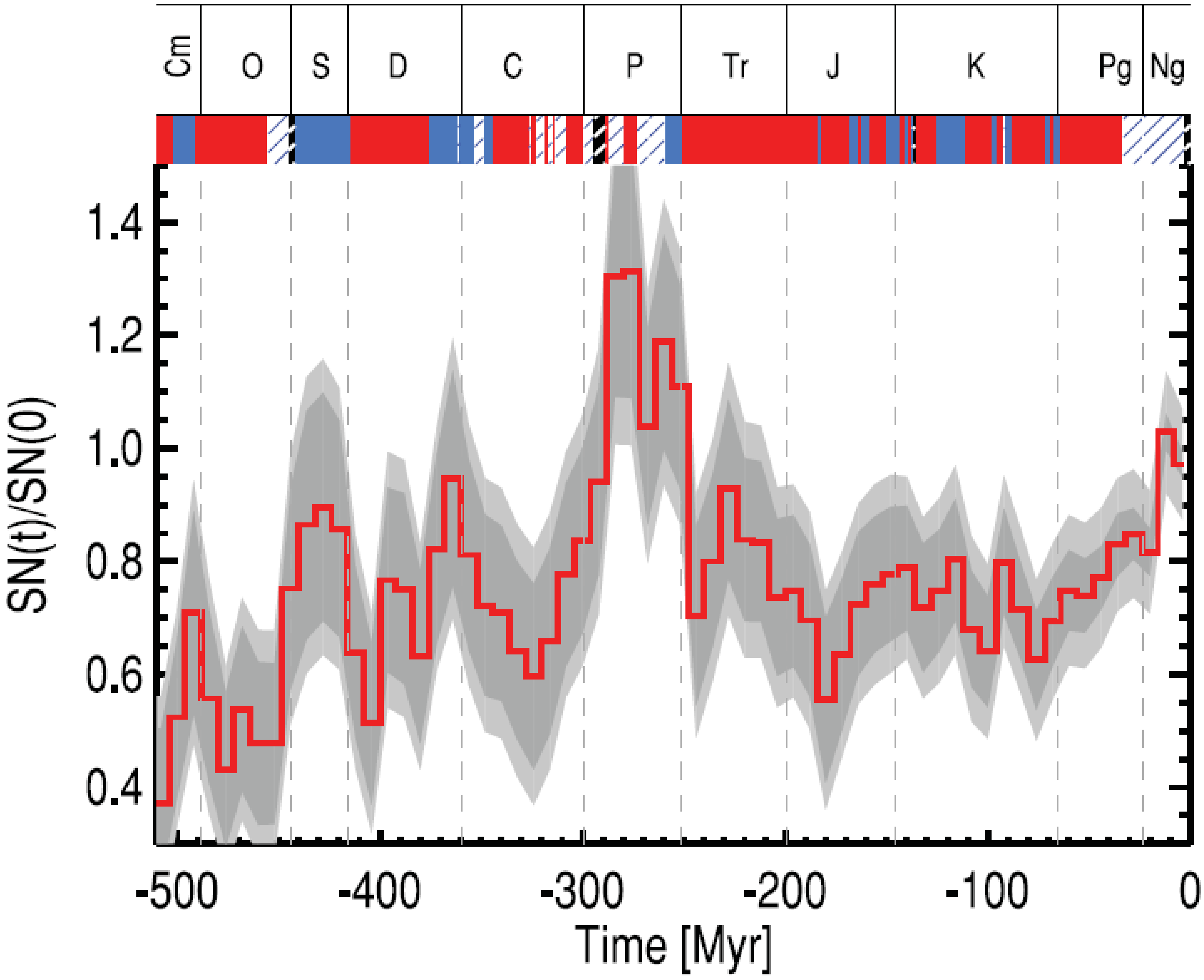
Sedimentary mountains (Grand Canyon)



PERMIAN PERIOD
PENNSYLVANIAN PERIOD
MISSISSIPPIAN PERIOD
DEVONIAN PERIOD
SILURIAN PERIOD
CAMBRIAN PERIOD
ORDOVICIAN PERIOD
TRIASSIC PERIOD
JURASSIC PERIOD
CRETACEOUS PERIOD
TERTIARY PERIOD
MESOZOIC ERA
CENOZOIC ERA
65 MILLION YEARS AGO
200 M.Y.
251 M.Y.
542 M.Y. AGO
416 M.Y.
56 M.Y.
34 M.Y.
Paleocene Epoch
Eocene Epoch
Oligocene Epoch
Miocene Epoch
Pliocene Epoch
Pleistocene Epoch
Holocene Epoch
QUATERNARY PERIOD
TERTIARY PERIOD
PRECAMBRIAN
1 BILLION YEARS AGO
2 BILLION YEARS AGO
3 BILLION YEARS AGO EARLIEST ORGANIC STRUCTURES
4.5 BILLION YEARS AGO

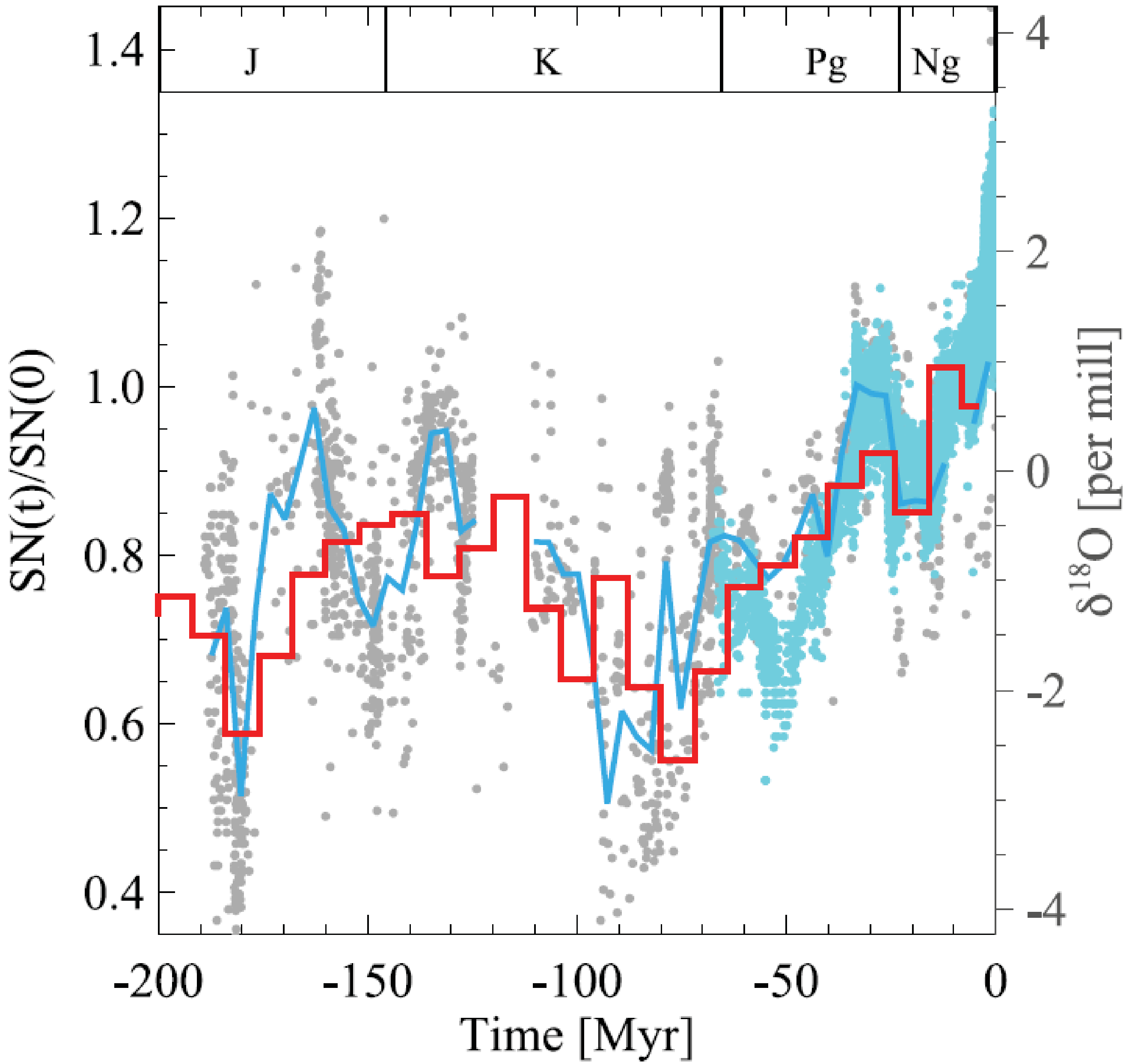

Evolution and super nova activity
Climate and SN history seems linked
450 myr old fossils

SN activity and glaciations during the last 500 Myr



Bradiopods
Fossil termometers

Proxy temperature and super nova activity during 200 Myr



Phanerozoic Trends in the Global Diversity of Marine Invertebrates

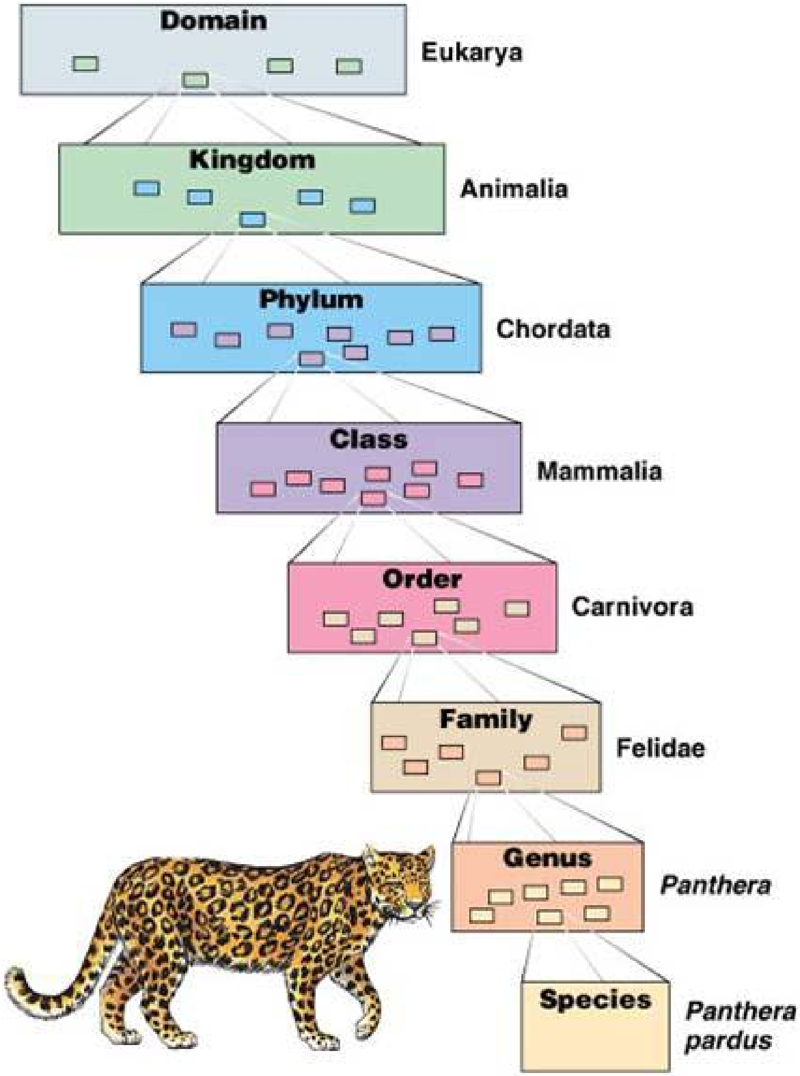
Science ***321, 97 (2008);***

John Alroy, Martin Aberhan, David J. Bottjer, Michael Foote, Franz T. Fürsich,
Peter J. Harries,6 Austin J. W. Hendy,7,8 Steven M. Holland,9 Linda C. Ivany,10
Wolfgang Kiessling,2 Matthew A. Kosnik,11 Charles R. Marshall,12 Alistair J. McGowan,13
Arnold I. Miller,7 Thomas D. Olszewski,14 Mark E. Patzkowsky,15 Shanan E. Peters,4,16
Loïc Villier,17 Peter J. Wagner,11 Nicole Bonuso,3,18 Philip S. Borkow,19
Benjamin Brenneis,2 Matthew E. Clapham,3,20 Leigh M. Fall,14 Chad A. Ferguson,7
Victoria L. Hanson,4,9 Andrew Z. Krug,4,15 Karen M. Layou,7,9,21 Erin H. Leckey,22
Sabine Nürnberg,2 Catherine M. Powers,3 Jocelyn A. Sessa,7,15 Carl Simpson,4,23
Adam Tomašových,4,24 Christy C. Visaggi10,25

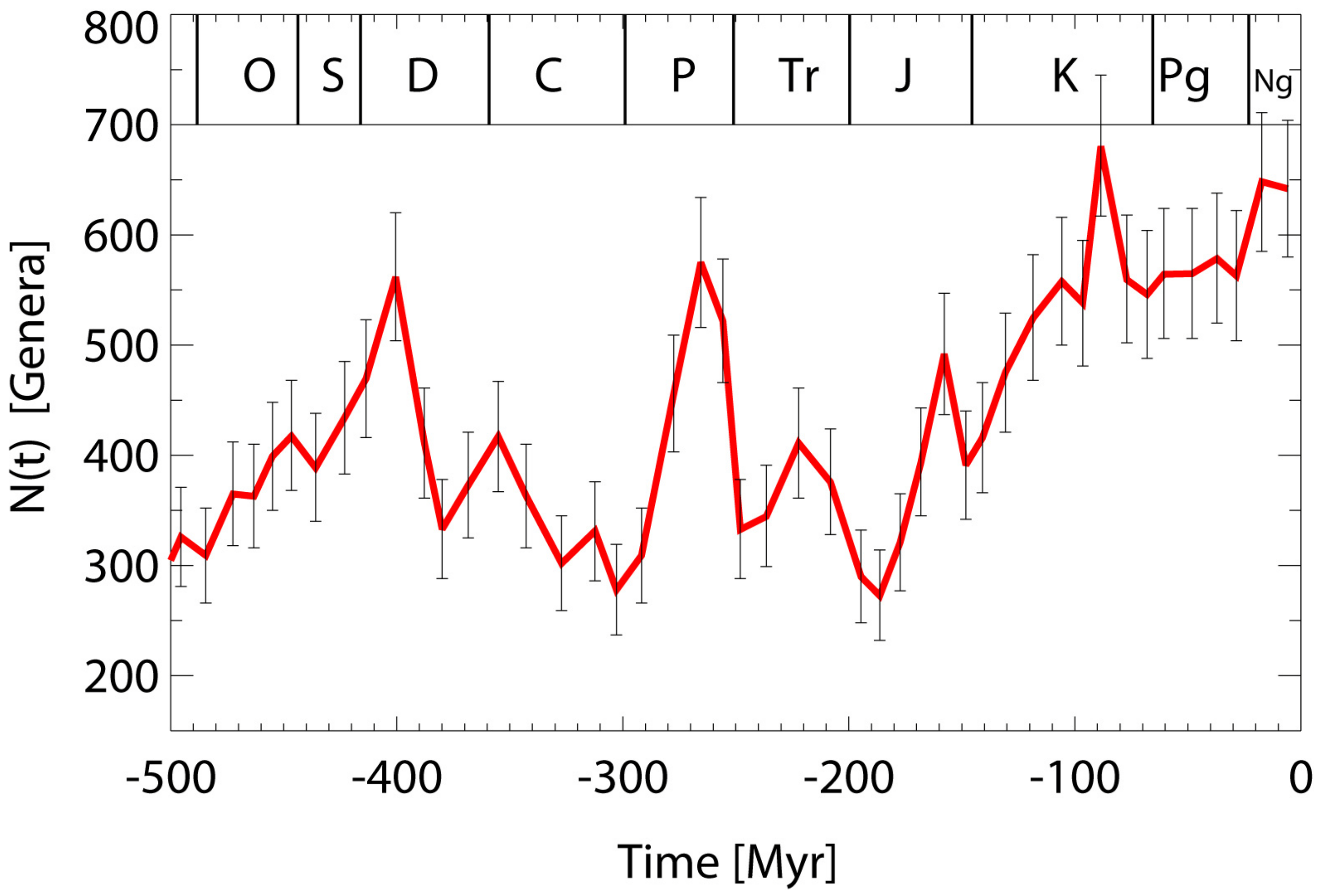
The data for this study contains 284,816 fossil occurrences of 18,702 genera that equals about 3.4 million specimens from 5384 literature sources.

The old curve, developed by J. John Sepkoski Jr., used a database that contained only about 60,000 occurrences.

Groups


Domain
Eukarya
Kingdom
Animalia
Phylum
Chordata
Class
Mammalia
Order
Carnivora
Family
Felidae
Genus
Panthera
Species
Panthera pardus

Marine Invertebrate Genera

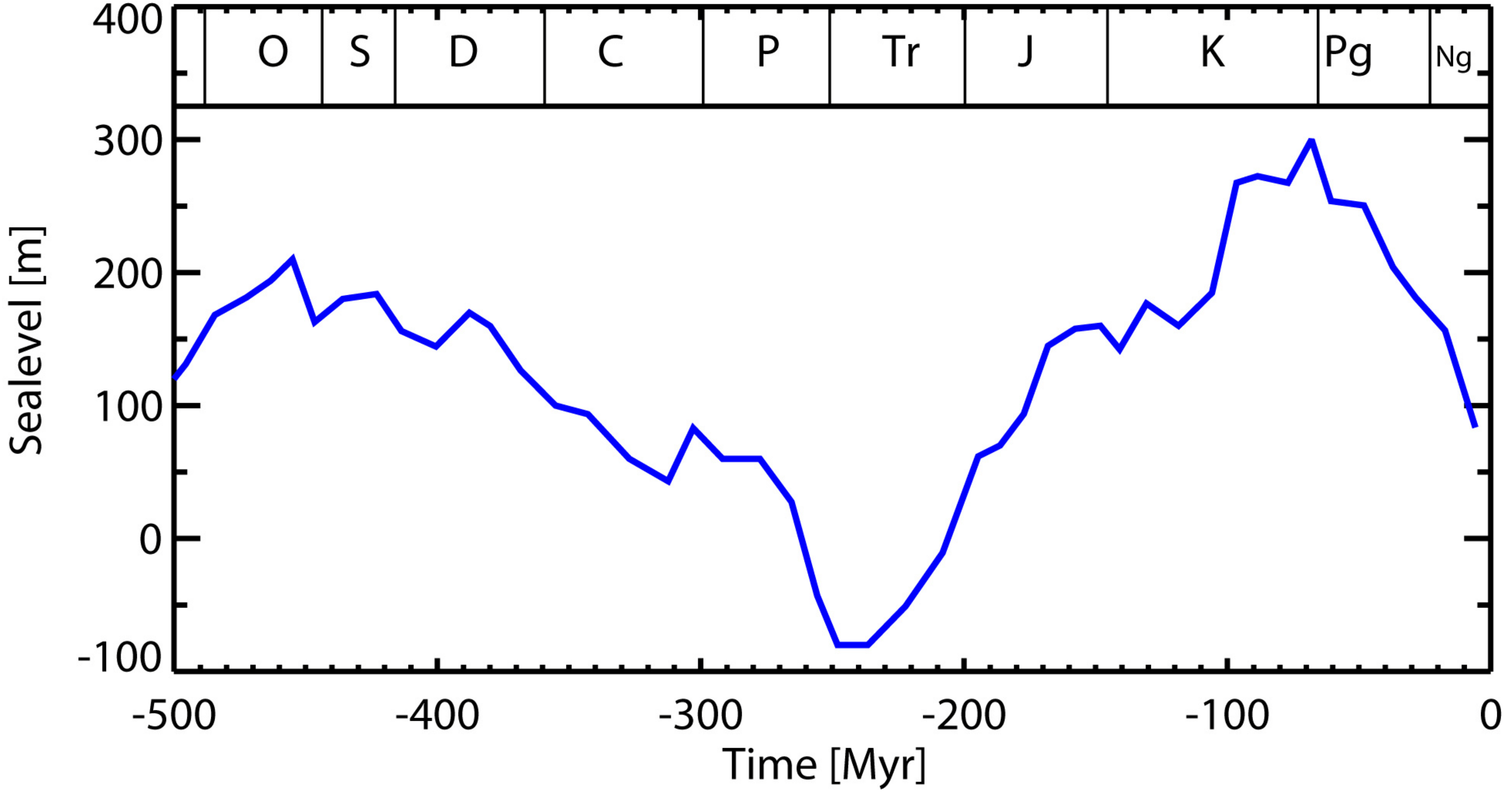


Looking for the causes of particular mass extinctions

- **Sea-level**
- **Climate**

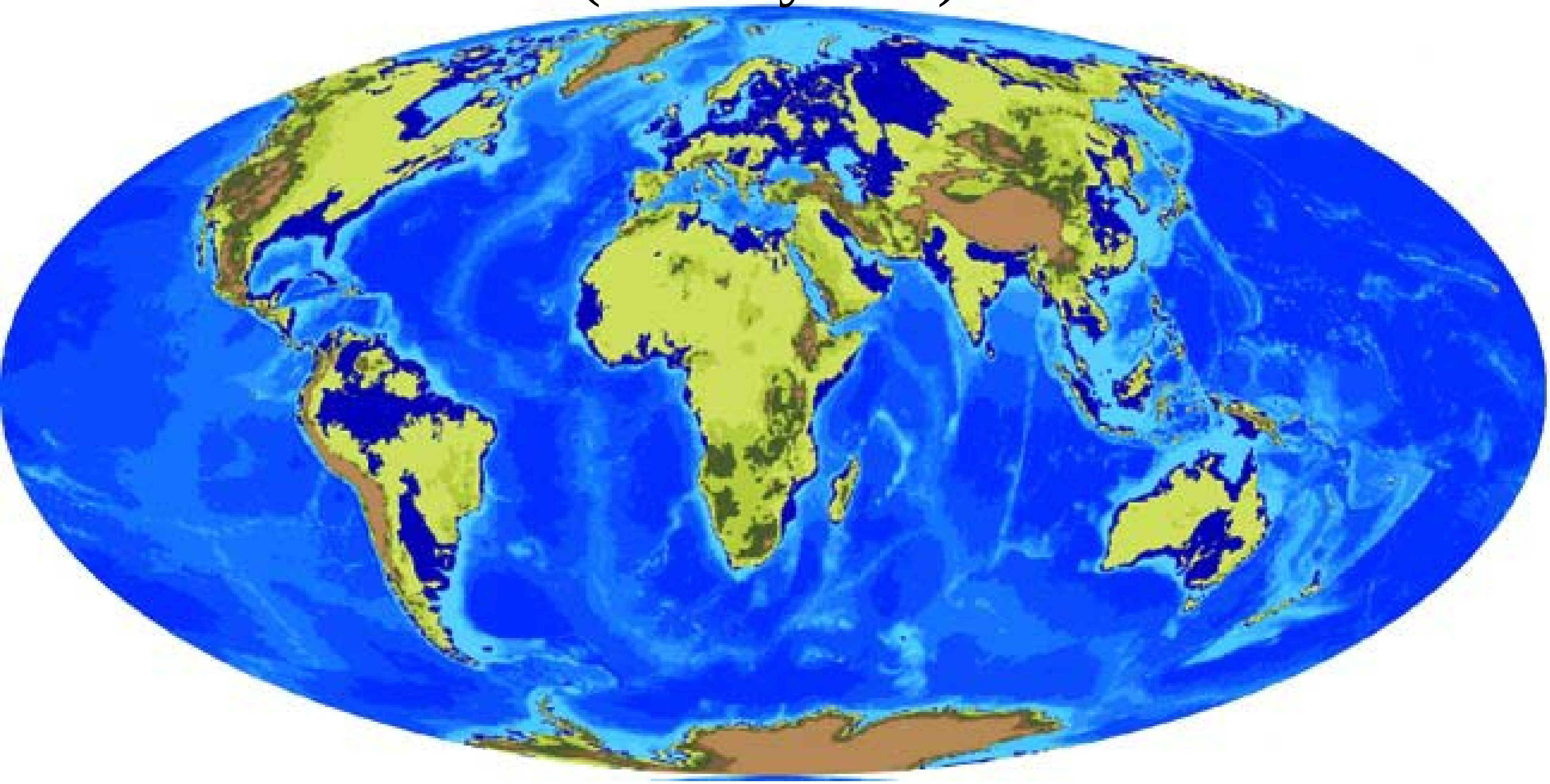
- Flood basalt events
- Sea-level falls
- Impact events
- Sustained and significant global cooling
- Sustained and significant global warming
- Clathrate gun hypothesis
- Anoxic events
- Hydrogen sulfide emissions from the seas
- Oceanic overturn
- A nearby nova, supernova or gamma ray burst
- Plate tectonics

Sealevel variation



Intercontinental flooding

(~70 myr BP)



The astrophysical connection

$$\mathrm{N}(t) = \Gamma(\mathrm{SN}, t)\Lambda(\mathrm{Sealevel}, t) + \epsilon(t)$$

$$\Lambda(\mathrm{Sealevel}, t) = \alpha + \beta\ \mathrm{Sealevel(t)}$$

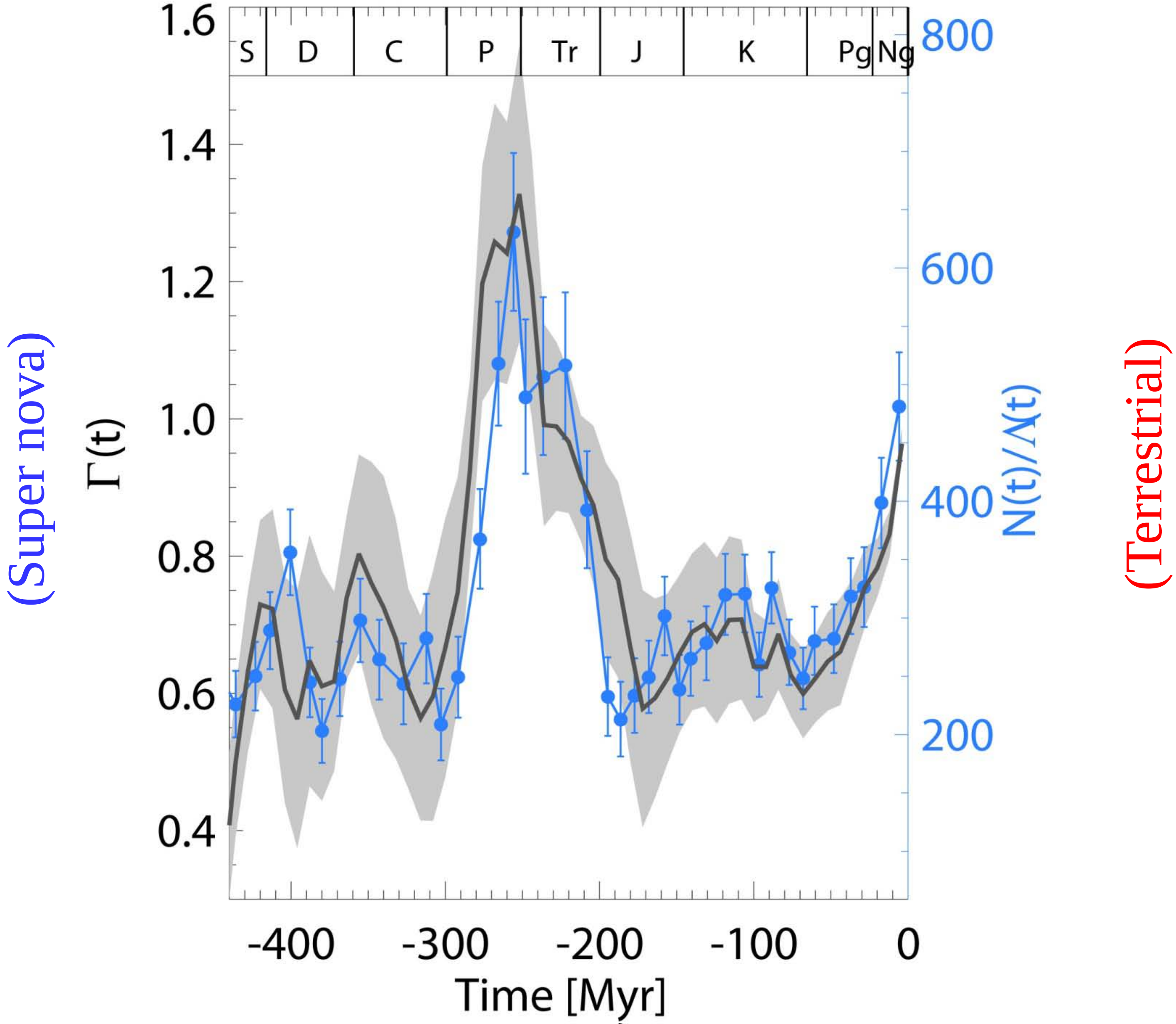
$$\Gamma(\mathrm{SN}, t) = \nu_1 \int_{-\infty}^{t} SN(t') \exp\left[-\lambda(t - t')\right] dt' + \nu_2$$

$$\frac{\mathrm{N}(t)}{\Lambda(\mathrm{Sealevel}, t)} = \nu_1 \int_{-\infty}^{t} SN(t') \exp\left[-\lambda(t - t')\right] dt' + \nu_2 + \epsilon(t)$$

Terrestrial

Astrophysical

Genera, sea level and supernova activity

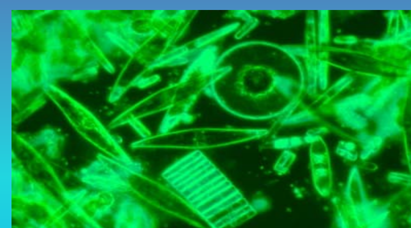


Biological Pump

Solar energy

Windblown and river runoff nutrients
Phospher, Fe, Nitrogen

Bio production



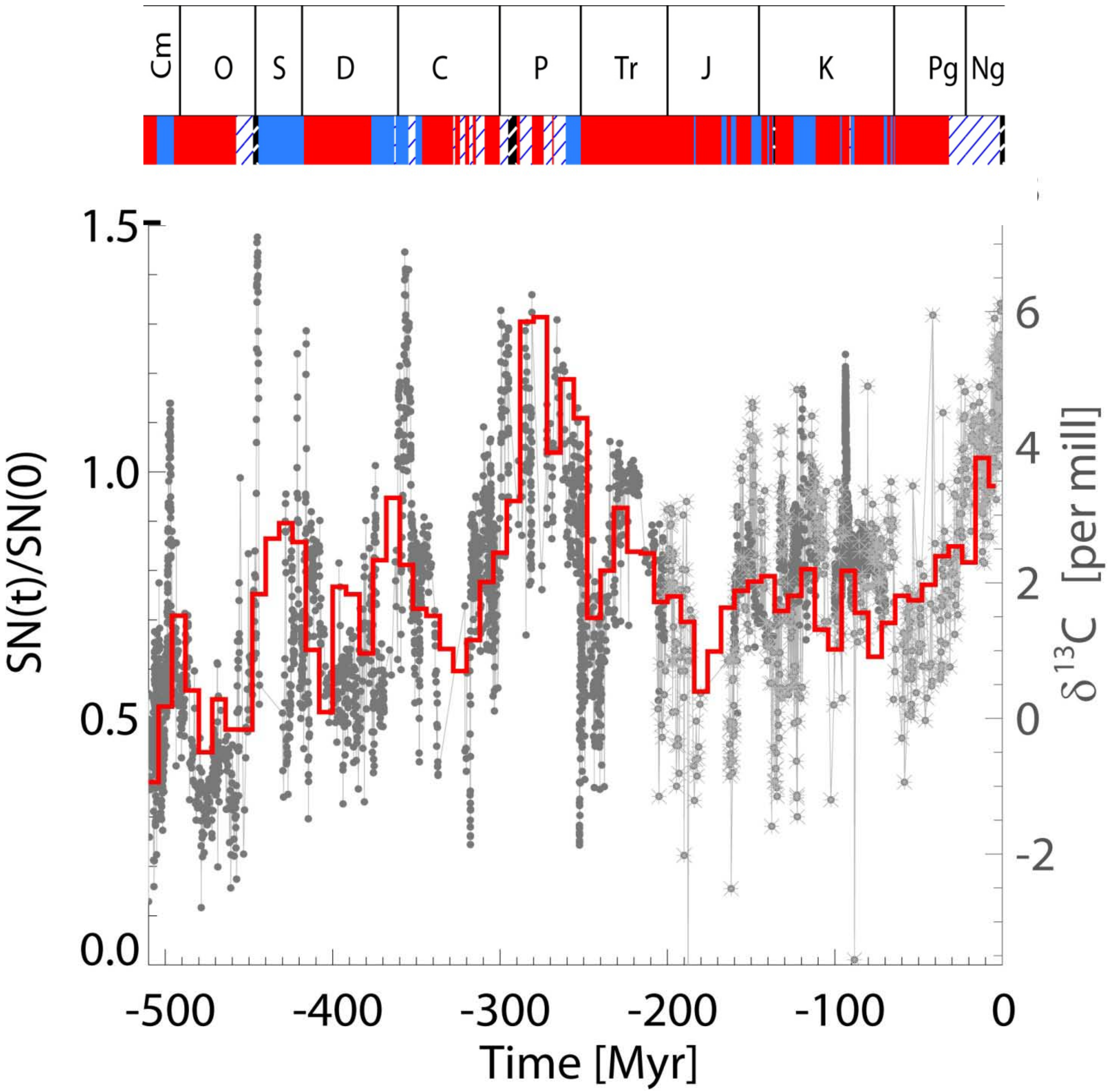
Nutrients

De-composion

Inorganic Carbonate
Sediments

Organic Sediments

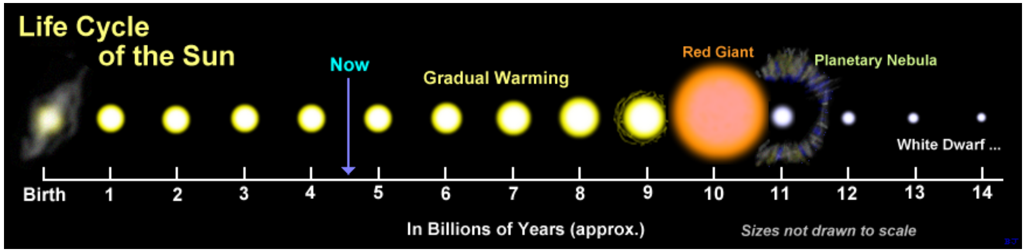
Carbon 13 and super nova activity



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

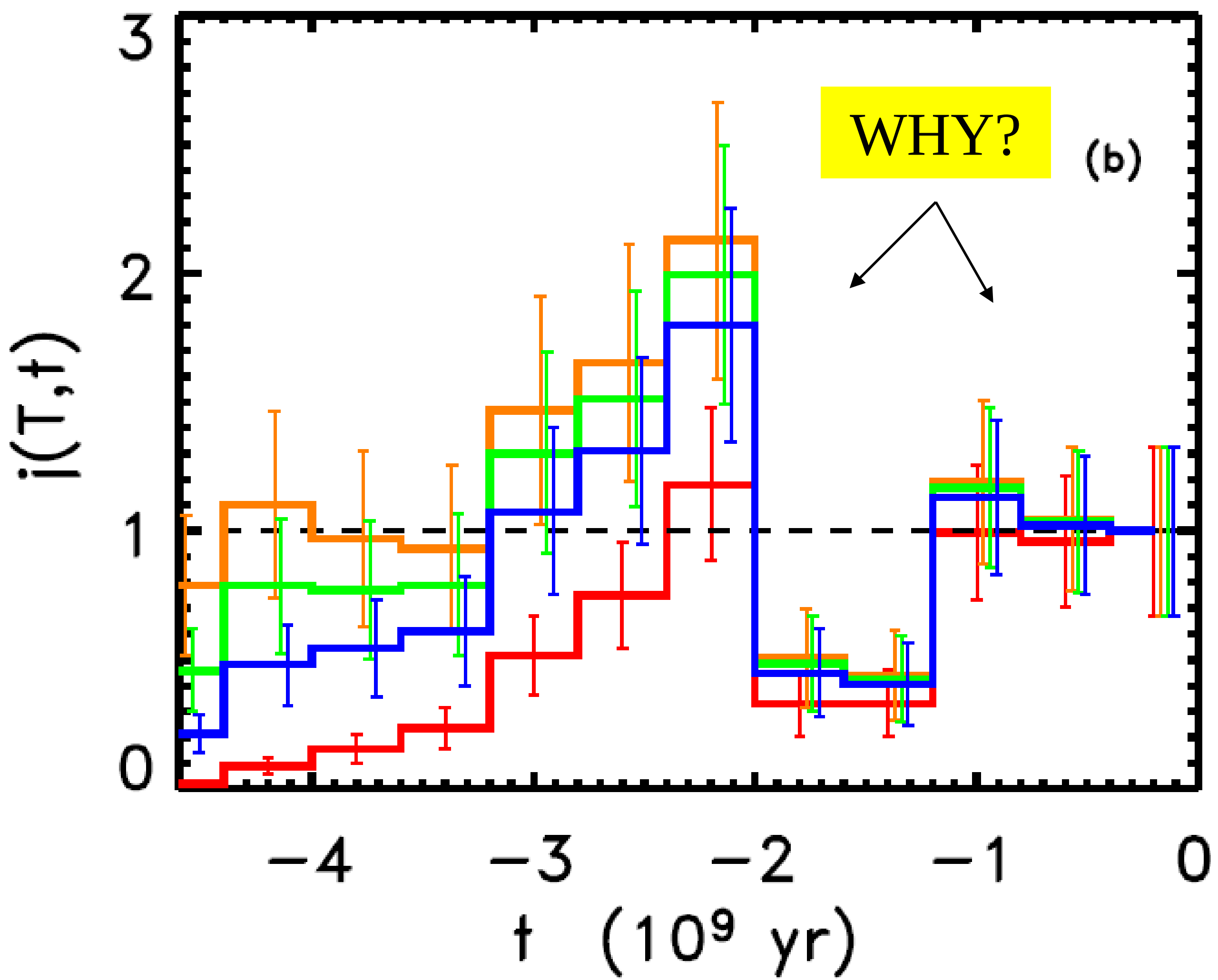
Although Cosmic ray fluxes are not known so far back in time, they can be constructed from knowledge of

1) Solar Evolution



2) History of Star Formation Rate in the Milky Way

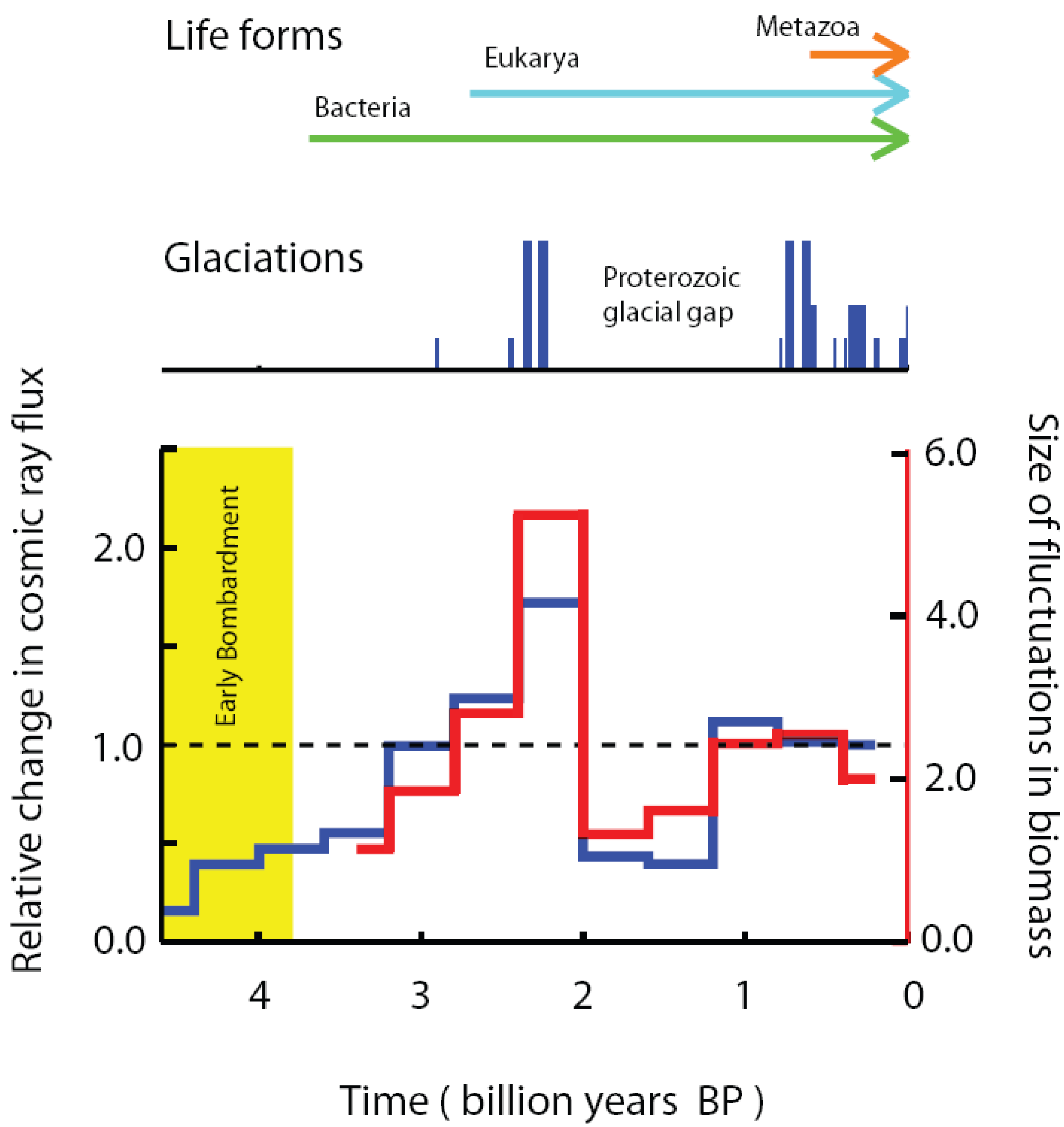
Solar Evolution, Star Rate Formation and Cosmic Rays



Svensmark, Astronomical Notes 2006

Interaction between galaxies

Cosmic Rays and the Biosphere in 4 Billion Years



Svensmark, Astronomical Notes 2006

Conclusion

Variation in cosmic rays are associated with changes in Earths climate. Strong empirical evidence.

Evidence suggest that clouds are the key player.

New insight to the physical mechanism has been demonstrated experimentally and observationally

- 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 the origin of changing conditions for life.

THE END