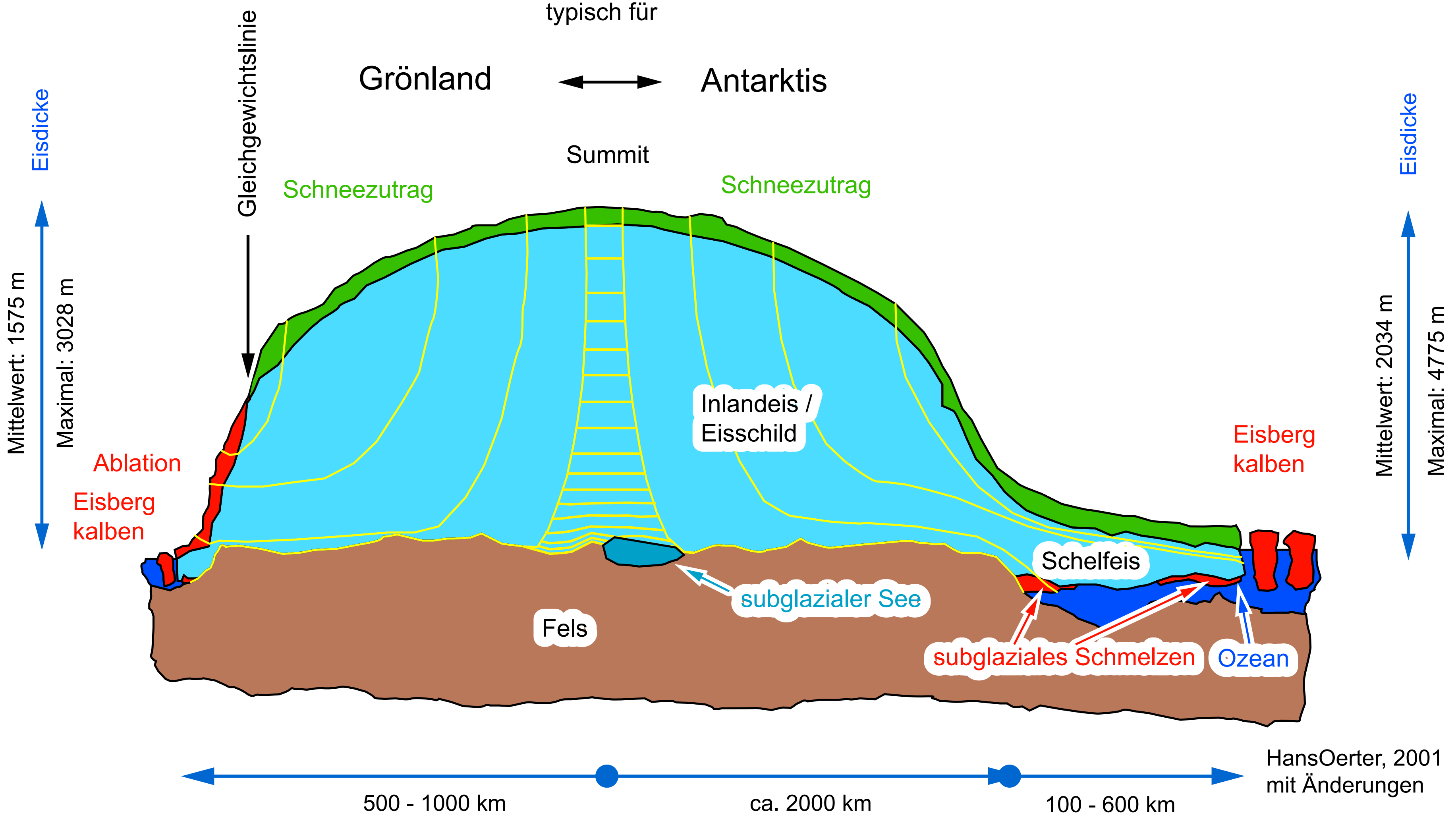
Schnee von gestern? – Rekonstruktion vergangener Umweltbedingungen aus polaren Eisschilden!

XLAB Science Festival
Göttingen, 27. Januar 2011

Frank.Wilhelms@awi.de

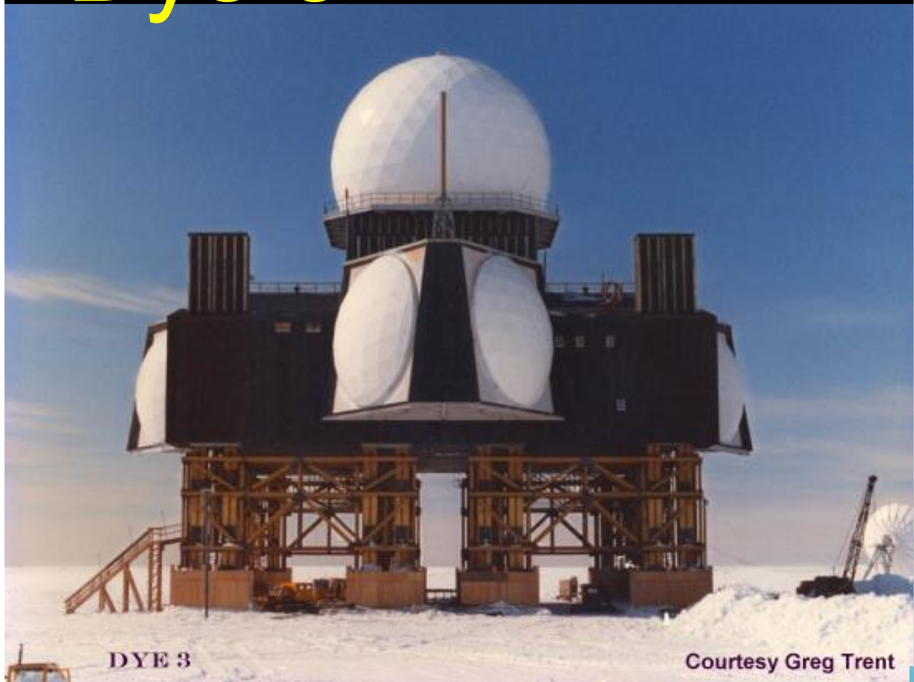
Alfred Wegener Institut
für Polar- und Meeresforschung
Georg-August-Universität Göttingen

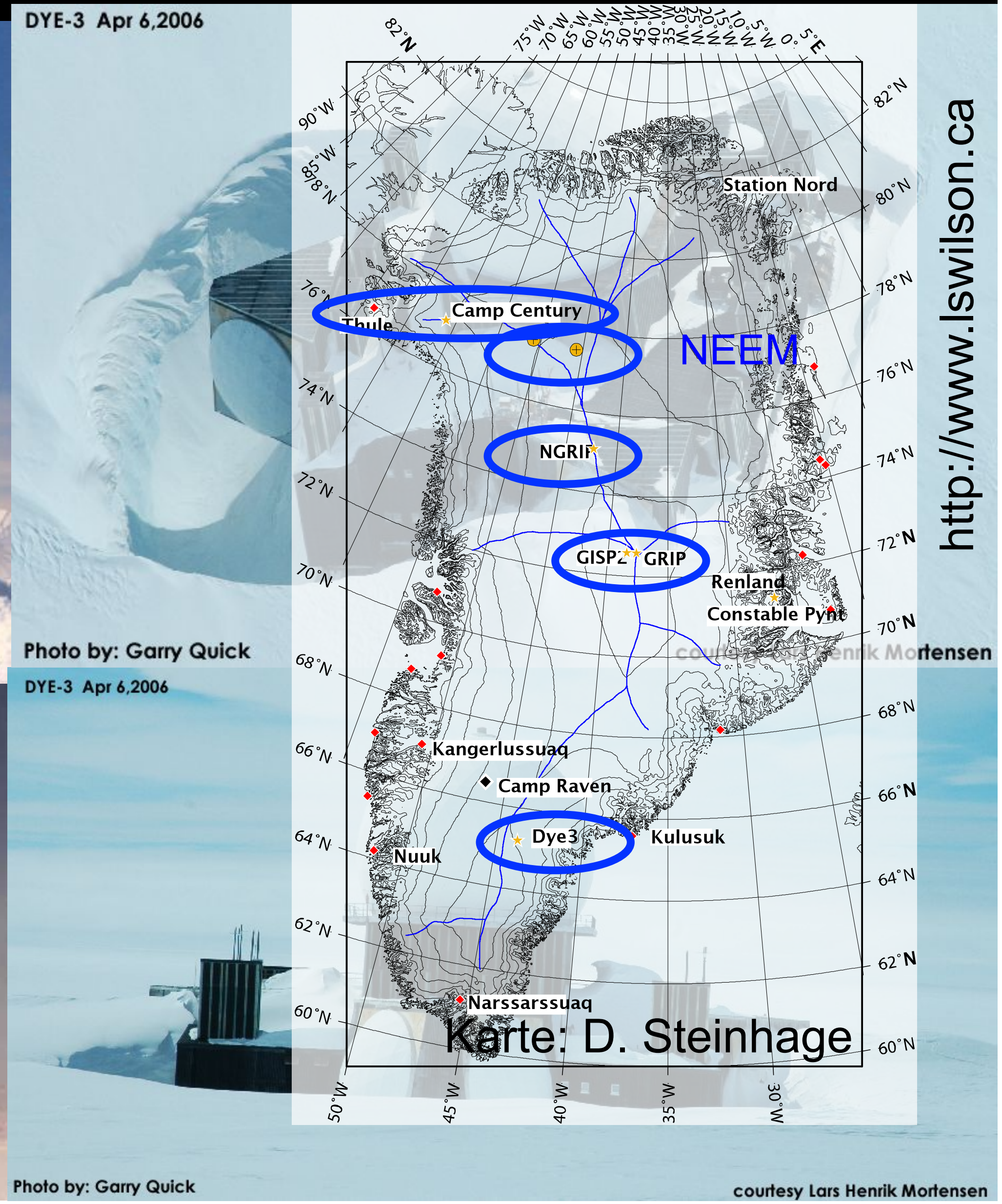
Polare Eisschilde



HansOerter, 2001
mit Änderungen

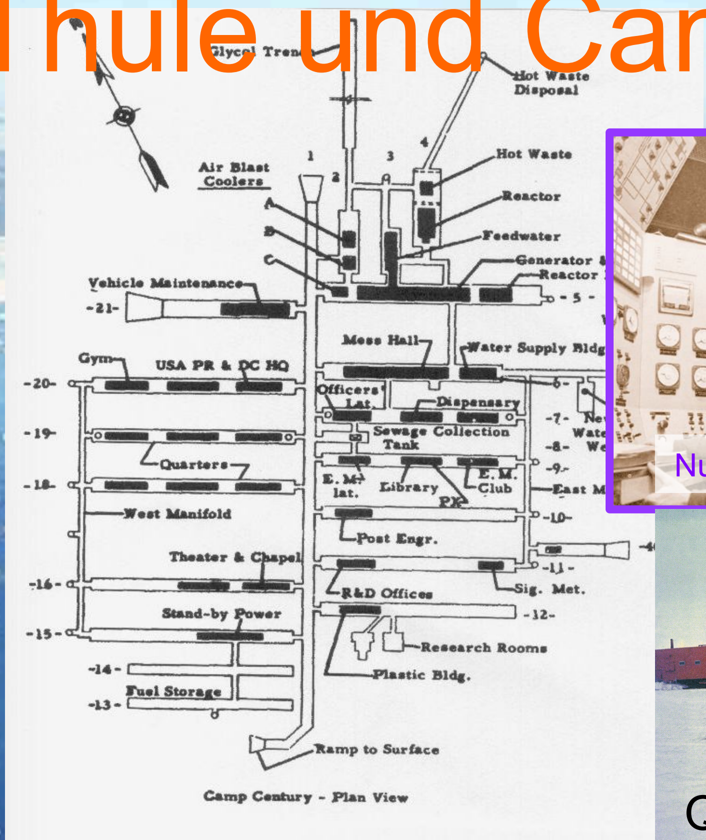
Grönland in den 50er & 60er Jahren, Dye 3

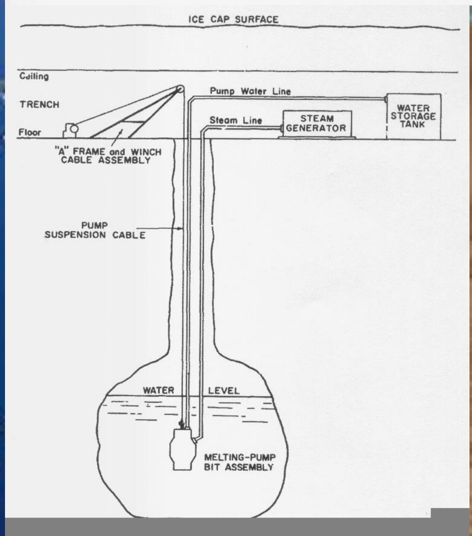




Thule und Camp Century

http://www.thuleab.dk





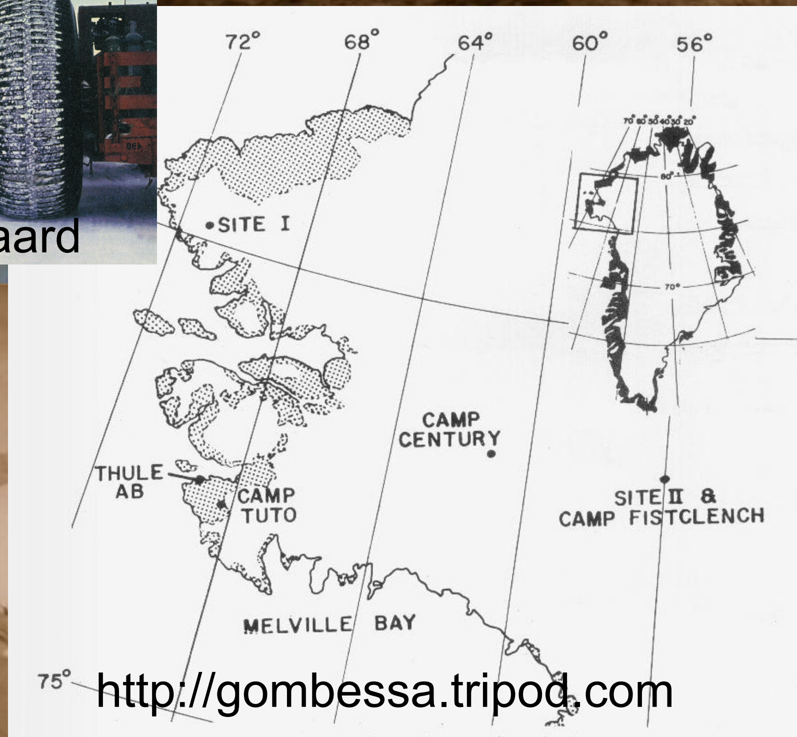


Figure 1. Location of Camp Century, Greenland.

Der erste tiefe Eiskern in Grönland

One Thousand Centuries of Climatic Record from Camp Century on the Greenland Ice Sheet

Abstract. *A correlation of time with depth has been evaluated for the Camp Century, Greenland, 1390 meter deep ice core. Oxygen isotopes in approximately 1600 samples throughout the core have been analyzed. Long-term variations in the isotopic composition of the ice reflect the climatic changes during the past nearly 100,000 years. Climatic oscillations with periods of 120, 940, and 13,000 years are observed.*

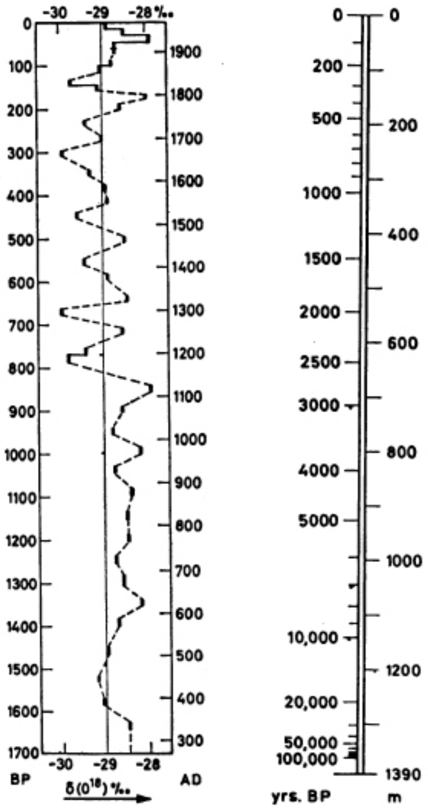
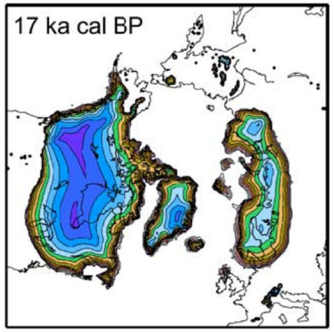


Fig. 2 (left). A depth-age nomograph for the 1390 m long Camp Century ice core. Fig. 3 (right). Variations in δ(O^{18}) in the upper 470 m of the Camp Century ice core plotted against the calculated age of the ice. Tl lines eorre of accumi lated as - the core se is observe



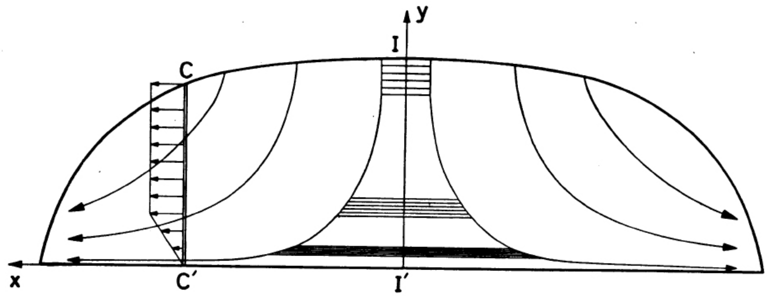


Fig. 1. Vertical cross section of an ice sheet resting upon a horizontal subsurface. Ice particles deposited upon the snow surface will follow lines that travel closer to the base the farther inland the site of deposition. An ice mass formed around the divide (*I–I′*) will be plastically deformed (thinned) with depth as suggested by the lined areas [compare (*35*)]. The horizontal arrows along the vertical ice core (*C–C′*) show the assumed profile of horizontal velocity component, V_x.

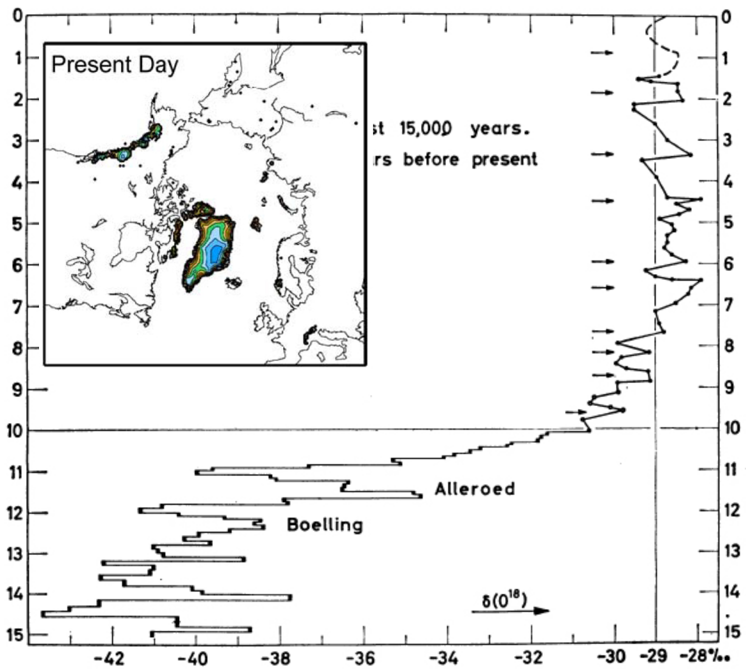
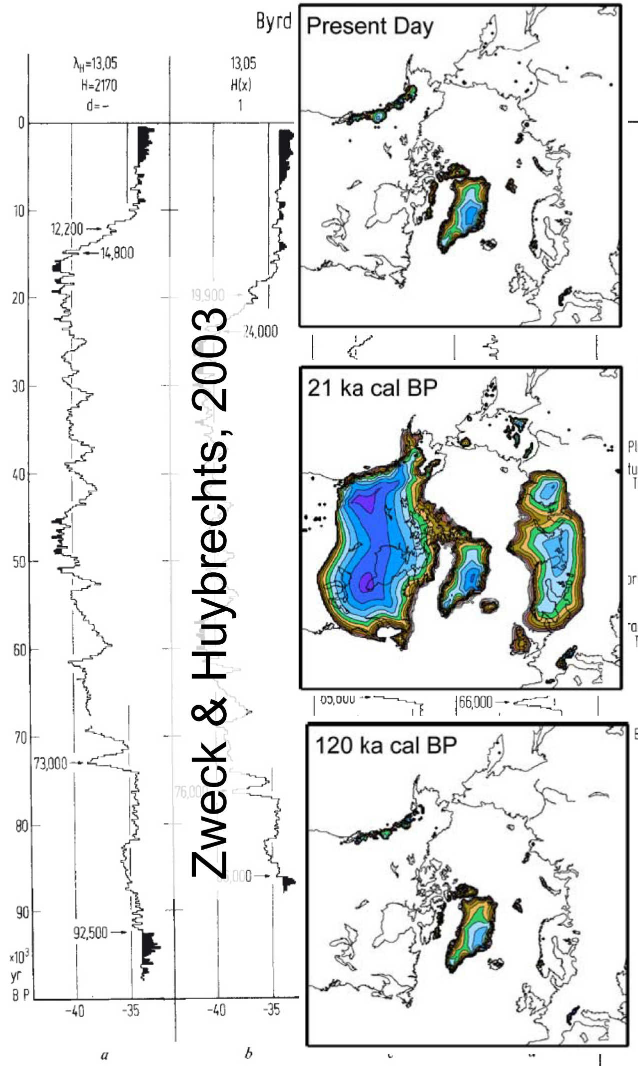


Fig. 4. Climatic variations reflected by δ(O^{18}) variations in the ice from the present to the ... Wisconsin glacial period. The data points in the upper portion of the curve repre... lower portion of the curve represents a continuous sequence of measured samples, each extending over approximately 100 years. ... 940-year climatic ... is suggested, which is indicated ... peaks in the lower curve.

Zweck & Huybrechts, 2003

Dansgaard, Johnsen, Møller, Langway, Science, 1969

Dansgaard-Oeschger-Zyklen



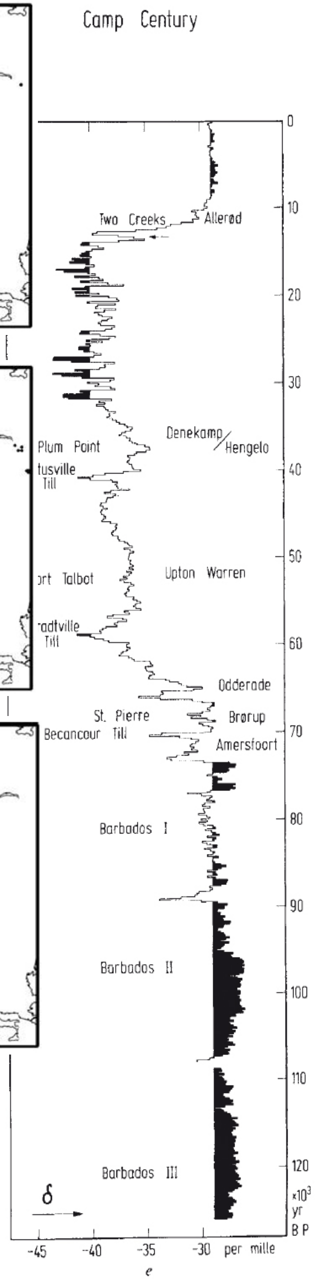
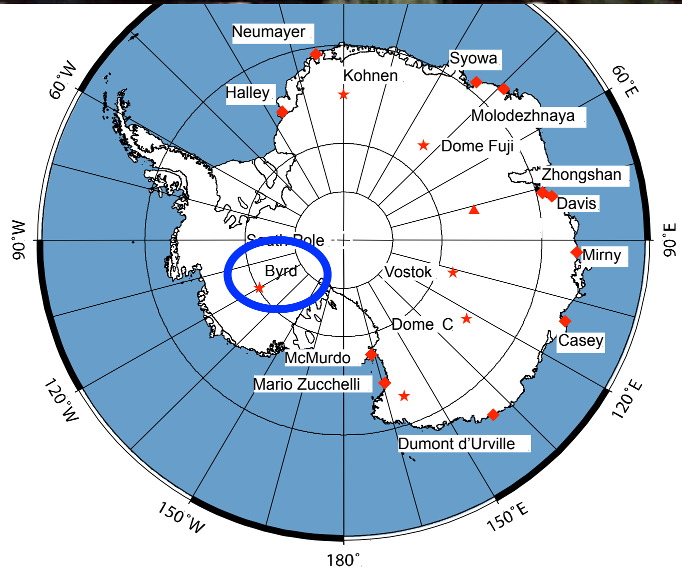


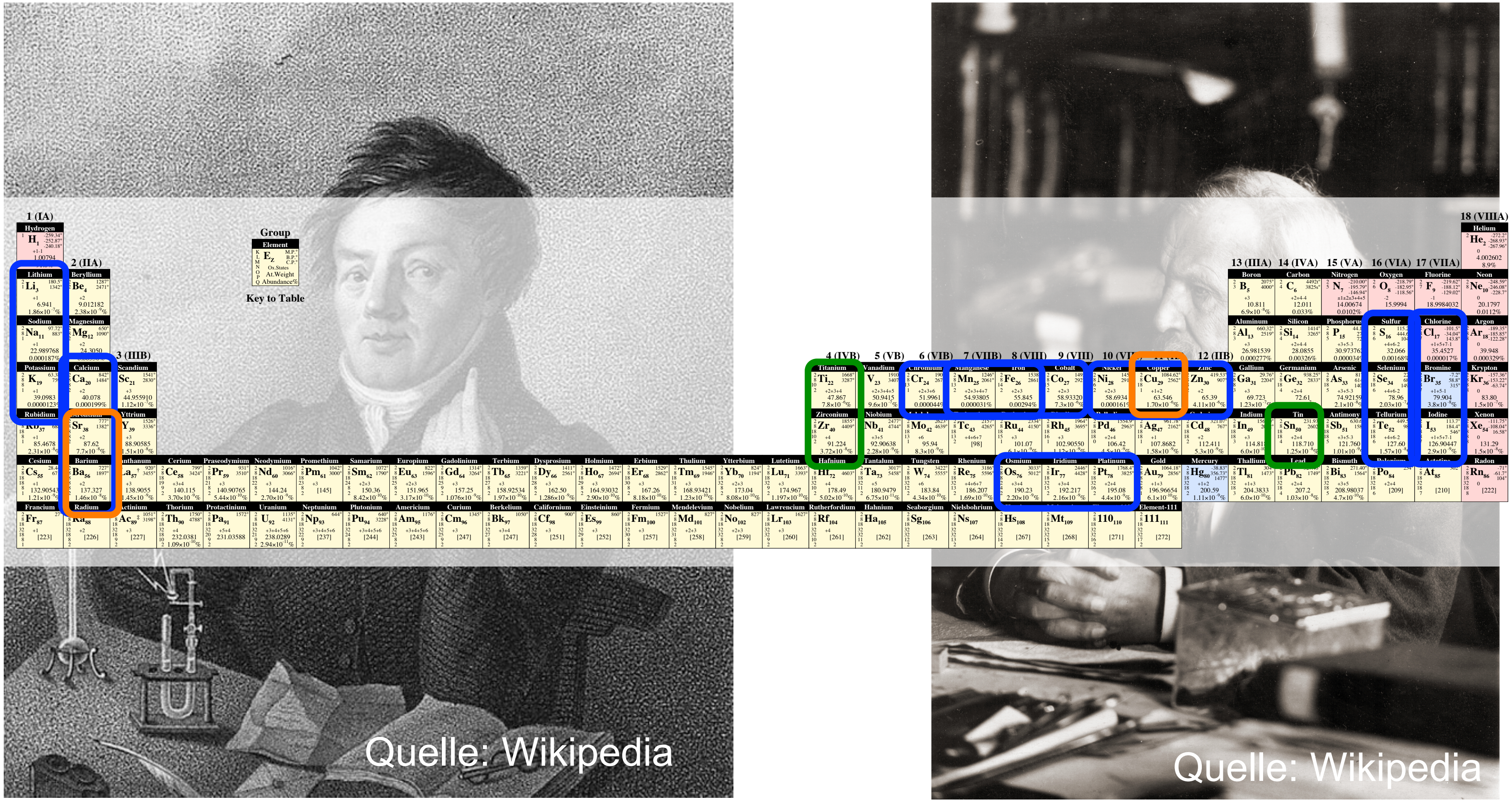
Fig. 5 The continuous δ record for the Byrd Station ice core measured on increments each covering approximately 200 yr and plotted on time scales calculated under various assumptions

Johnsen, Dansgaard, Clausen, Langway, Nature, 1972



Antarctic Digital Database, Ekholm, 1998, map by Steinhage with modifications

Dreiheit (Trias) als Grundlage der Ordnung

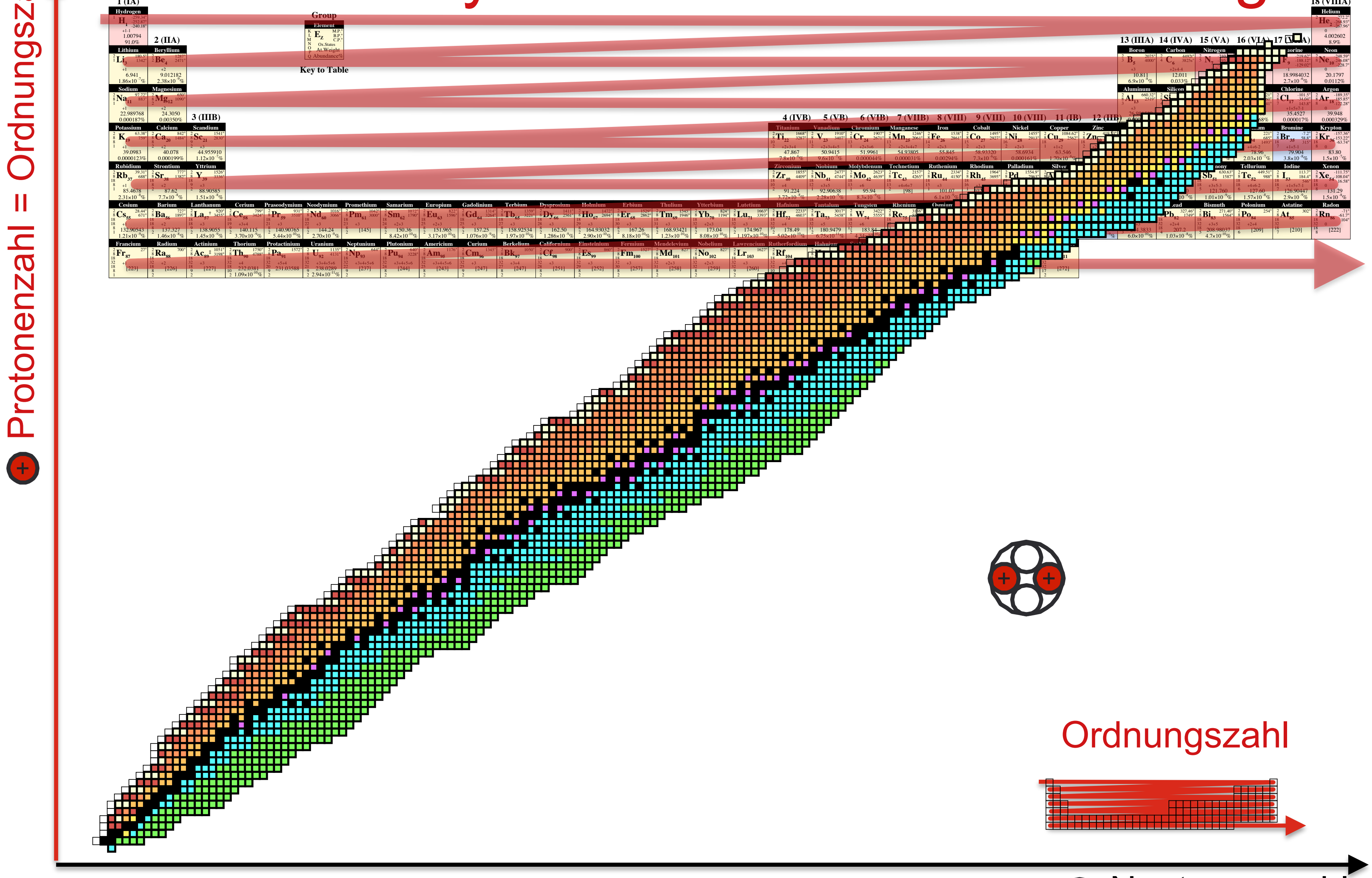


Johann Wolfgang Döbereiner
13. 12.1780 – 24.03.1849

Dmitri Iwanowitsch Mendelejew
(russ. ДмитрийИвановичМенделеев)
8.2.1834 – 2.2.1907

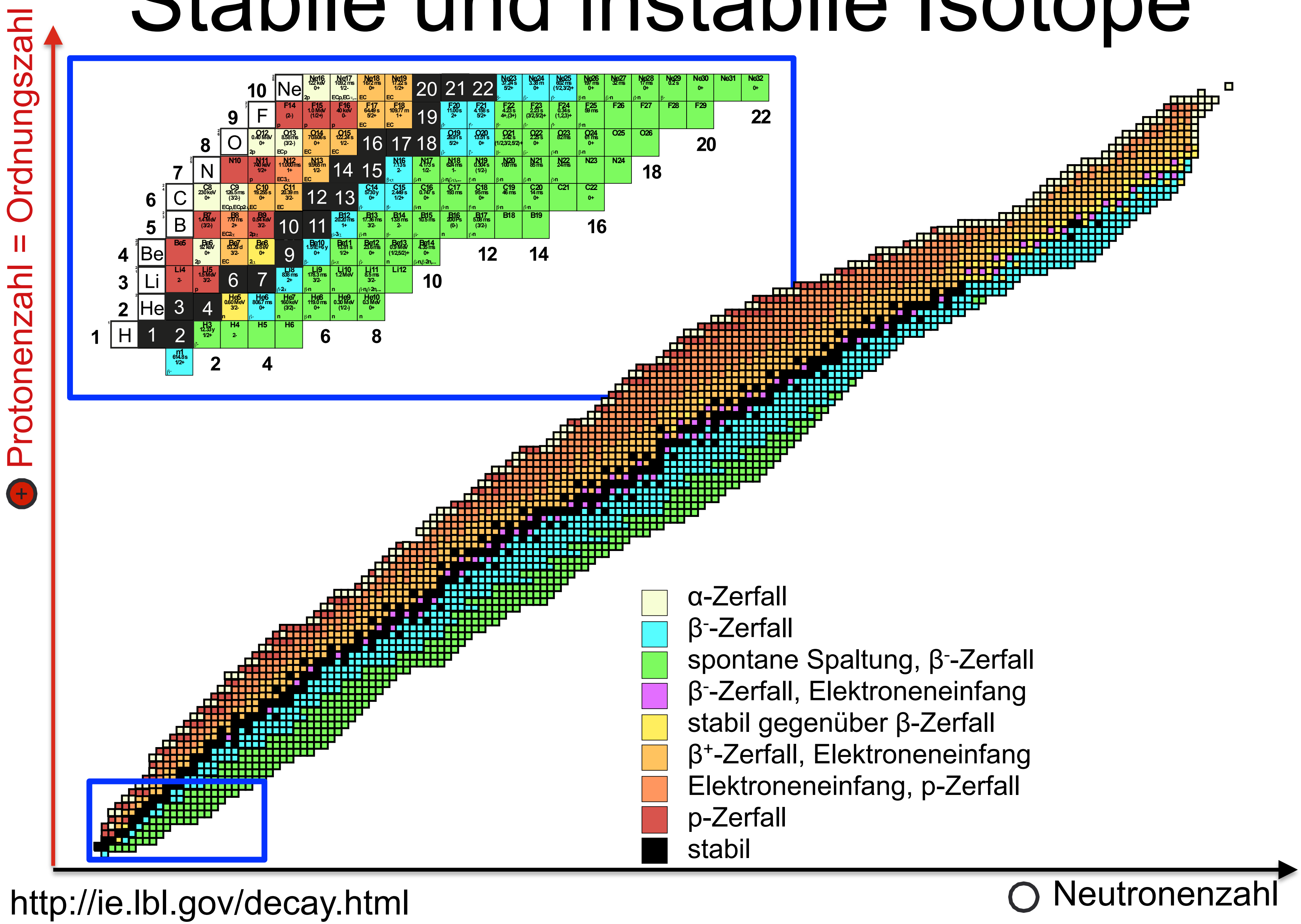
Elemente und Isotope

Periodensystem ordnet nach Ordnungszahl



http://ie.lbl.gov/decay.html

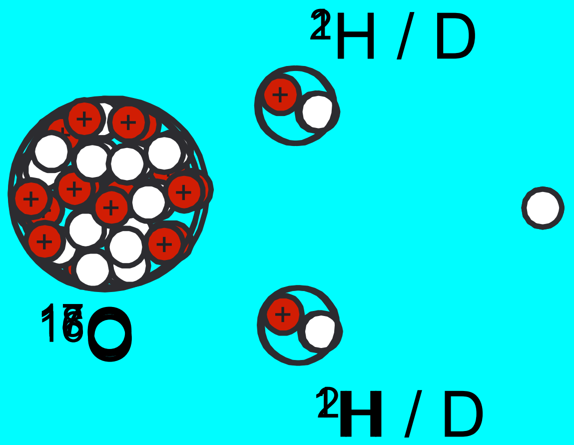
Stabile und instabile Isotope



http://ie.lbl.gov/decay.html

Stabile Isomere im Meerwasser

Vienna Standard MeanOceanWater (VSMOW)

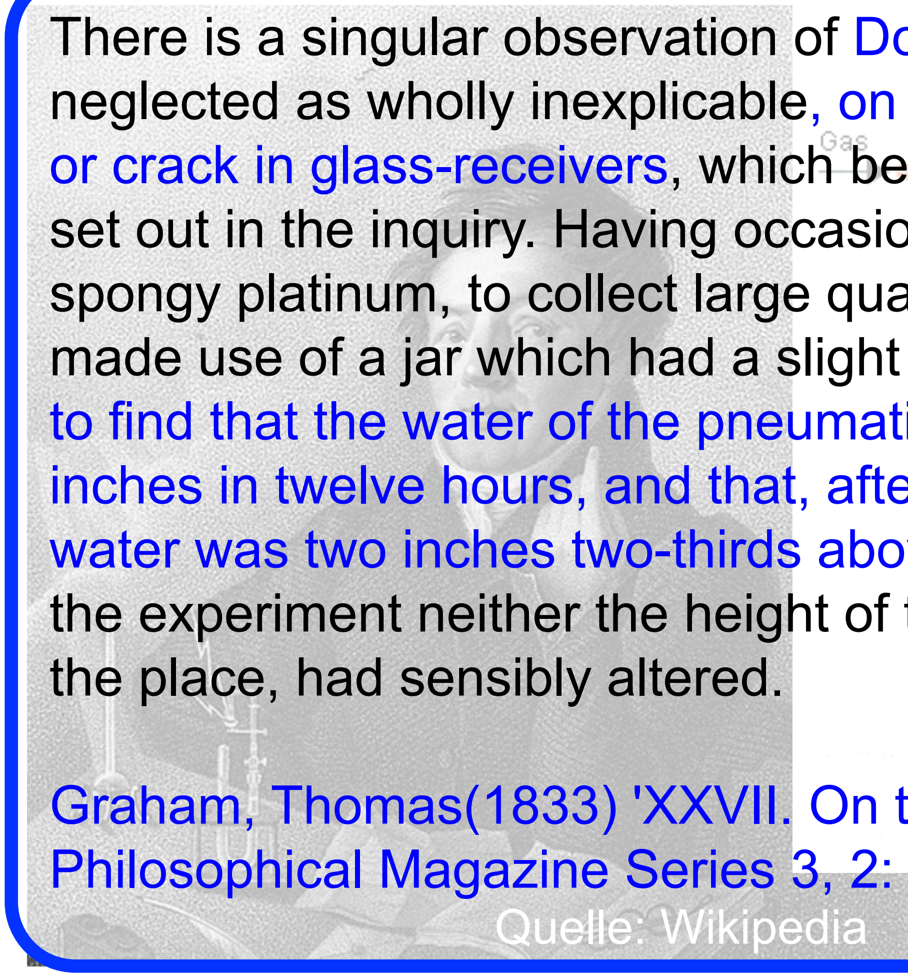


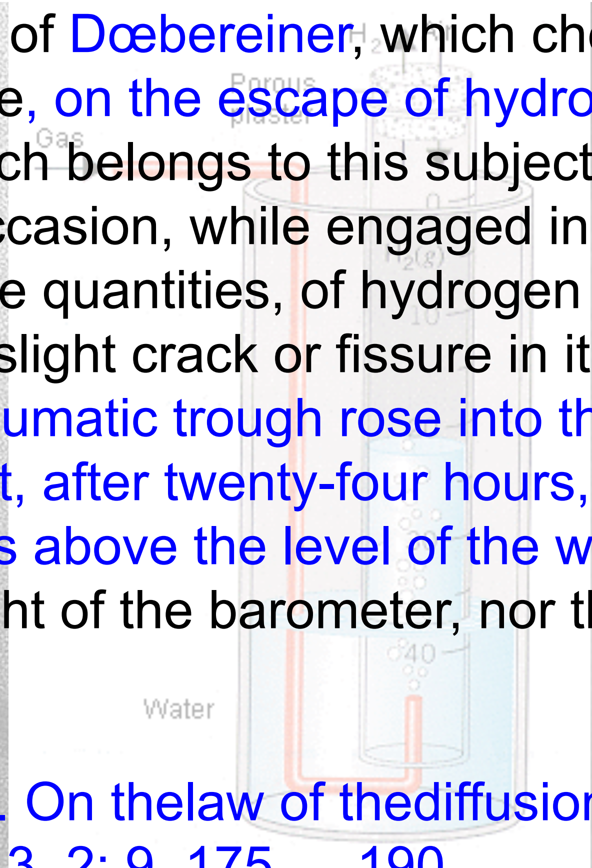
1000 ‰

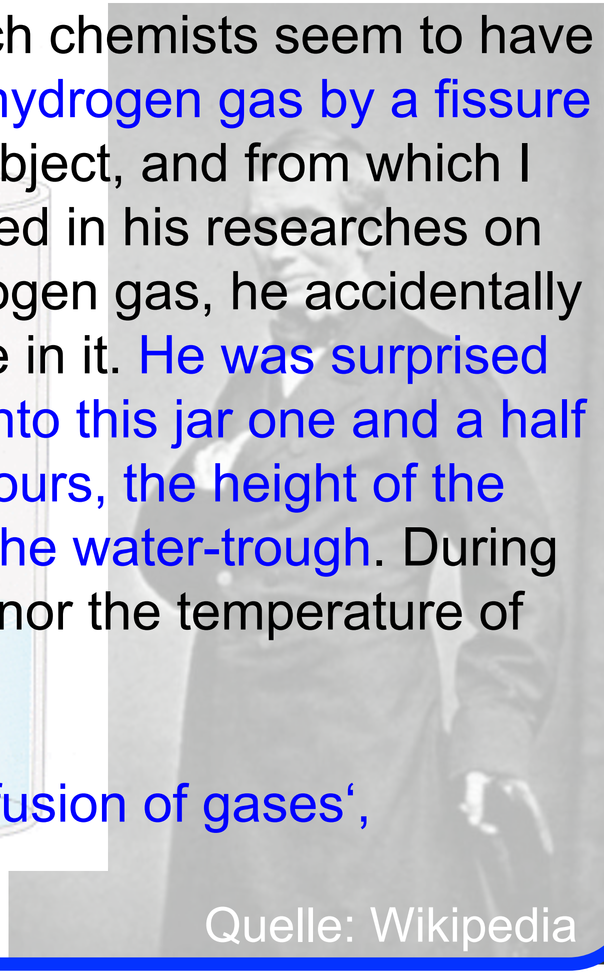
^{16}O	997,6 ‰
^{17}O	0,4 ‰
^{18}O	2,0 ‰
^{1}H	999,8 ‰
^{2}H/D	0,2 ‰

$H_2{}^{16}O$	997,3 ‰
$HD^{16}O$	0,2 ‰
$D_2{}^{16}O$	< 10^{-4}‰
$H_2{}^{17}O$	0,4 ‰
$HD^{17}O$	< 10^{-4}‰
$D_2{}^{17}O$	< 10^{-8}‰
$H_2{}^{18}O$	2,0 ‰
$HD^{18}O$	< 10^{-3}‰
$D_2{}^{18}O$	< 10^{-7}‰

Fraktionierung von Gasen – Das Grahamsche Effusionsgesetz







There is a singular observation of Dœbereiner, which chemists seem to have neglected as wholly inexplicable, on the escape of hydrogen gas by a fissure or crack in glass-receivers, which belongs to this subject, and from which I set out in the inquiry. Having occasion, while engaged in his researches on spongy platinum, to collect large quantities, of hydrogen gas, he accidentally made use of a jar which had a slight crack or fissure in it. He was surprised to find that the water of the pneumatic trough rose into this jar one and a half inches in twelve hours, and that, after twenty-four hours, the height of the water was two inches two-thirds above the level of the water-trough. During the experiment neither the height of the barometer, nor the temperature of the place, had sensibly altered.

Graham, Thomas(1833) 'XXVII. On thelaw of thediffusion of gases‘, Philosophical Magazine Series 3, 2: 9, 175 — 190

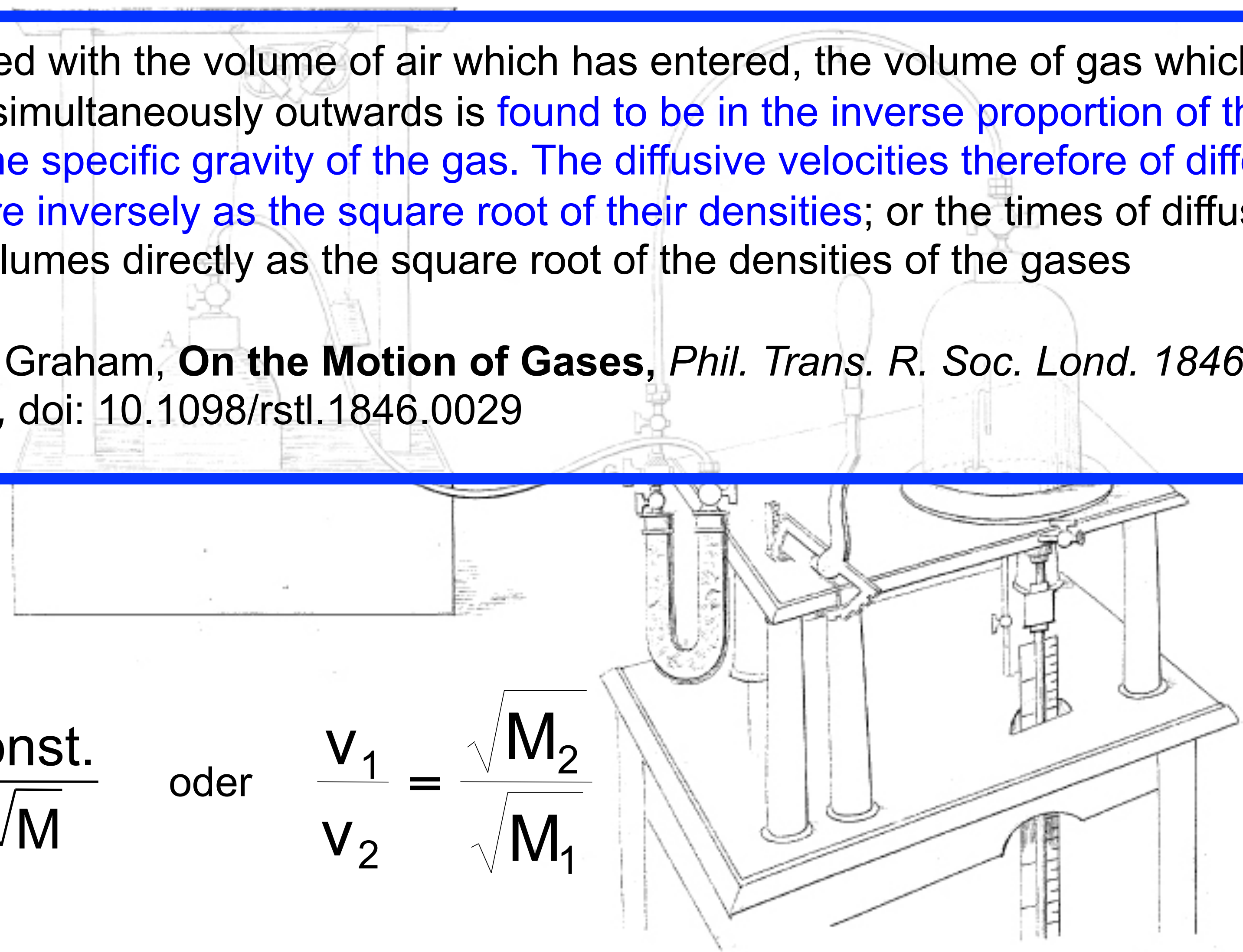
Quelle: Wikipedia

Quelle: Wikipedia

Johann Wolfgang Döbereiner
13. 12.1780 – 24.03.1849

Thomas Graham
21.12.1805 – 11.09.1869

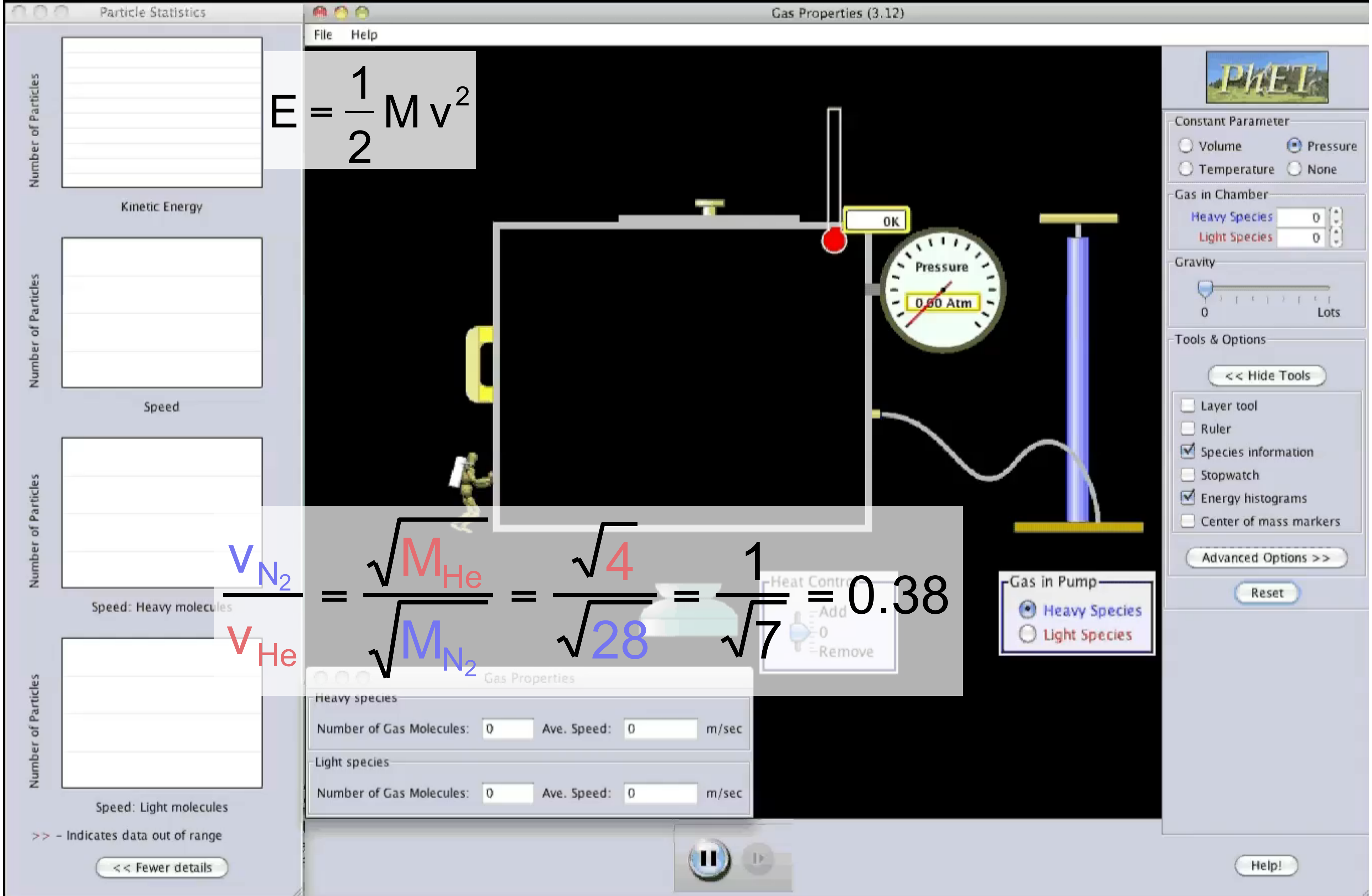
Fraktionierung durch Diffusion – Das Grahamsche Effusionsgesetz



Compared with the volume of air which has entered, the volume of gas which has passed simultaneously outwards is found to be in the inverse proportion of the square root of the specific gravity of the gas. The diffusive velocities therefore of different gases are inversely as the square root of their densities; or the times of diffusion of equal volumes directly as the square root of the densities of the gases

Thomas Graham, **On the Motion of Gases,** *Phil. Trans. R. Soc. Lond. 1846* ***136, 573-631,*** doi: 10.1098/rstl.1846.0029

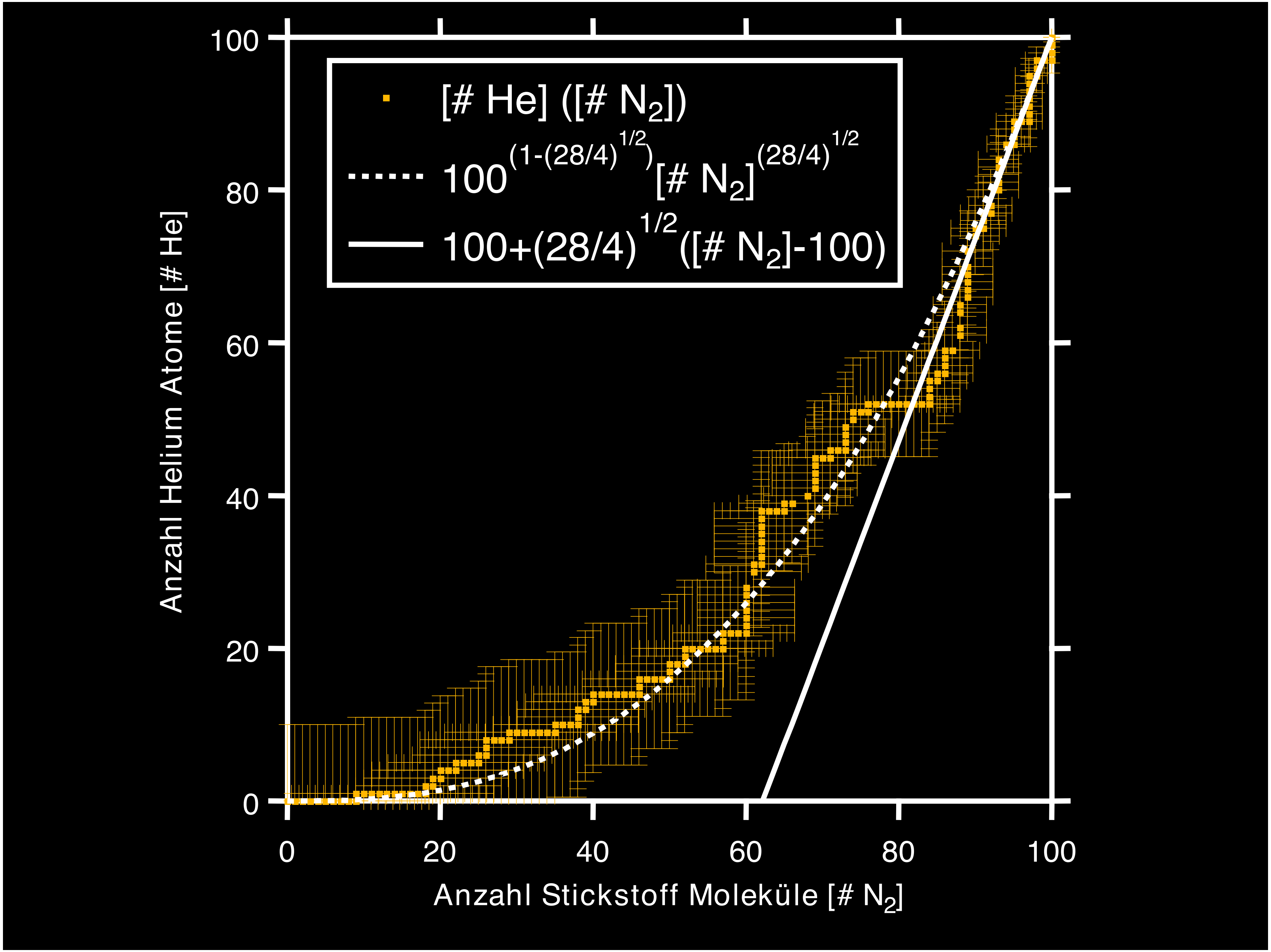
$$v = \frac{\text{const.}}{\sqrt{M}} \quad \text{oder} \quad \frac{v_1}{v_2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$$



$$E = \frac{1}{2} M v^2$$

$$\frac{v_{N_2}}{v_{He}} = \frac{\sqrt{M_{He}}}{\sqrt{M_{N_2}}} = \frac{\sqrt{4}}{\sqrt{28}} = \frac{1}{\sqrt{7}} = 0.38$$

http://phet.colorado.edu/en/simulation/gas-properties


[# He] ([# N2])
100^(1-(28/4)^1/2)[# N2]^(28/4)^1/2
100+(28/4)^1/2([# N2]-100)
Anzahl Helium Atome [# He]
Anzahl Stickstoff Moleküle [# N2]
0
20
40
60
80
100
0
20
40
60
80
100

Das Grahamsche Effusionsgesetz

- Fraktionierung durch molekulare Diffusion

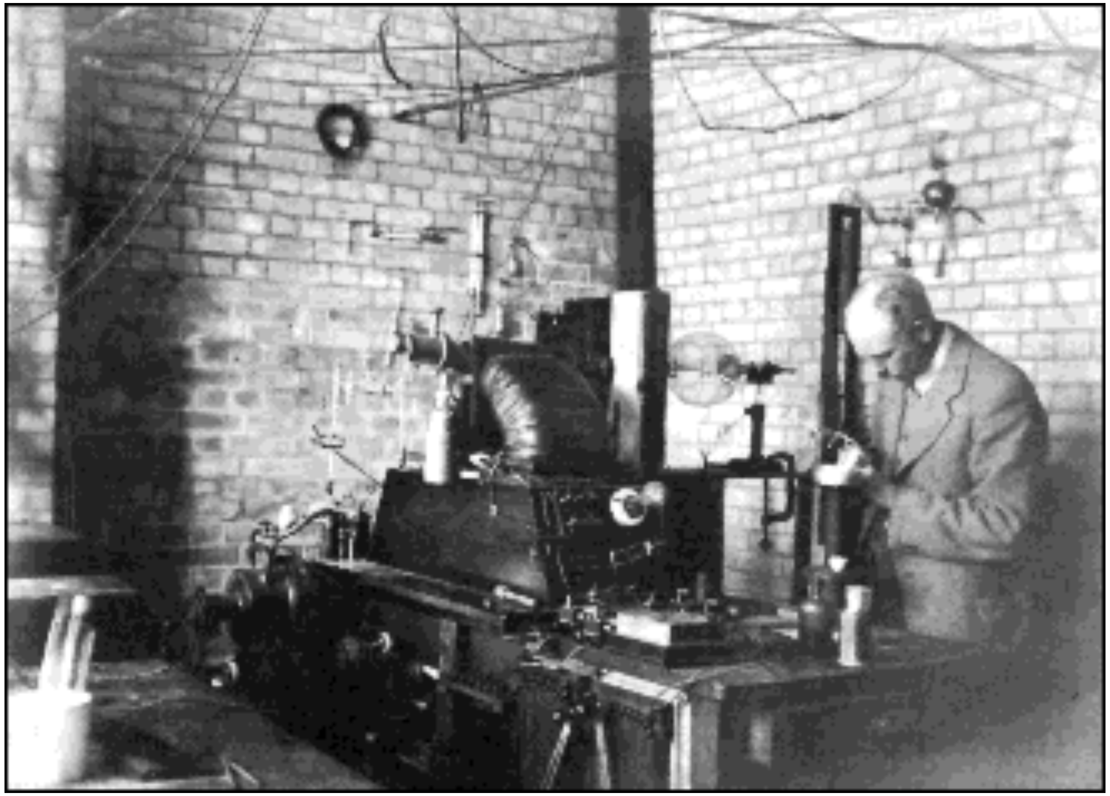
$$\frac{v_{H_2{}^{16}O}}{v_{H_2{}^{18}O}} = \frac{\sqrt{M_{H_2{}^{18}O}}}{\sqrt{M_{H_2{}^{16}O}}} = \frac{\sqrt{20}}{\sqrt{18}} = 1{,}05$$

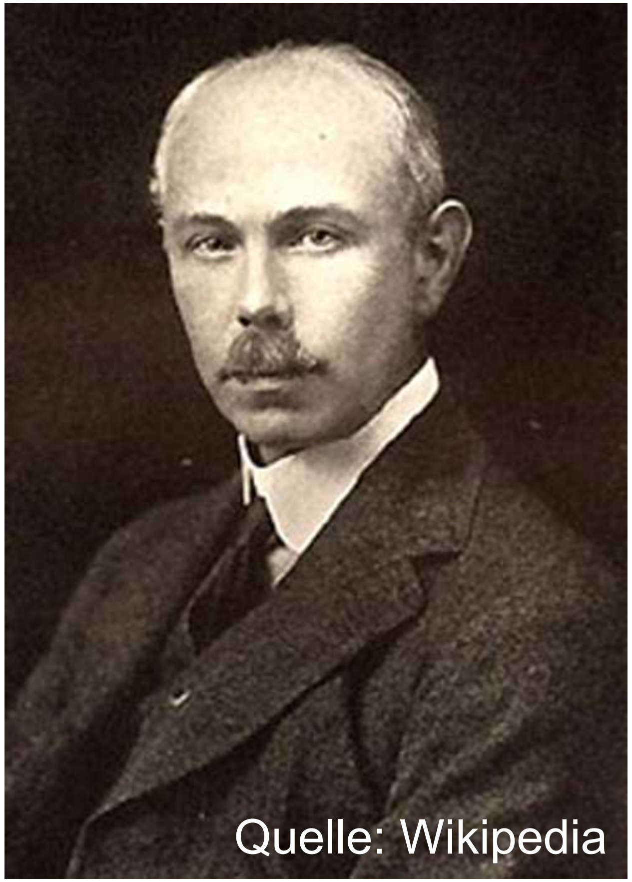
$$\frac{v_{H_2{}^{16}O}}{v_{HD^{16}O}} = \frac{\sqrt{M_{HD^{16}O}}}{\sqrt{M_{H_2{}^{16}O}}} = \frac{\sqrt{19}}{\sqrt{18}} = 1{,}03$$

$$\frac{v_{H_2{}^{16}O}}{v_{H_2{}^{17}O}} = \frac{\sqrt{M_{H_2{}^{17}O}}}{\sqrt{M_{H_2{}^{16}O}}} = \frac{\sqrt{19}}{\sqrt{18}} = 1{,}03$$

- neben Gleichgewichts- und kinetischer Fraktionierung
- aufgrund höherer Bindungsenergie für die schwereren Isomere

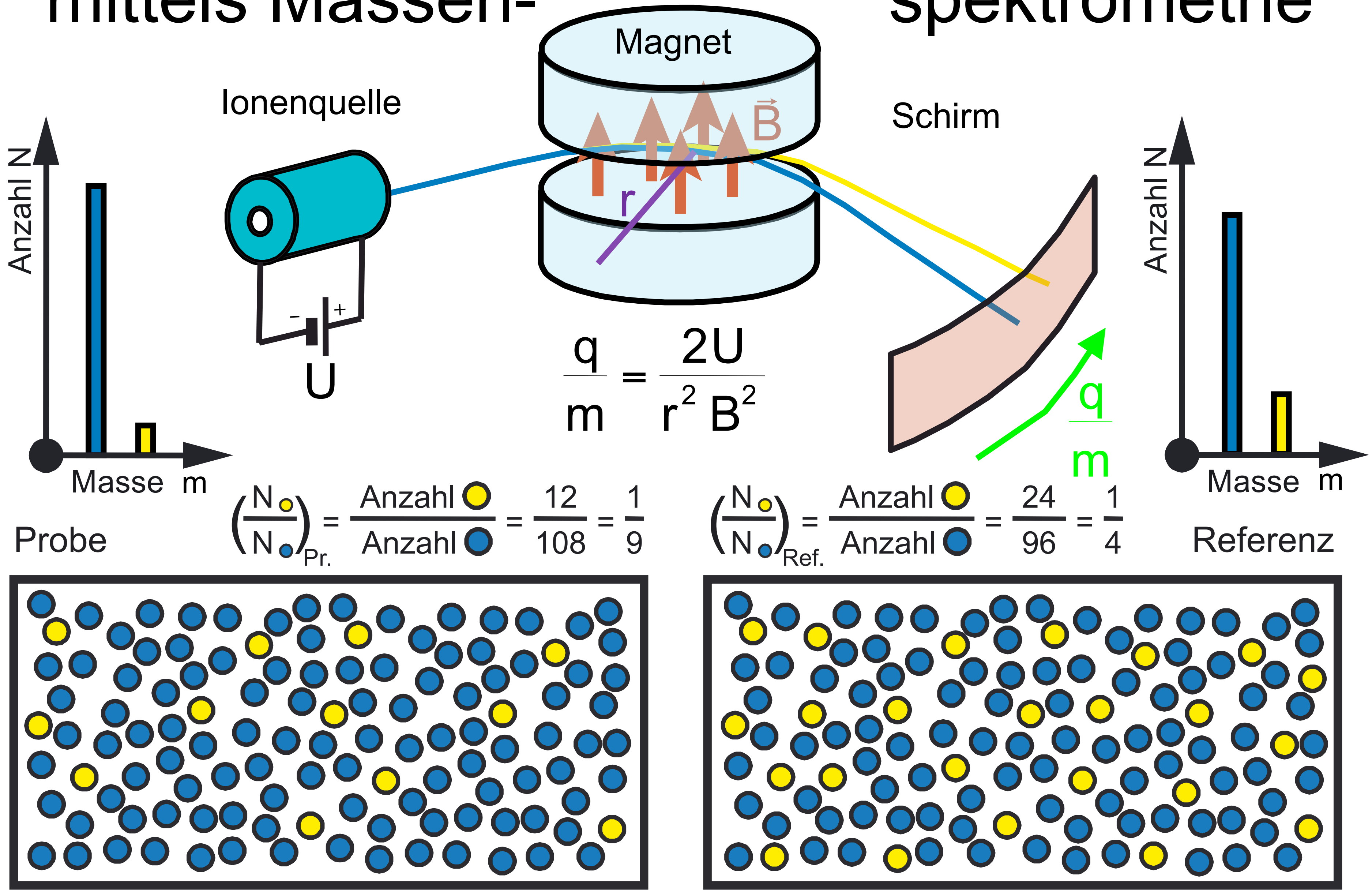
Massenspektrometer





Francis William Aston
(1.9.1877 − 20.11.1945)

Bestimmung relativer Isotopenverhältnisse mittels Massen- spektrometrie



Bestimmung relativer Isotopen-verhältnisse mittels Massenspektrometrie

$$\delta = \frac{\left(\frac{N_{\color{yellow}\bullet}}{N_{\color{blue}\bullet}}\right)_{Pr.} - \left(\frac{N_{\color{yellow}\bullet}}{N_{\color{blue}\bullet}}\right)_{Ref.}}{\left(\frac{N_{\color{yellow}\bullet}}{N_{\color{blue}\bullet}}\right)_{Ref.}} = \frac{\left(\frac{N_{\color{yellow}\bullet}}{N_{\color{blue}\bullet}}\right)_{Pr.}}{\left(\frac{N_{\color{yellow}\bullet}}{N_{\color{blue}\bullet}}\right)_{Ref.}} - 1 = -\frac{5}{9} = -556\ ‰$$

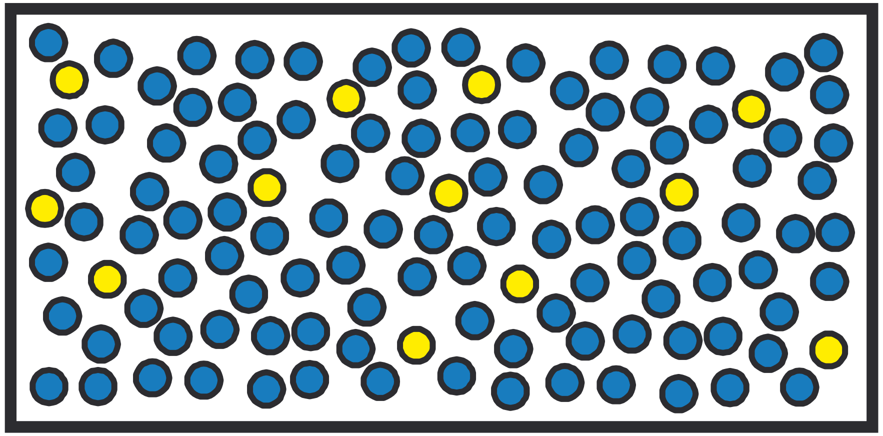
Im Wasser untersucht man meist $\delta^{18}O$ und δD

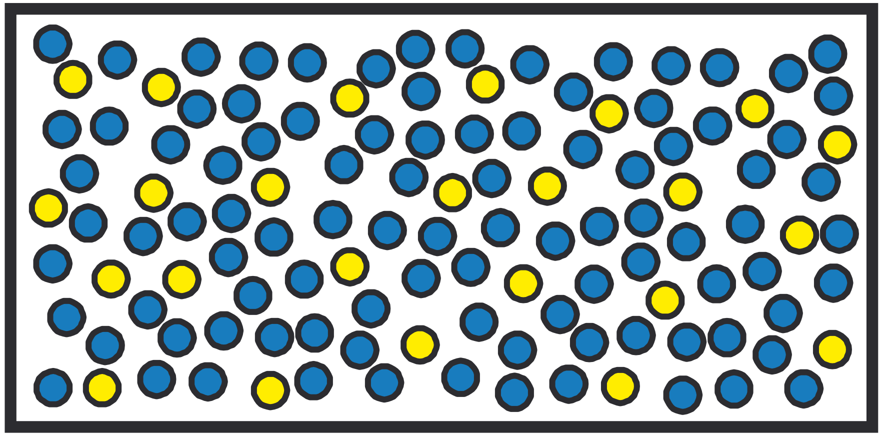
Probe

$$\left(\frac{N_{\color{yellow}\bullet}}{N_{\color{blue}\bullet}}\right)_{Pr.} = \frac{\text{Anzahl}\ {\color{yellow}\bullet}}{\text{Anzahl}\ {\color{blue}\bullet}} = \frac{12}{108} = \frac{1}{9}$$

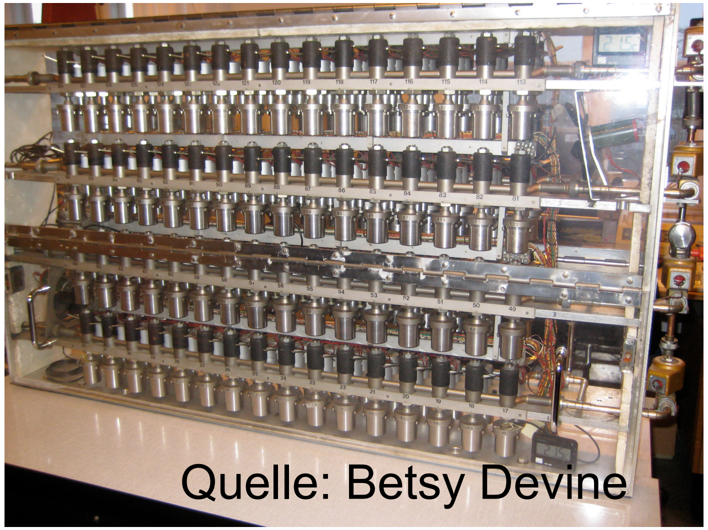
$$\left(\frac{N_{\color{yellow}\bullet}}{N_{\color{blue}\bullet}}\right)_{Ref.} = \frac{\text{Anzahl}\ {\color{yellow}\bullet}}{\text{Anzahl}\ {\color{blue}\bullet}} = \frac{24}{96} = \frac{1}{4}$$

Referenz



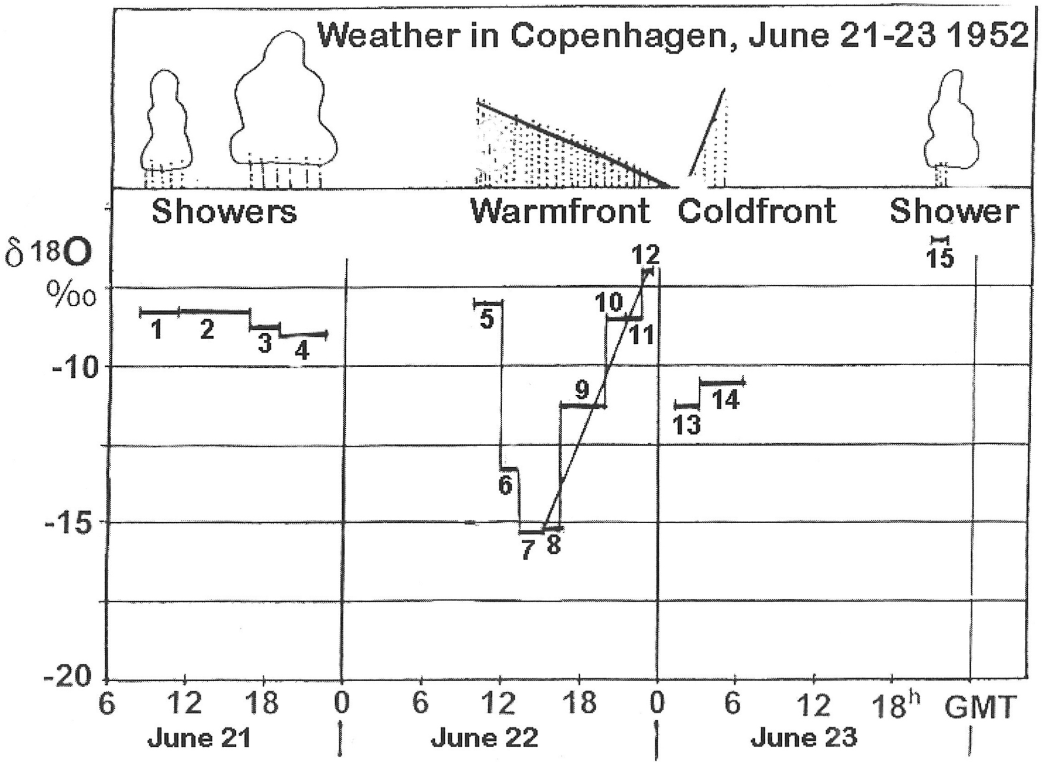


Probenvorbereitung



Grundlegende Arbeiten zur Isotopenfraktionierung

Ändert sich die isotopische Zusammensetzung des Wassers wegen unterschiedlicher Kinetik und Dampfdruck für $H_2{}^{18}O$ und $H_2{}^{16}O$ bei Verdunstungs- bzw. Kondensationsvorgängen?

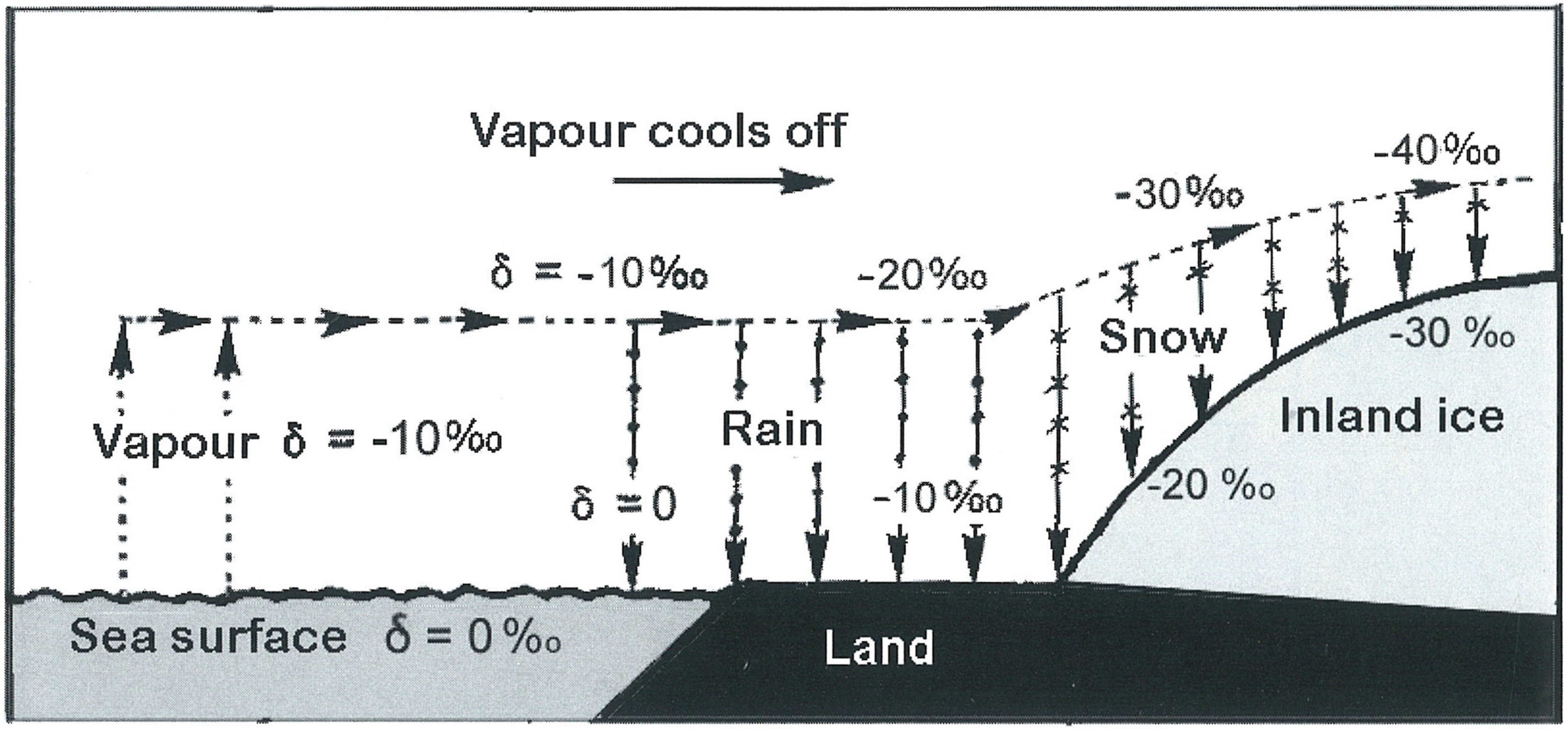


Ja !

Unter anderem in Abängigkeit von der Temperatur bei der Bildung des Niederschlags

Dansgaard, W., *The abundance of* ^{18}*O in atmospheric water and water vapour*. Tellus 5, 461–469, 1953.

Fraktionierung im Wasserkreislauf



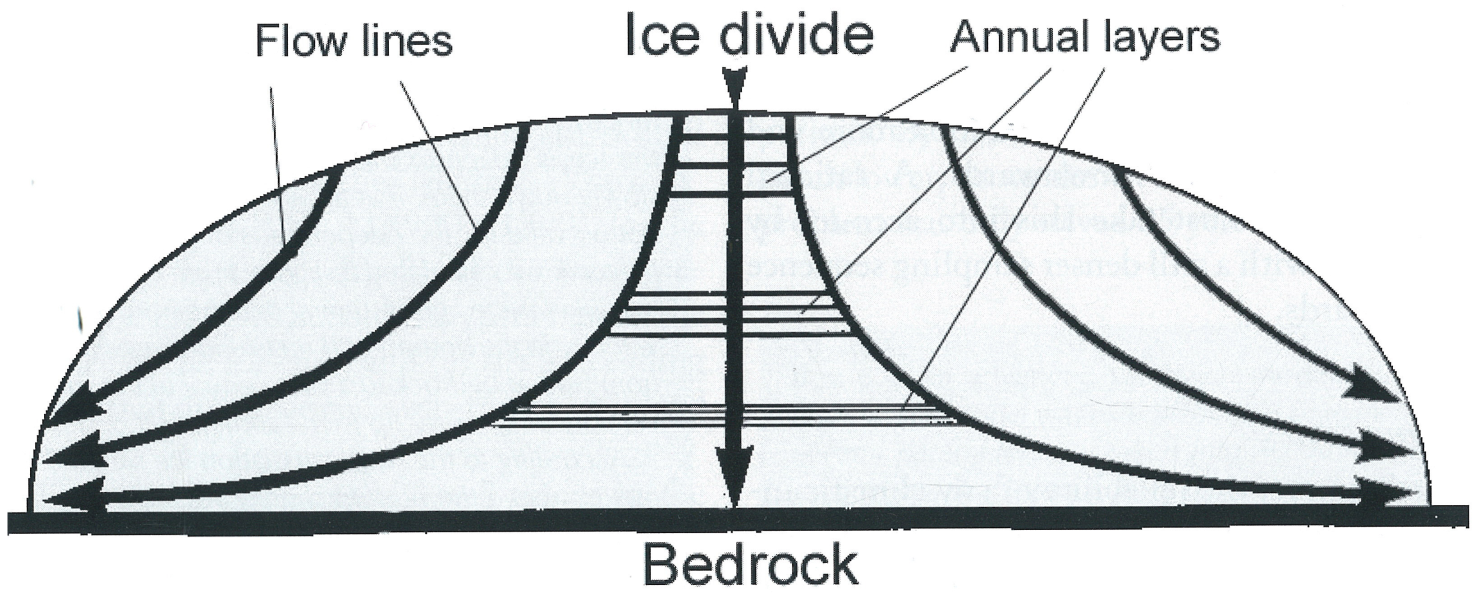
$$\delta = 0.695\ ‰/°C * T - 13.6\ ‰$$

$$T = 1.4\ °C/‰ * \delta + 19.6\ °C$$

Isotopenthermometer

Dansgaard, W., 1964

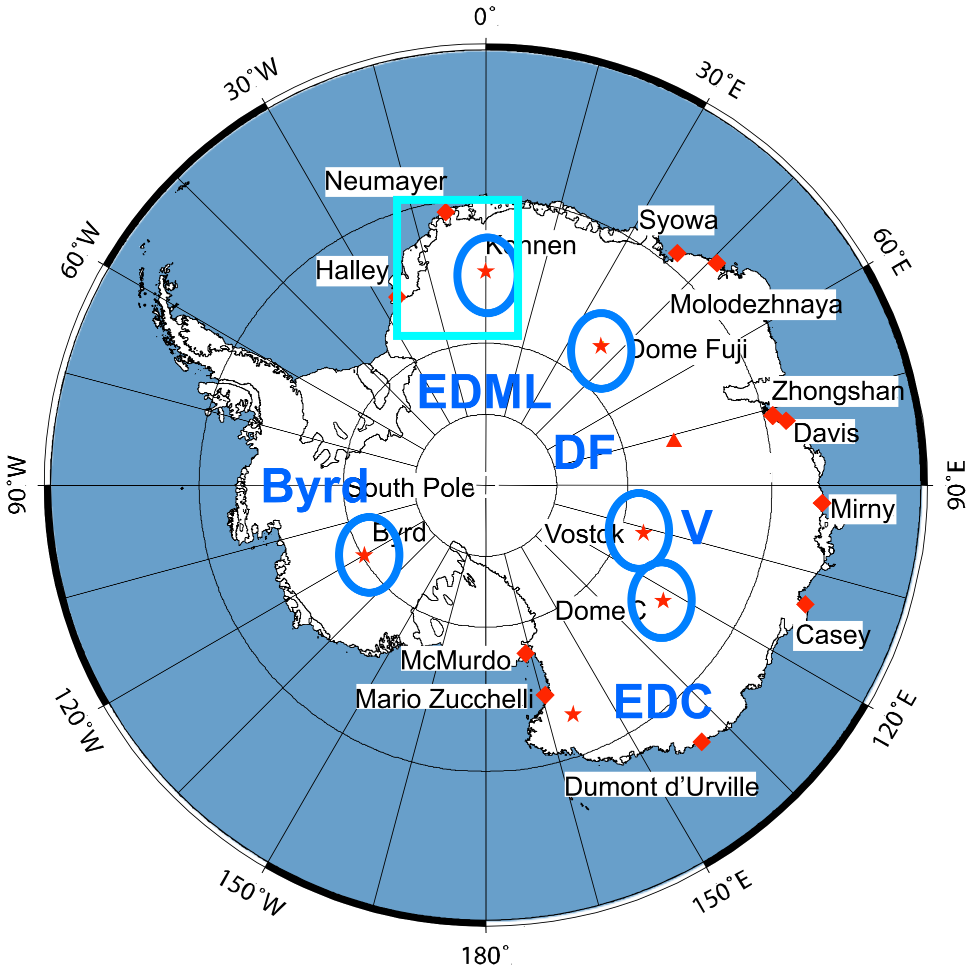
Eis ist Schnee von Gestern!



"In certain areas on the Greenland Ice Cap is a distinct layer formation caused by melting in the summer season. On the supposition that the character of the circulatory processes, in all essentials, have not varied over a long period of time, the above, in the opinion of this author, offers the possibility by measurements of the af (i.e. the amount of the heavy oxygen isotope) *in these layers of ice to determine climatic changes over a period of time of several hundred years of the past. ... An investigation will be undertaken as soon as the opportunity offers."*

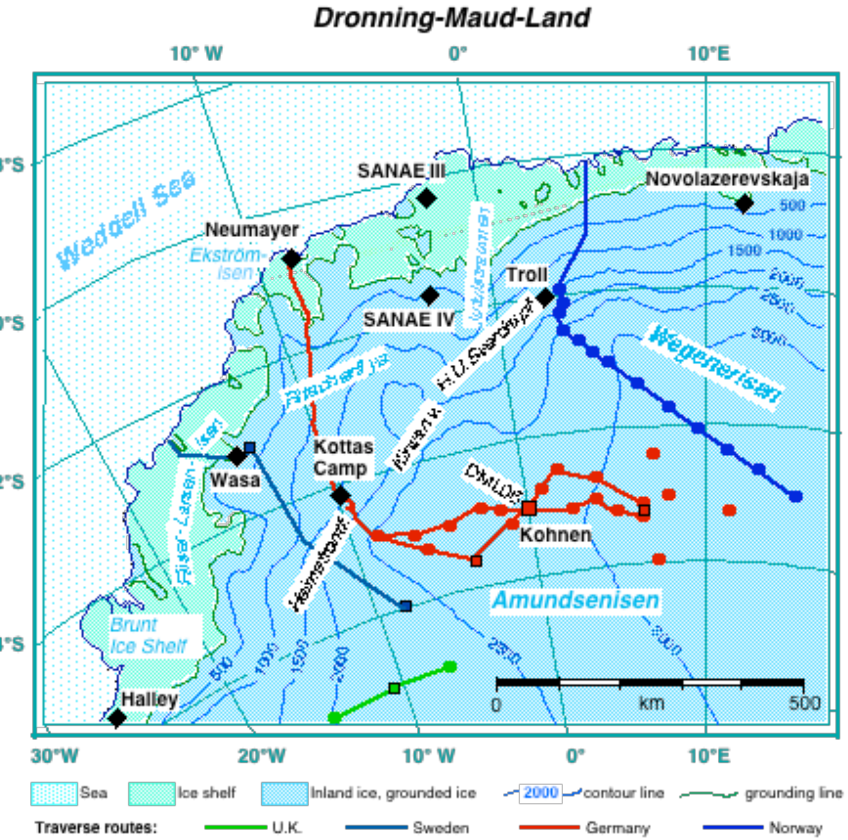
Dansgaard, W., *The O18-abundance in fresh water*, Geochim. et Cosmochim. Acta 6, 1954

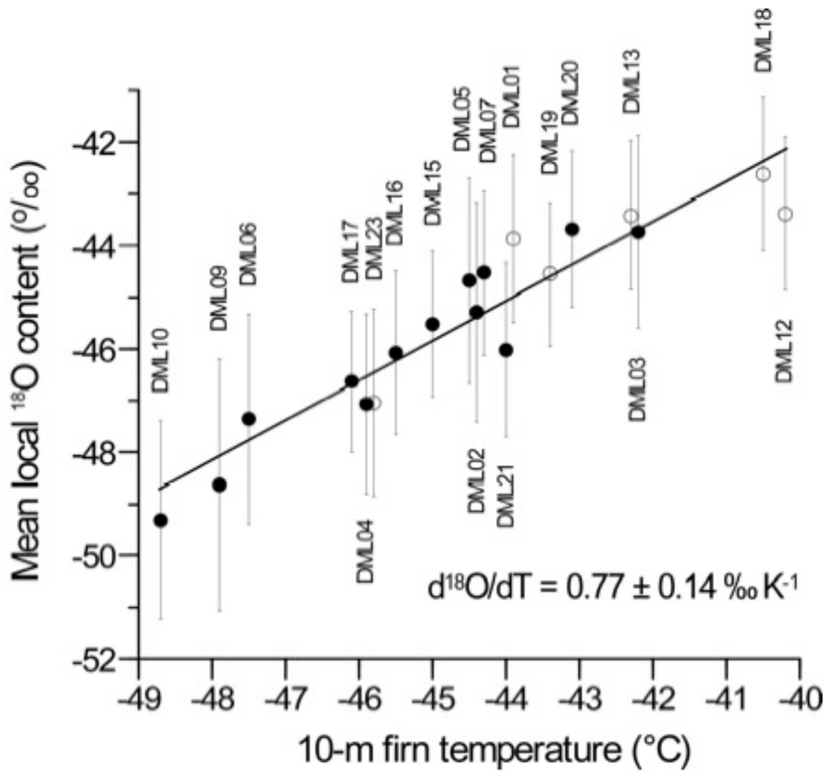
The European Project for Ice Coring in Antarctica



Antarctic Digital Database, Ekholm, 1998, map by Steinhage with modifications

Das Isotopenthermometer für EDML



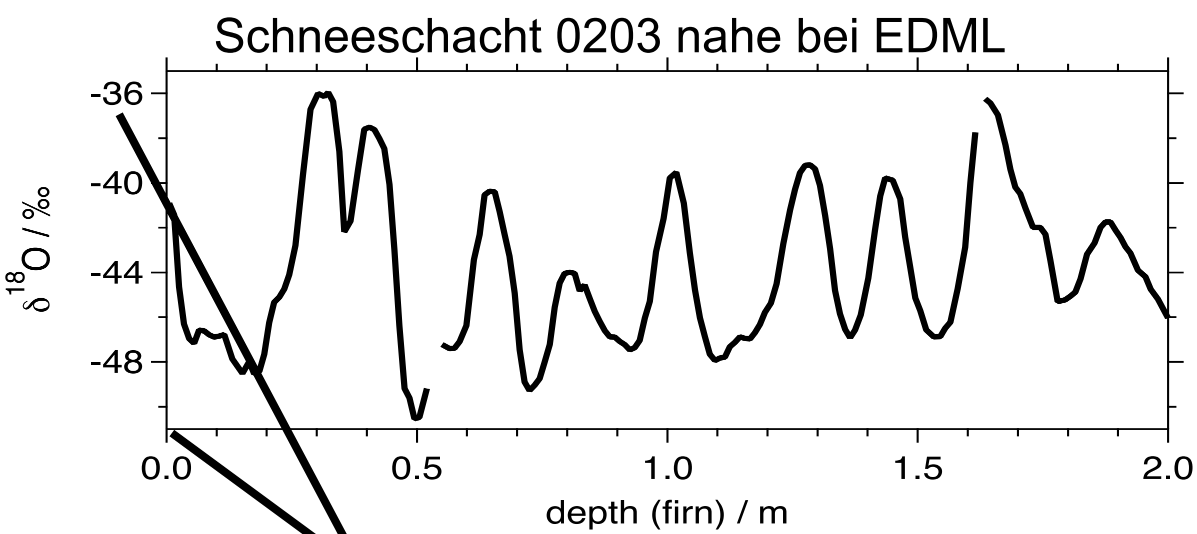


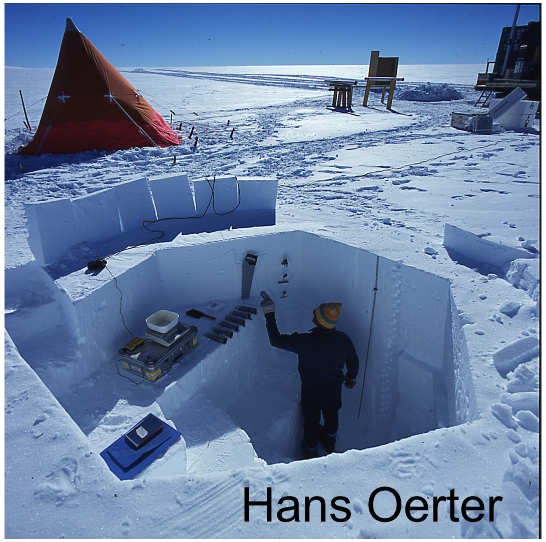
Antarktis (Dronning Maud Land)

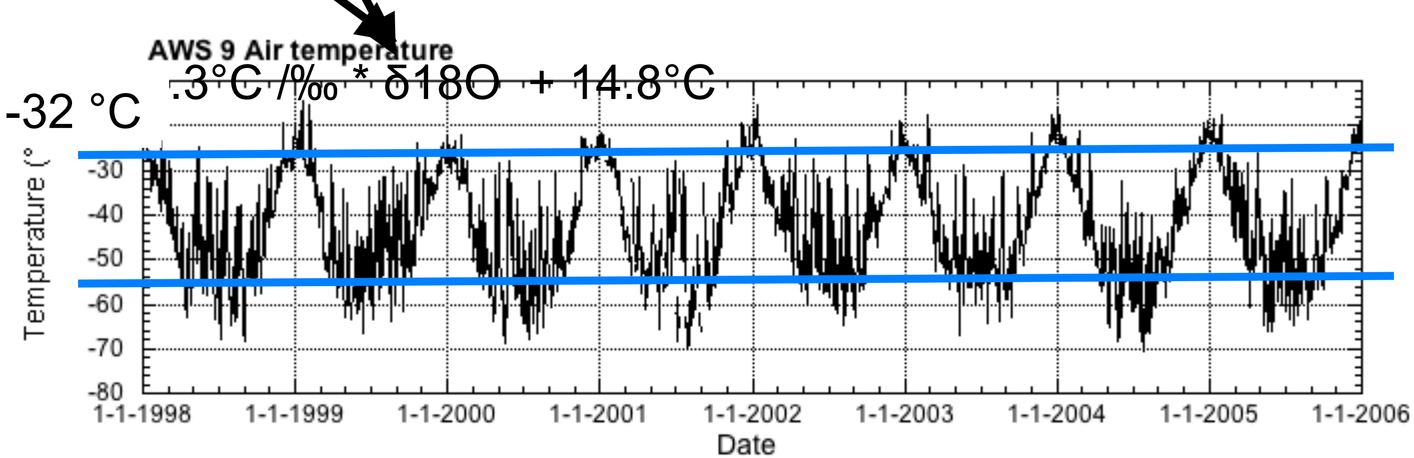
$T = 1.3°C /‰ * \delta^{18}O + 14.8°C$

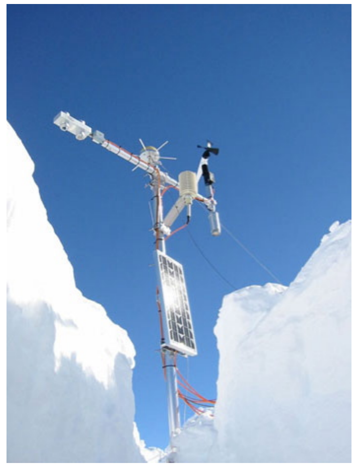
Graf, W., Oerter, H., Reinwarth, O., Stichler, W., Wilhelms, F., Miller, H., Mulvaney, R. *Stable-isotope records from Dronning Maud Land, Antarctica*, Annals of Glaciology, 35, 195–201, 2002.

Variationen im Jahresgang



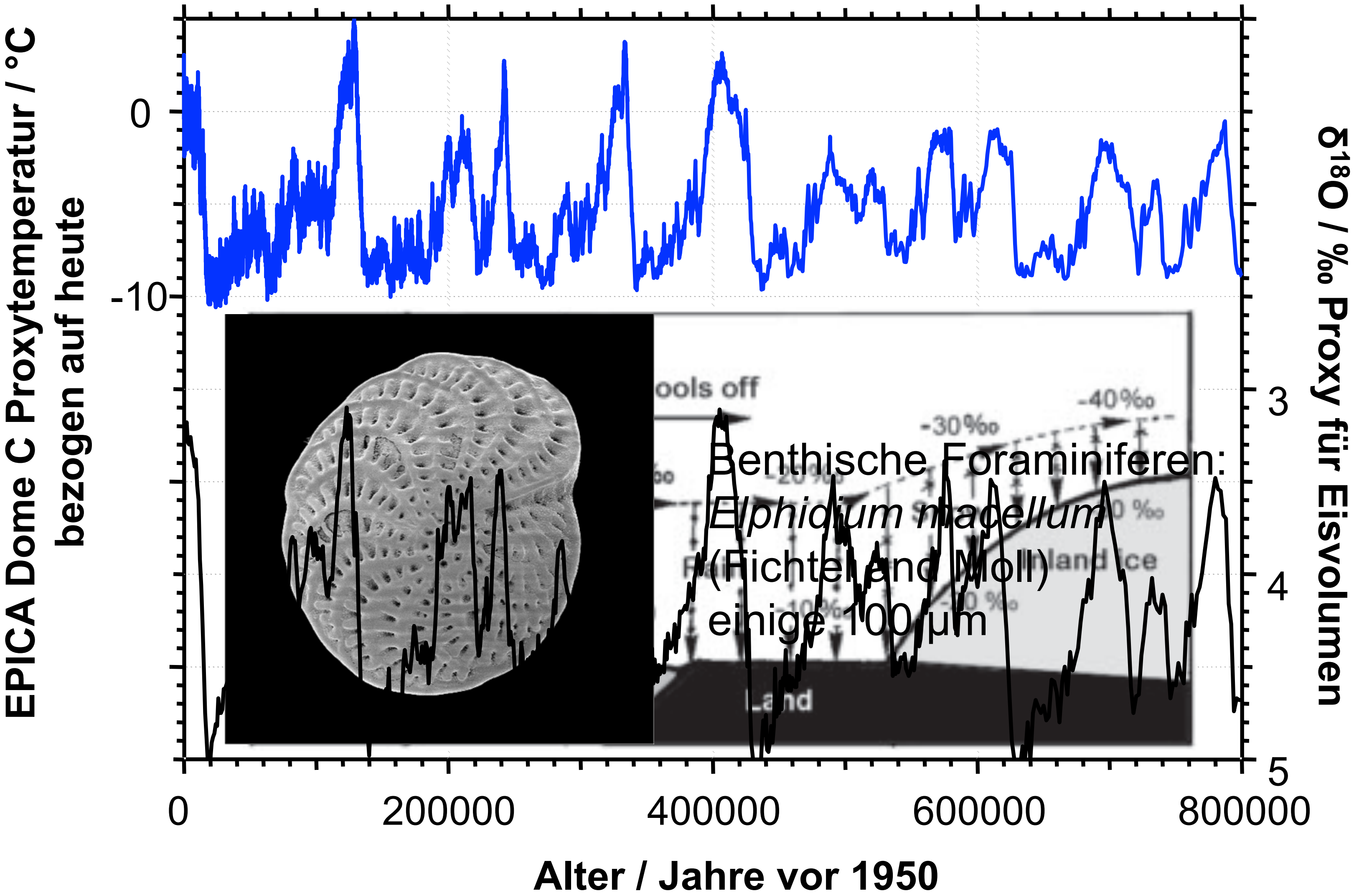






Oerter et al., Annals of Glaciology, 2004.
C. H. Reijmer et al., JGR, 2006: http://www.phys.uu.nl/~wwwimau/research/ice_climate/aws/antarctica_stations.html#aws9

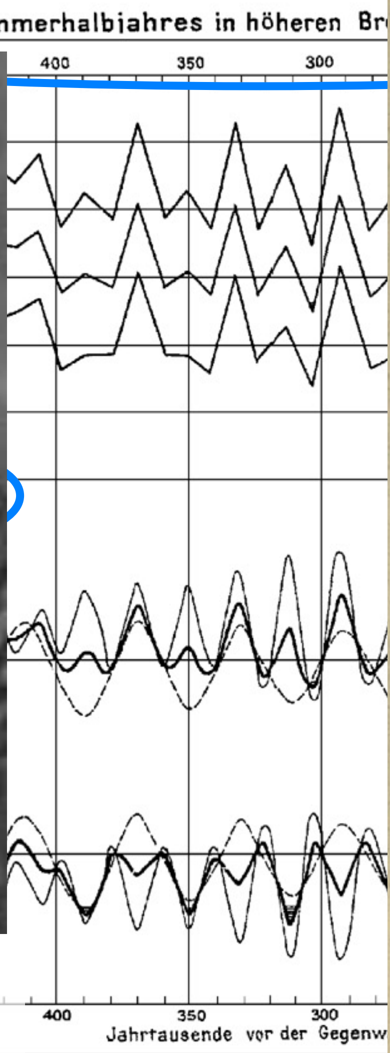
Längste Zeitreihe beobachteter Variationen

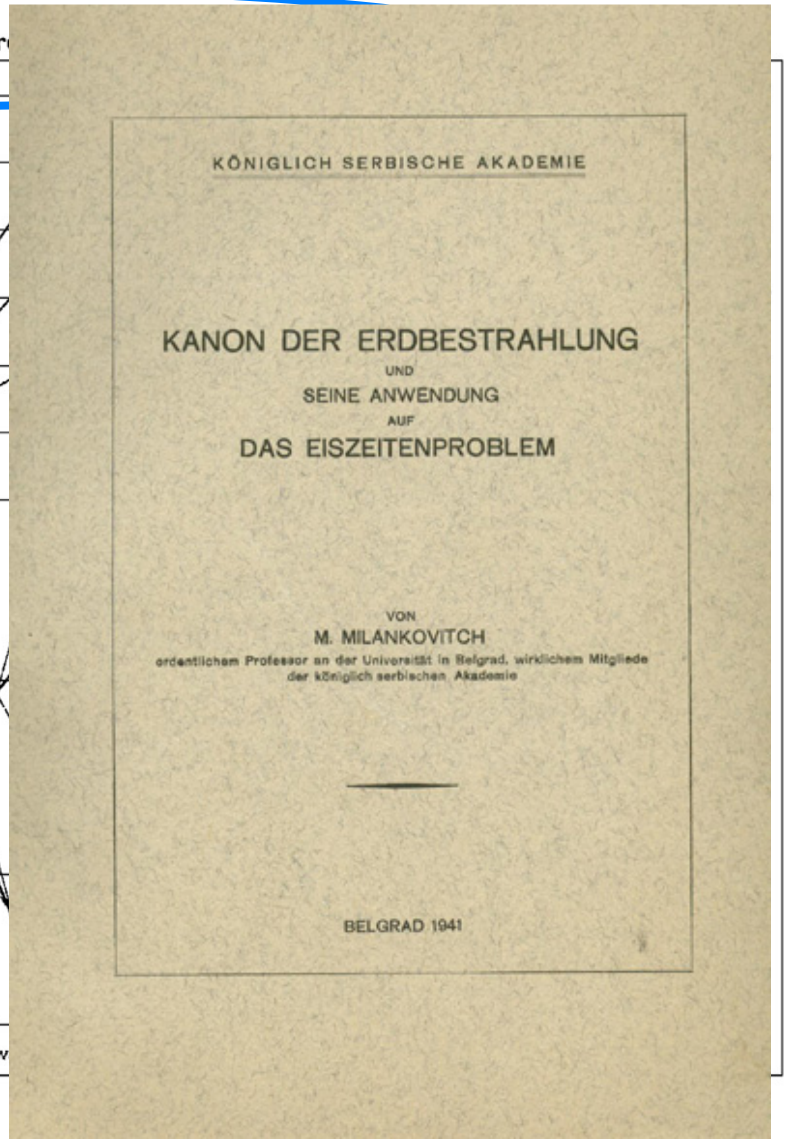


Jouzel et al., Science, 2007
Lisiecki & Raymo, Paleoceanography, 2005
http://www.ucl.ac.uk/GeolSci/micropal/

Milanković Theorie

Milutin Milanković
kyrill. Милутин Миланковић
28.5.1879 – 12.12.1958





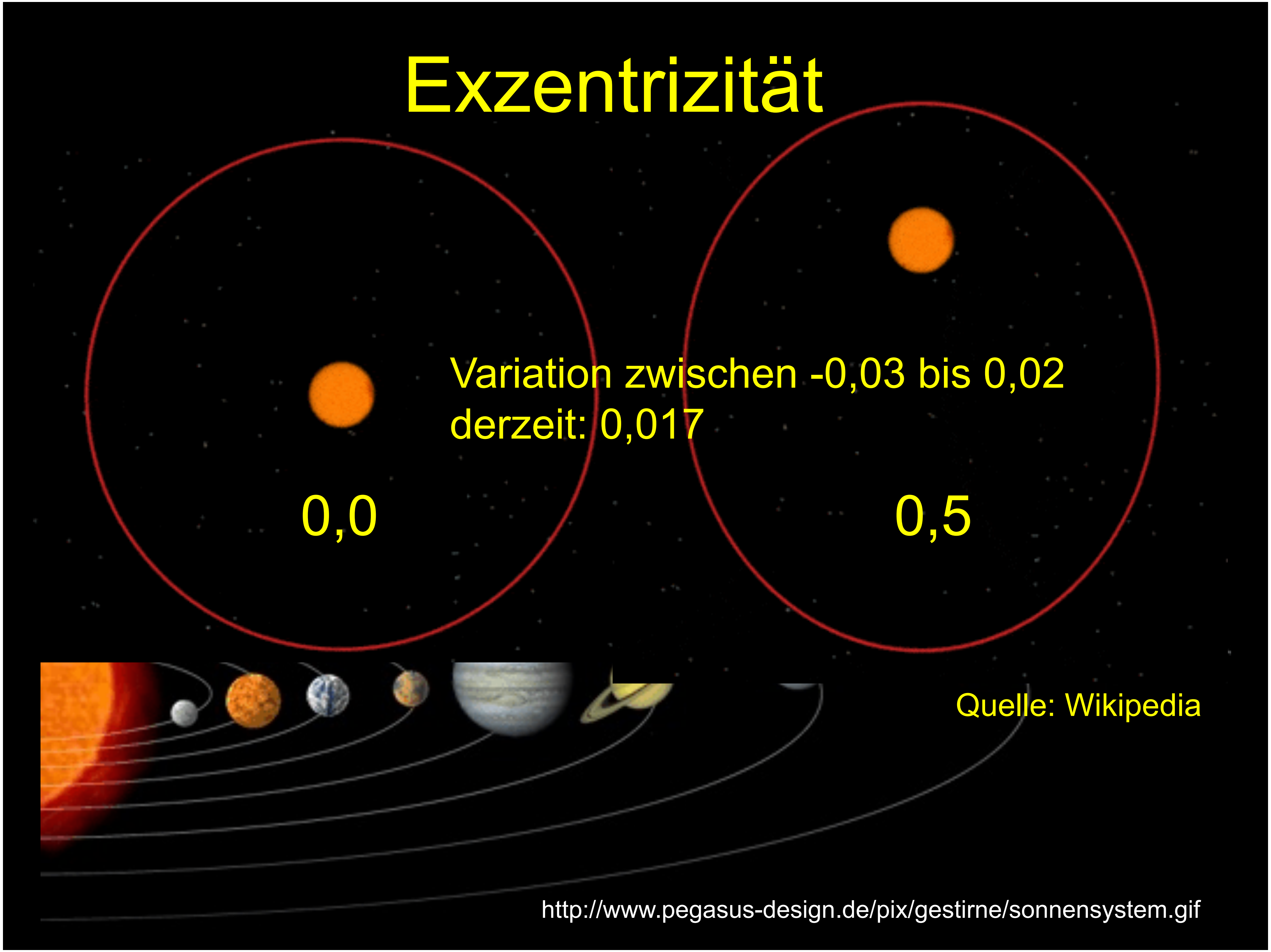
KÖNIGLICH SERBISCHE AKADEMIE

KANON DER ERDBESTRAHLUNG
UND
SEINE ANWENDUNG
AUF
DAS EISZEITENPROBLEM

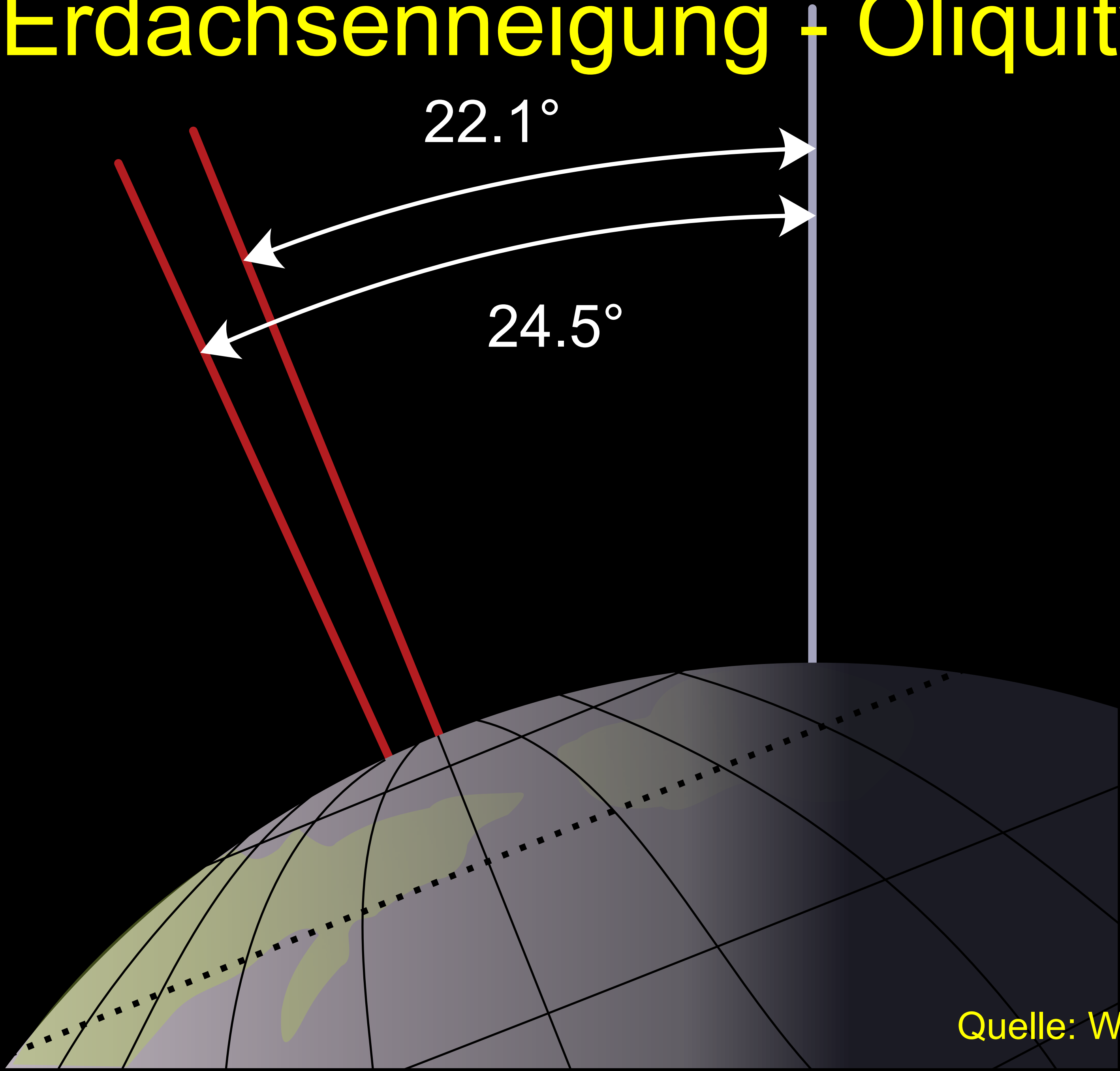
VON
M. MILANKOVITCH
ordentlichem Professor an der Universität in Belgrad, wirklichem Mitgliede der königlich serbischen Akademie

BELGRAD 1941

aus Köppen, W., Wegener, A.: Die Klimate der geologischen Vorzeit. 256 S.- Berlin: Borntraeger, 1924

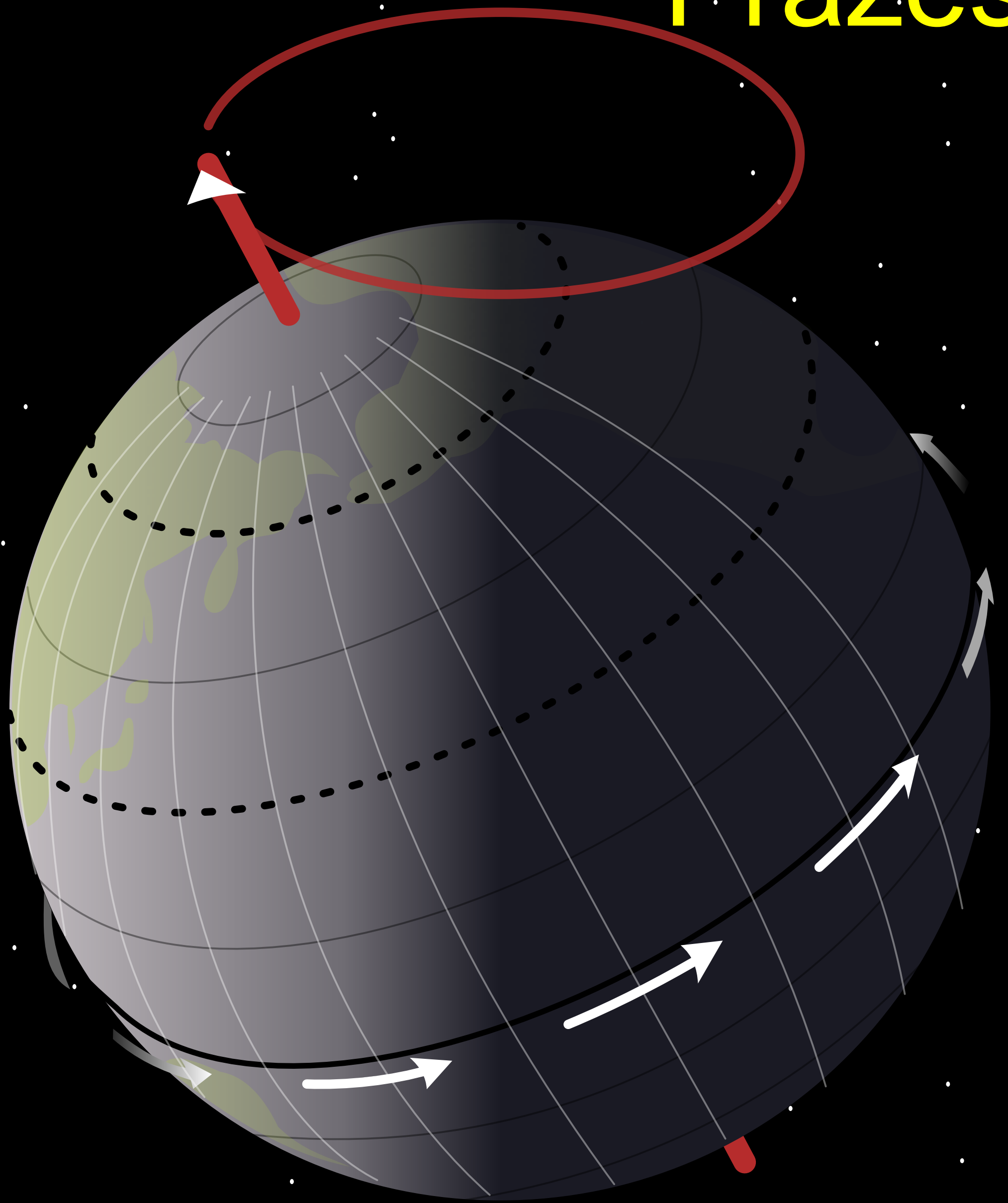

Exzentrizität
Variation zwischen -0,03 bis 0,02
derzeit: 0,017
0,0
0,5
Quelle: Wikipedia
http://www.pegasus-design.de/pix/gestirne/sonnensystem.gif

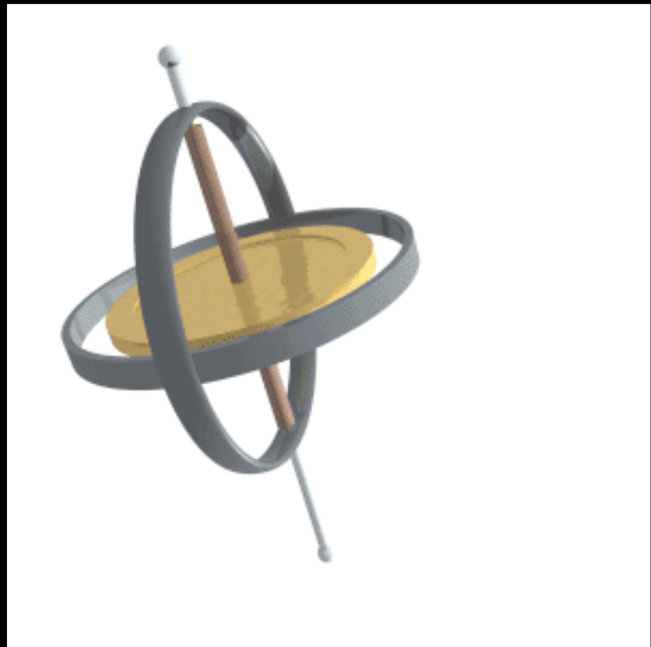
Erdachsenneigung - Oliquity



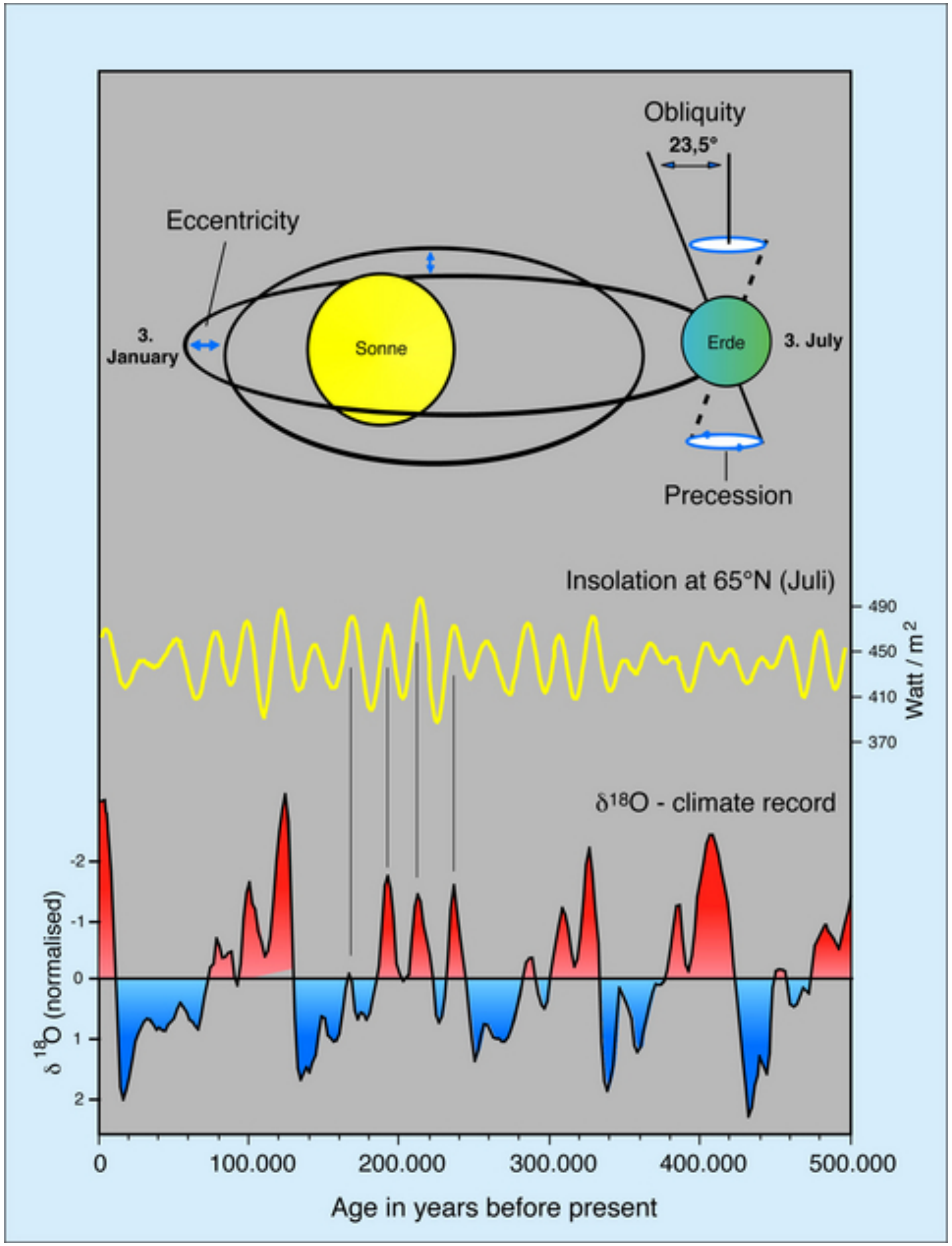
Quelle: Wikipedia

Präzession





Quelle: Wikipedia



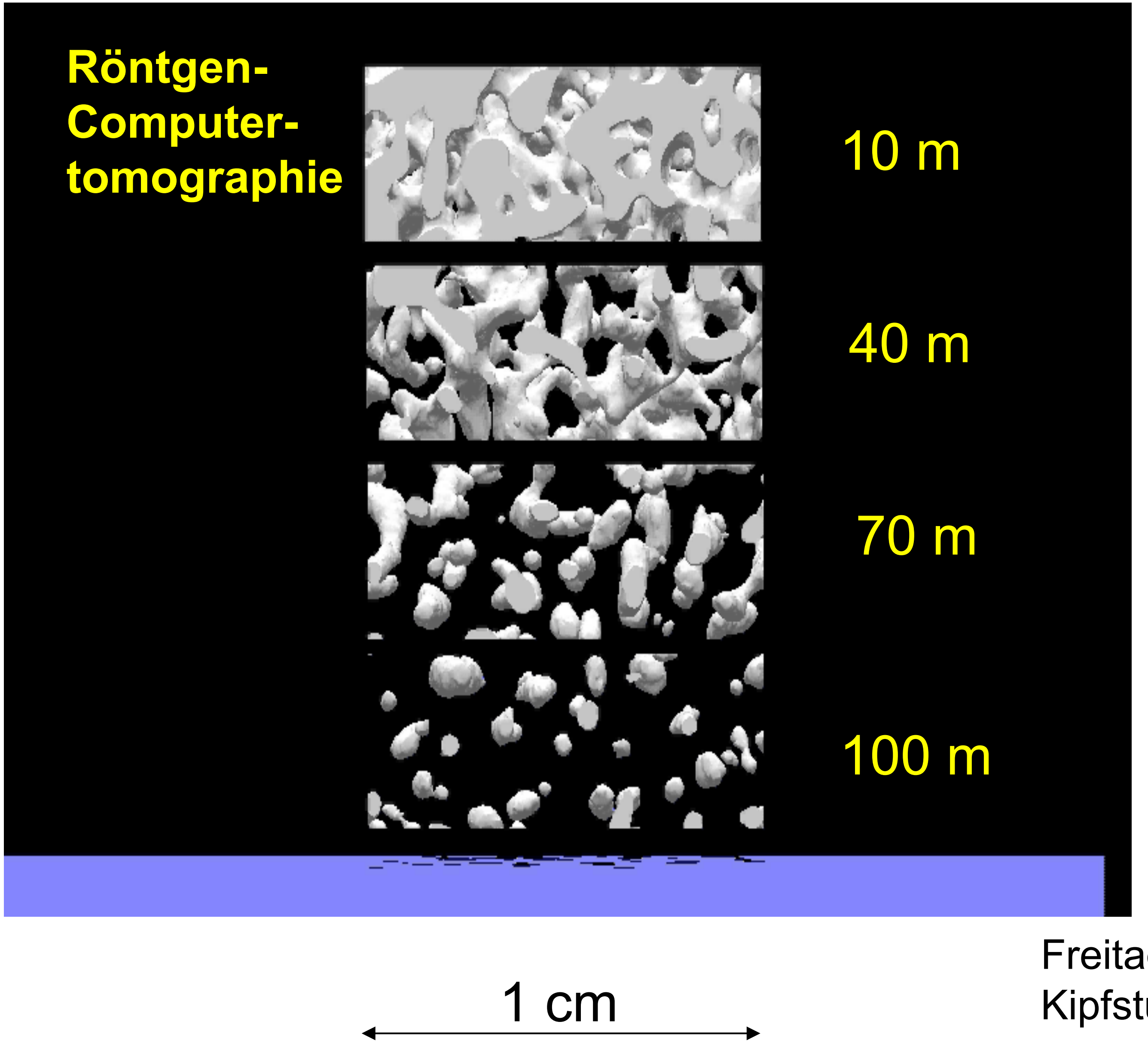
Veränderliche Einstrahlung

- Exzentrizität: Einfluß von anderen Planeten (Jupiter, Saturn), kreis- / ellipsenförmige Gestalt Zyklus 413000 und 100000 Jahre
- Obliquität: Erdachsenneigung variiert zwischen 22.2° and 24.5° Zyklus 41000 Jahre

- Präzession: Der Mond übt ein Drehmoment auf die Erde aus Zyklus 21000 Jahre

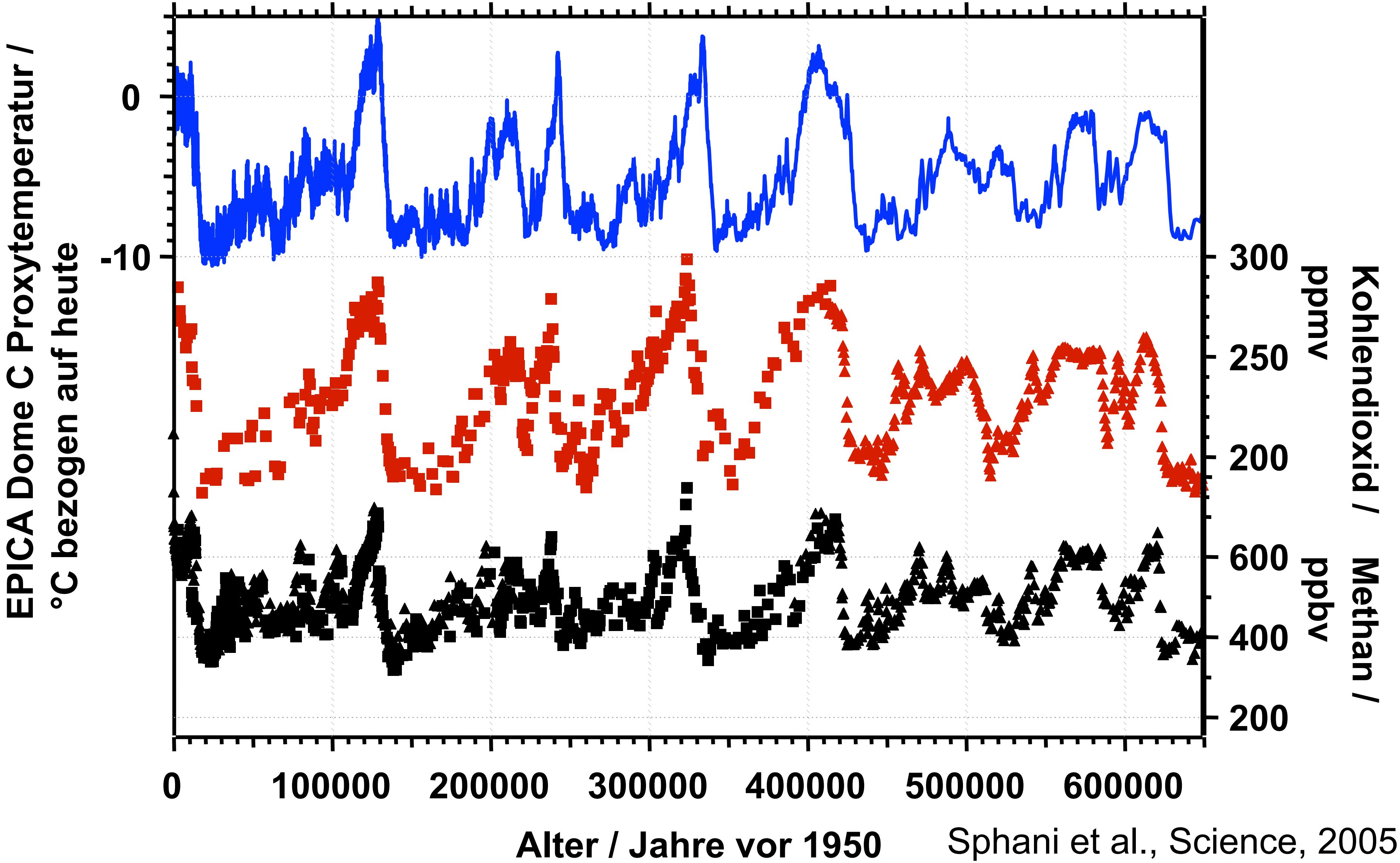
Milankovic, 1941
Berger, 1976
Hays et al., 1976
Bassinot et al. 1994
Graphics by R. Tiedemann

Der Lufteinschluss im Firn



Freitag, Wilhelms,
Kipfstuhl, JGlaciol, 2004

Die längsten verfügbaren atmosphärischen Treibhausgas Zeitreihen

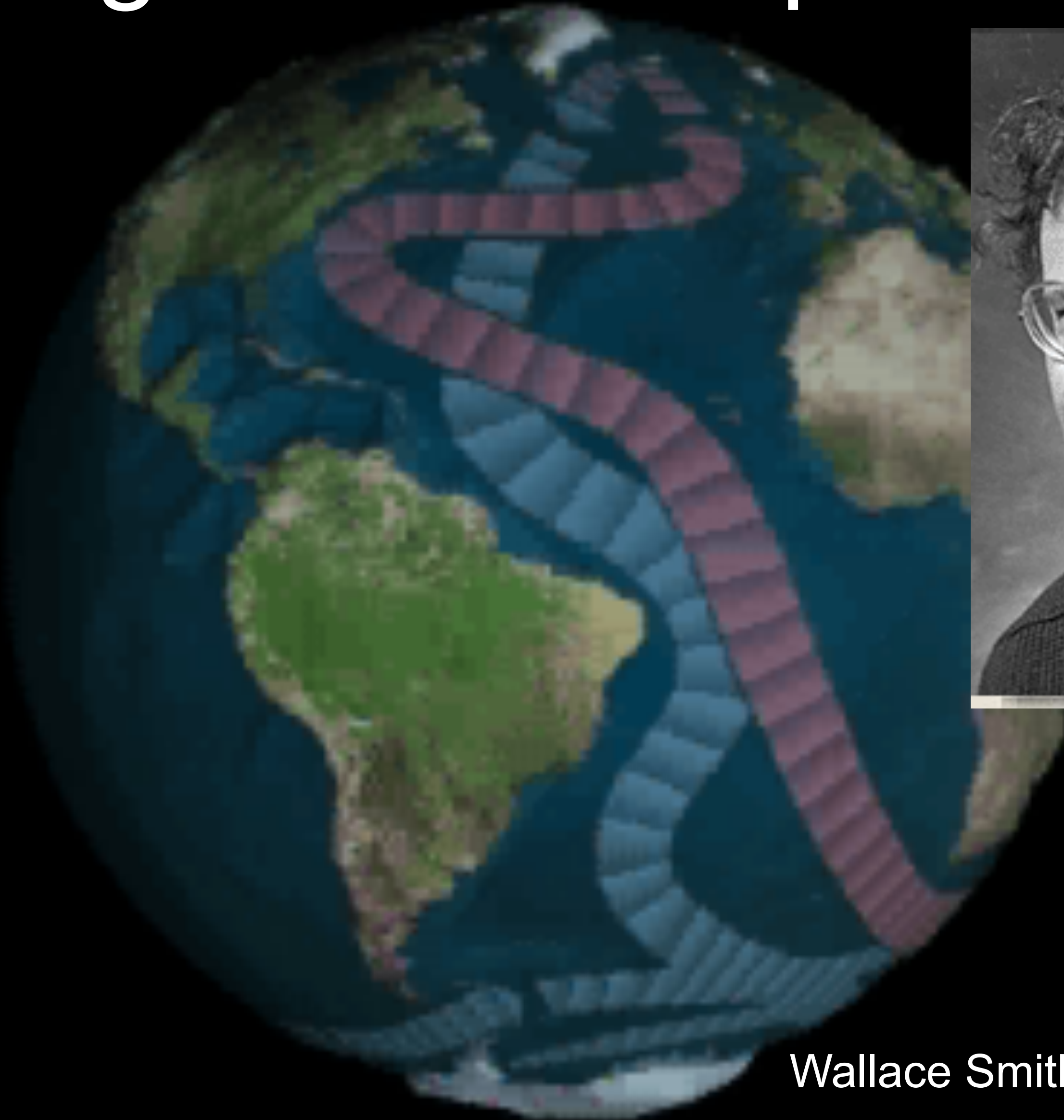


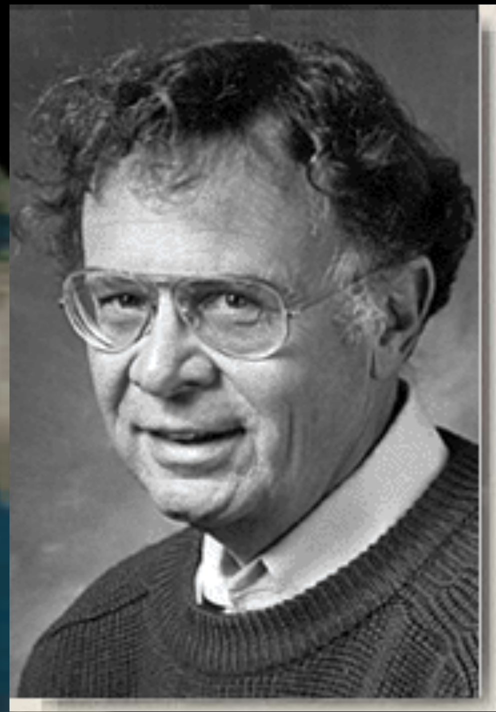
Sphani et al., Science, 2005

Petit et al., Nature, 1999

Siegenthaler et al., Science, 2005

Das globale Transportband

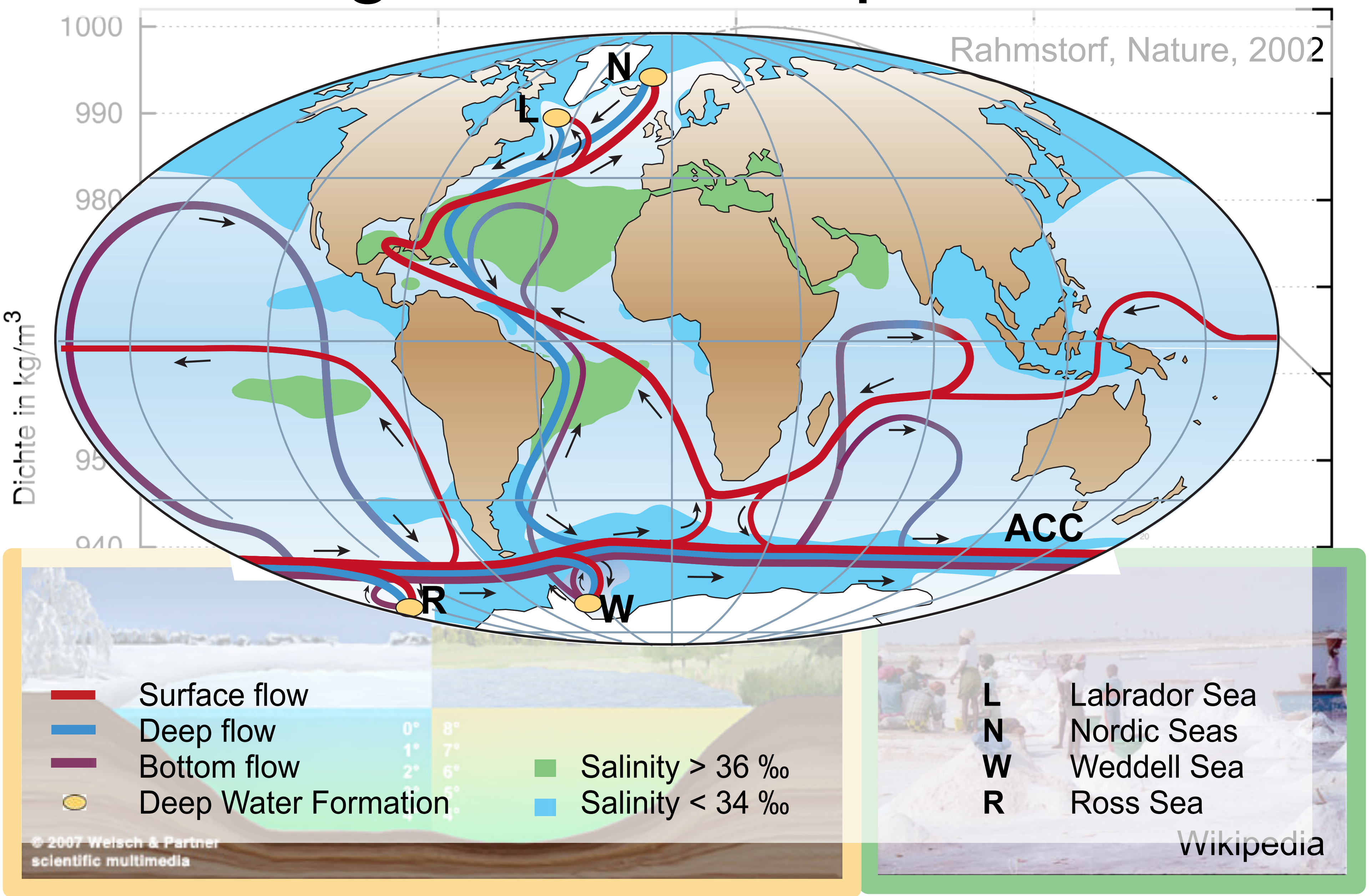




Wallace Smith Broecker, 1991

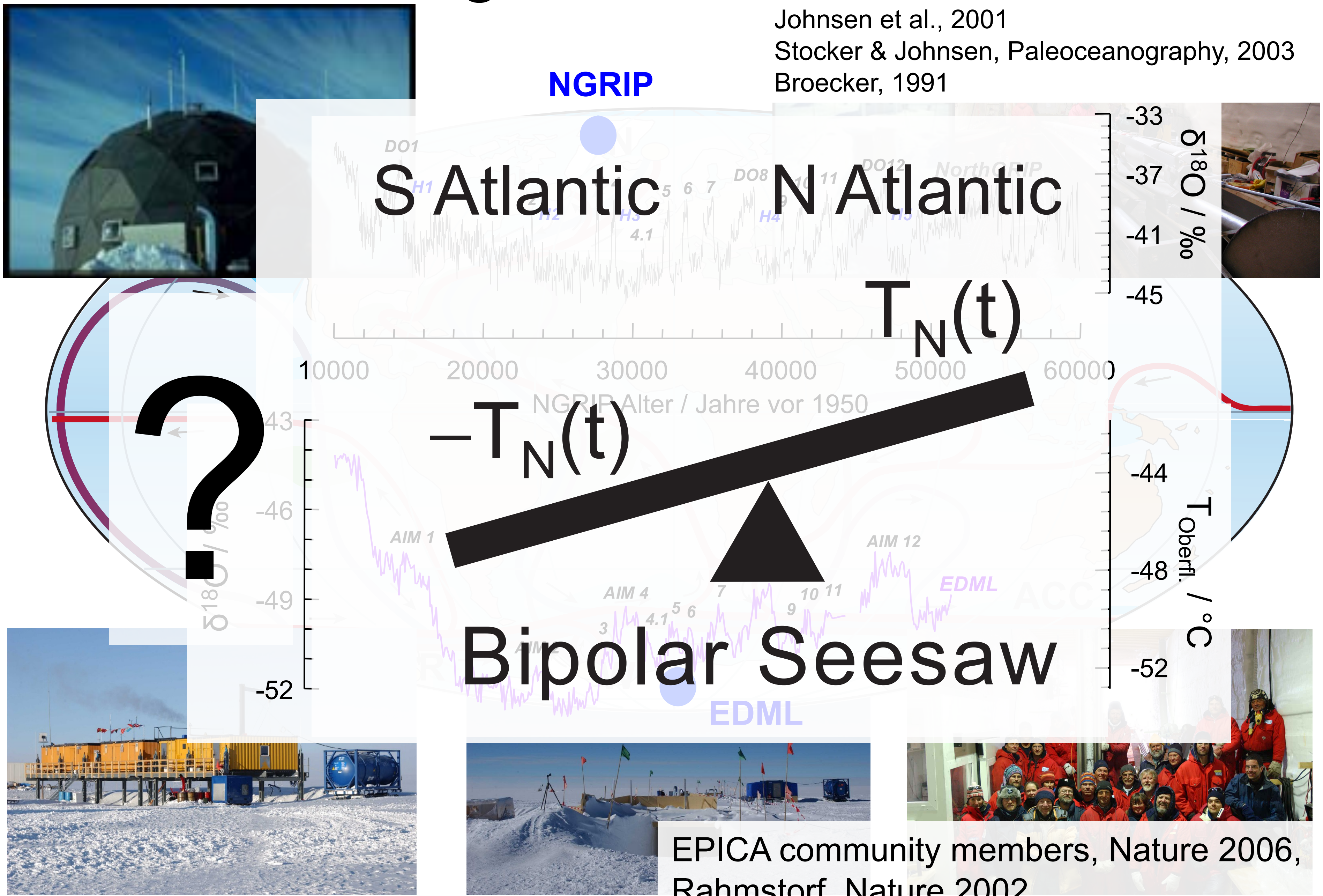
http://www.dkrz.de/dkrz/gallery/vis/ocean

Das globale Transportband



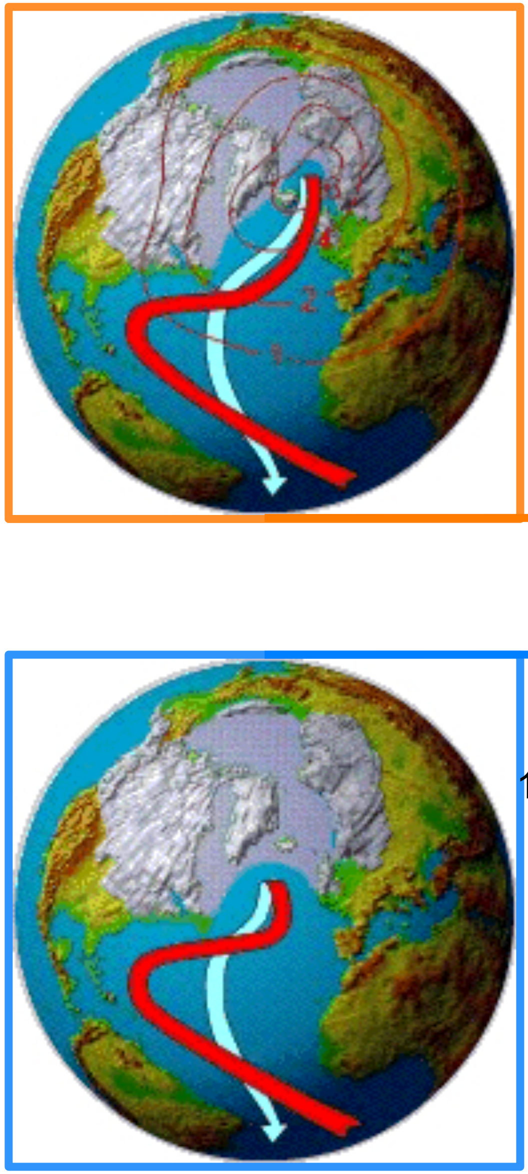
Die Beziehung zwischen Nord und Süd

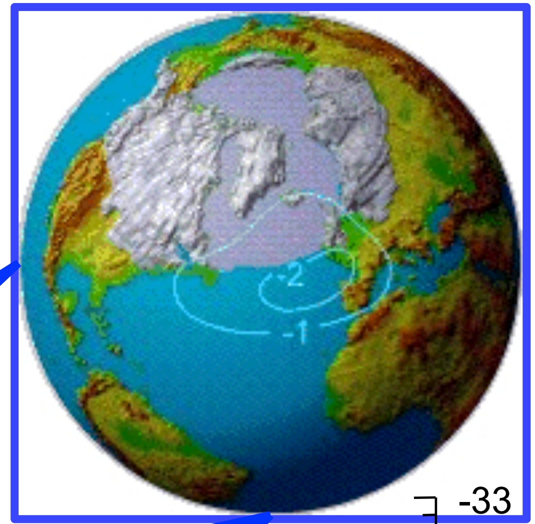
Johnsen et al., 2001
Stocker & Johnsen, Paleoceanography, 2003
Broecker, 1991

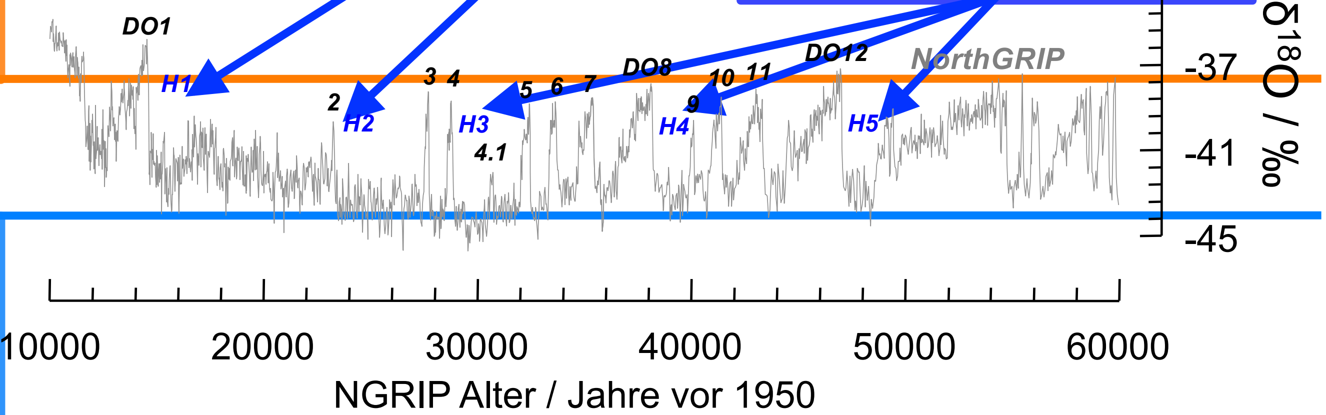


EPICA community members, Nature 2006,
Rahmstorf, Nature 2002

Moden des Transportbands in der Eiszeit

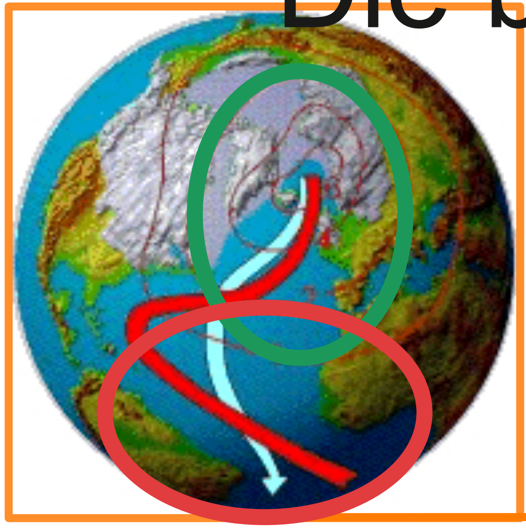


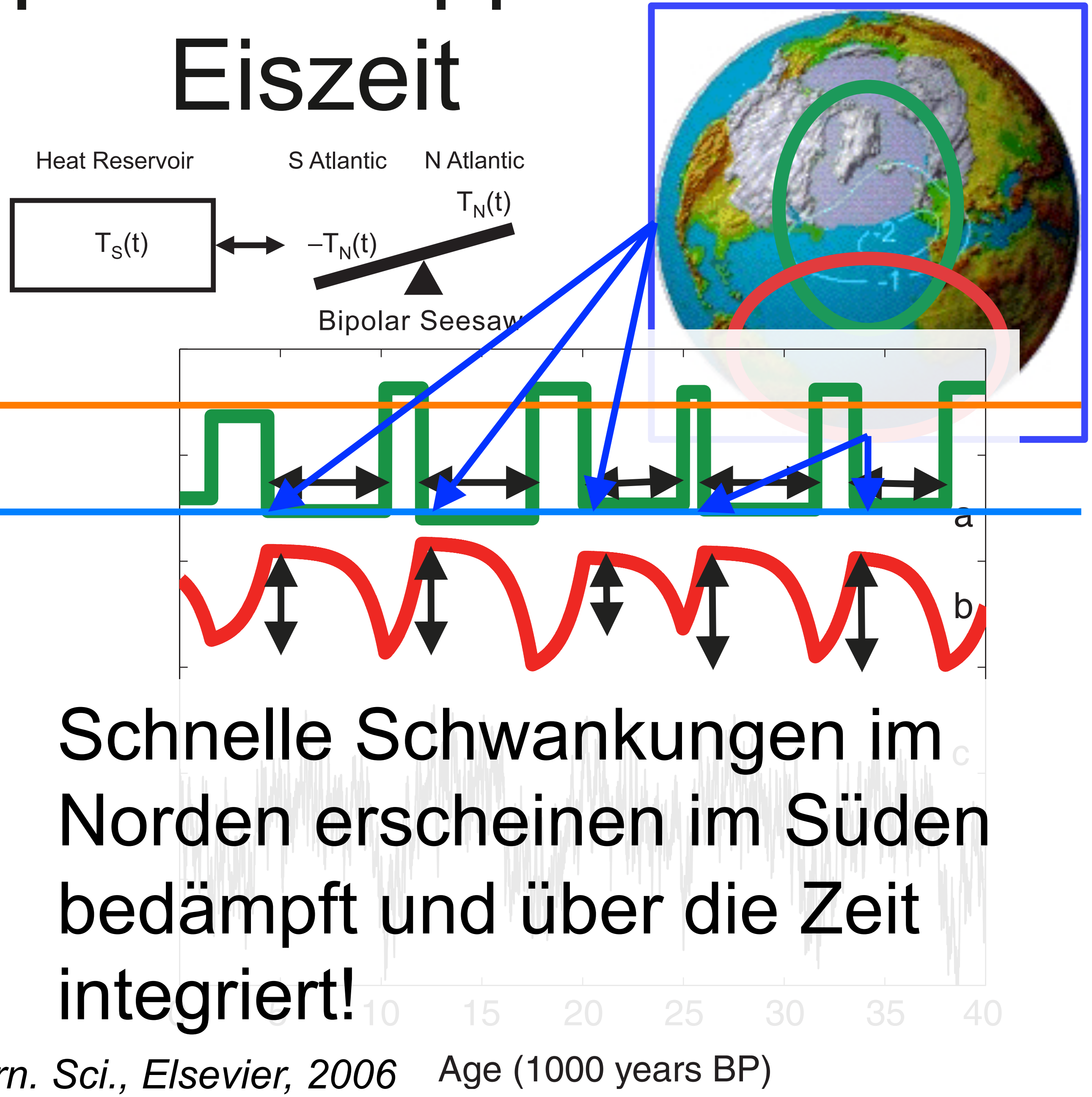




Rahmstorf, *Enc. of Quatern. Sci., Elsevier, 2006*
EPICA community members, Nature 2006

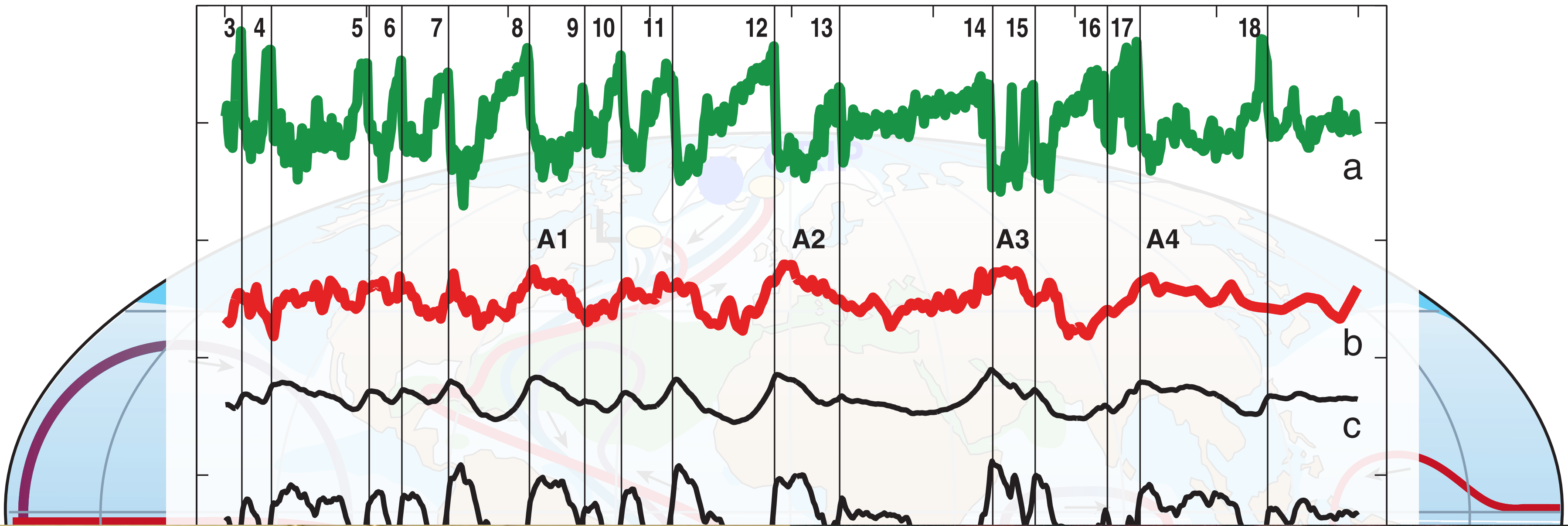
Die bipolare Wippe in der Eiszeit





Schnelle Schwankungen im Norden erscheinen im Süden bedämpft und über die Zeit integriert!

Stocker & Johnsen, 2003
Rahmstorf, *Enc. of Quatern. Sci., Elsevier, 2006*

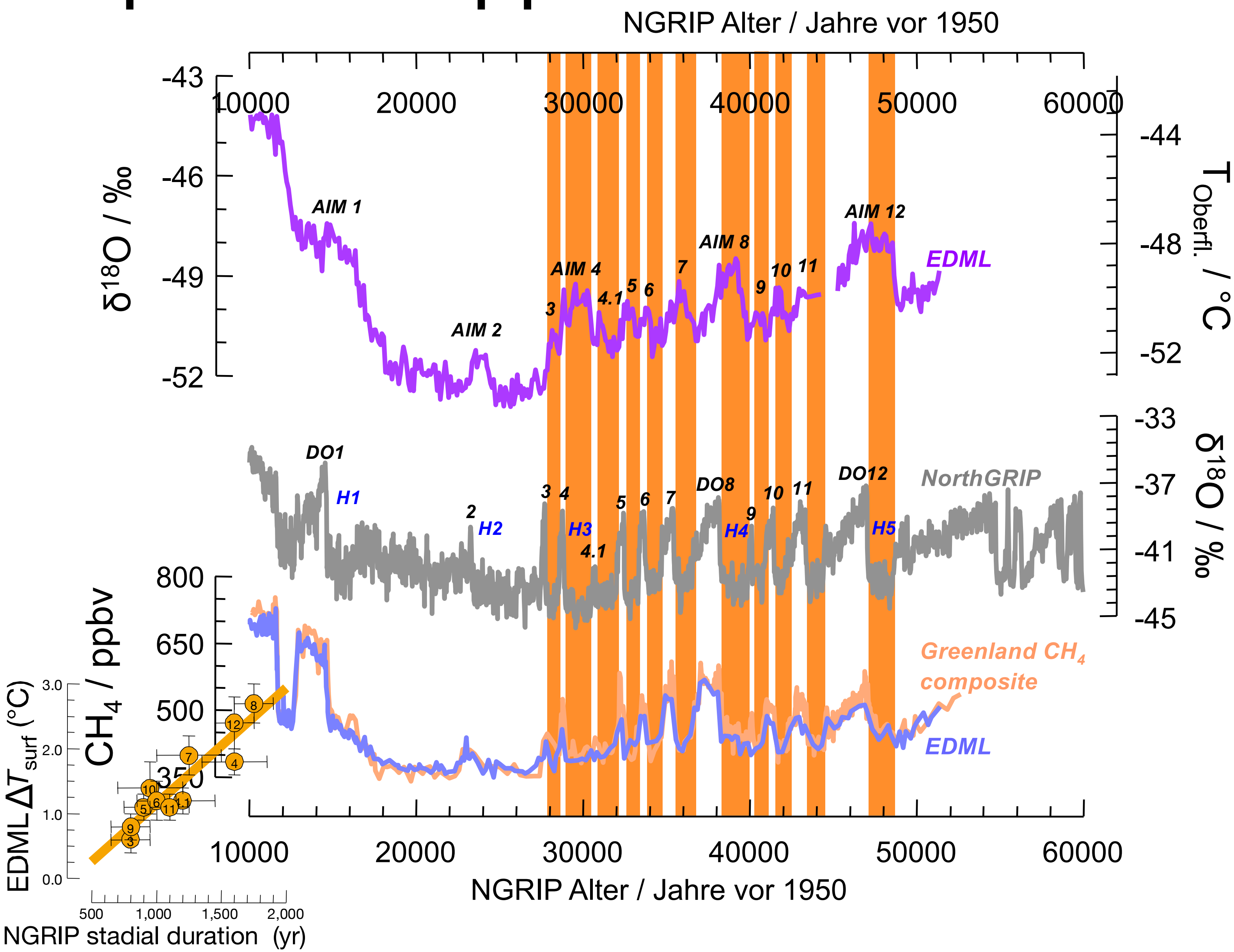



Thomas Stocker, Uni Bern


Sigfus Johnsen, Universität Ísland & København

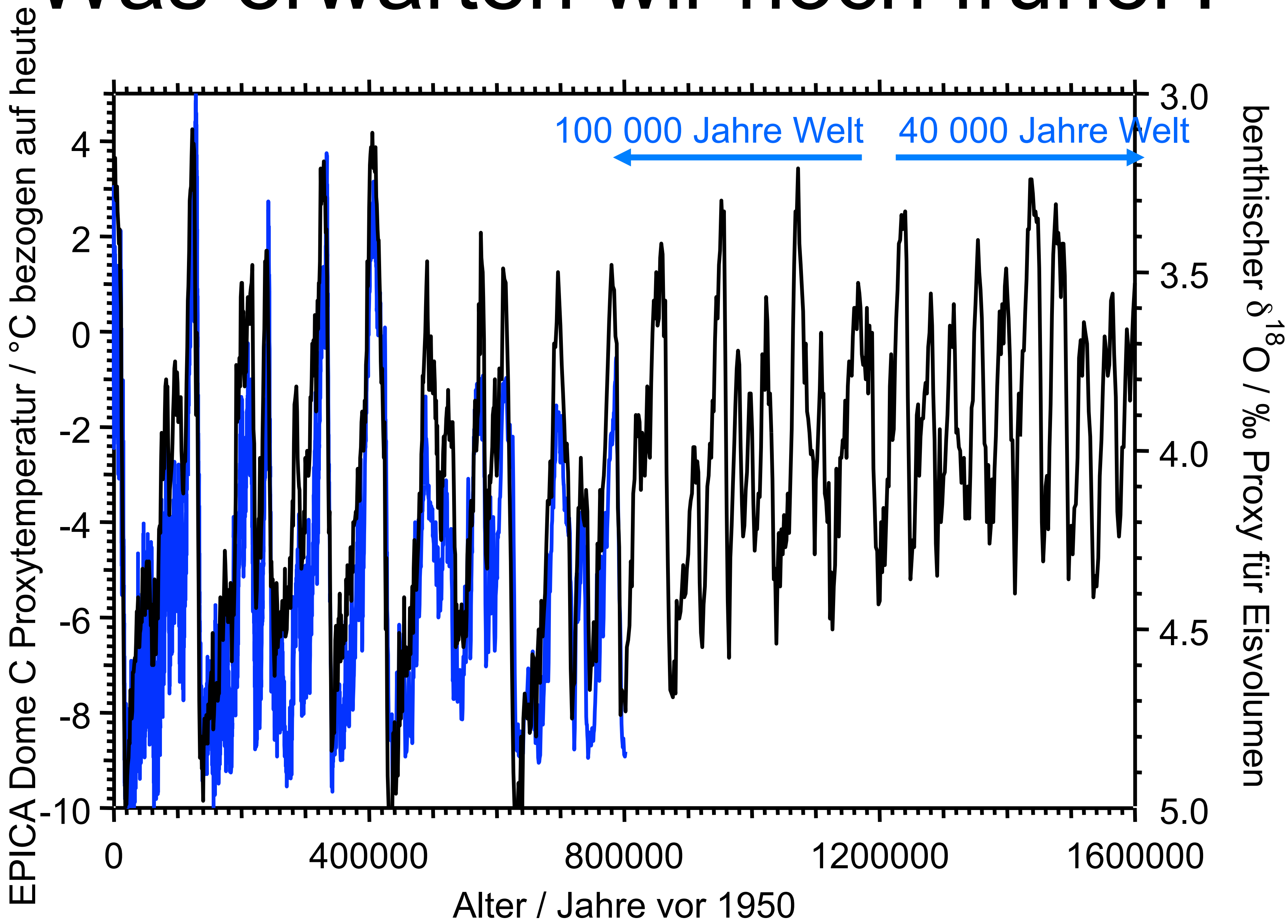
Stocker & Johnsen, 2003

Die bipolare Wippe



EPICA community members, Nature 2006

Was erwarten wir noch früher?



Jouzel et al. (2007)

Lisiecki & Raymo (2005)

Projekte für die Zukunft: IPICS

1. Der älteste Eiskern: Eine 1.5 Millionen Jahre zurückreichende Zeitreihe über das Klima und die Treibhausgase in der Antarktis (In eine Zeit zurückreichend als das Erdklima von 40,000 Jahreszyklen zu 100,000 Jahreszyklen wechselte).
2. Das letzte Interglazial und weiter zurück: Ein Nordwestgrönländisches Eiskern-bohrprojekt (Ein tiefer Eiskern in Grönland zur Gewinnung einer ungestörten Zeit-reihe des letzten Interglazials.
3. Das IPICS 40,000 Jahre Netzwerk: Eine bipolare Zeitreihe des Klimaantriebs und der Klimaantwort
4. Das IPICS 2k Muster: Ein Netzwerk zur Rekonstruktion von Klima aus Eiskernen und Klimaantrieb über die letzten 2000 Jahre.

Ein fünftes, und kritisches Element von IPICS ist die Weiterentwicklung von Bohrtechnologie. Womit sich ein technisches Weißpapier „technische Heraus-forderungen bei der Gewinnung von Eiskernproben “ befasst.

www.pages.unibe.ch/science/initiatives/ipics

Willi Dansgaard

Professor emeritus

Willi Dansgaard

født 30. 8. 1922
er stille sovet ind 8. 1. 2011

Børn, børnebørn, svigerbørn og oldebarn