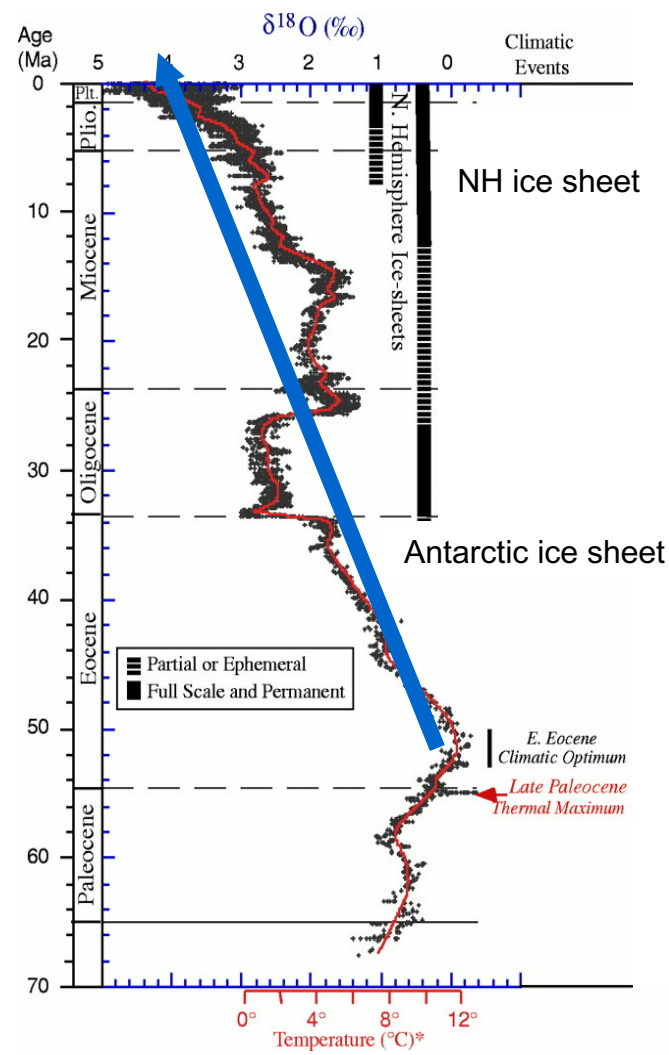
Climate System II course 2020 (4th lecture)

G. Lohmann & M. Werner

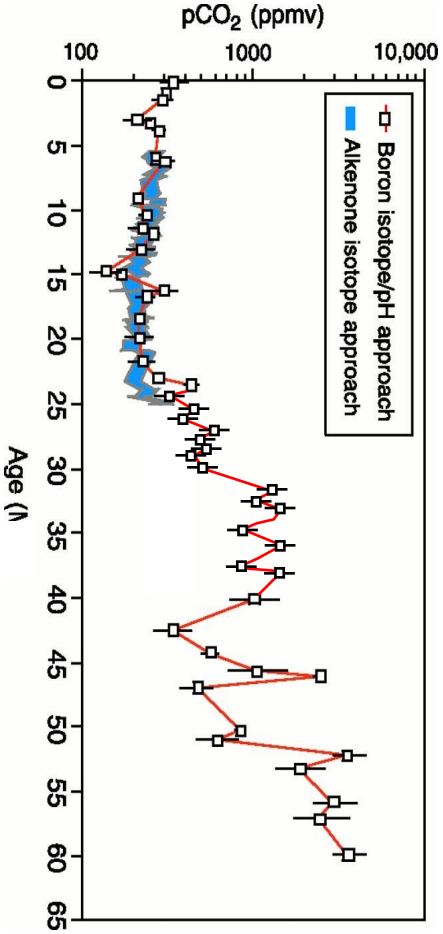
Orbital Theory, Ice Ages, Abrupt climate change

Gerrit Lohmann

Transitions from Greenhouse to Icehouse Climate: Evidence from Marine Sediments

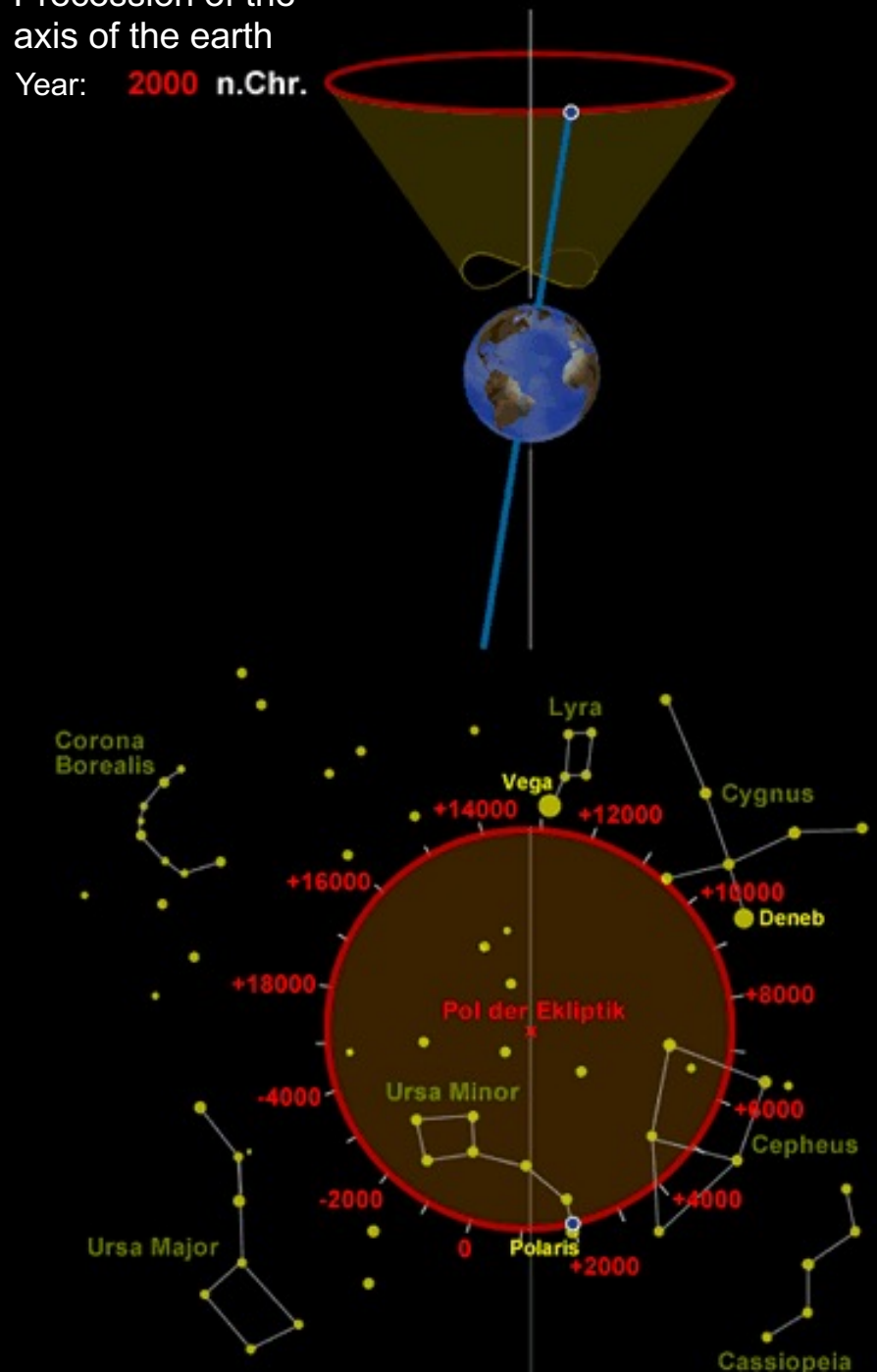


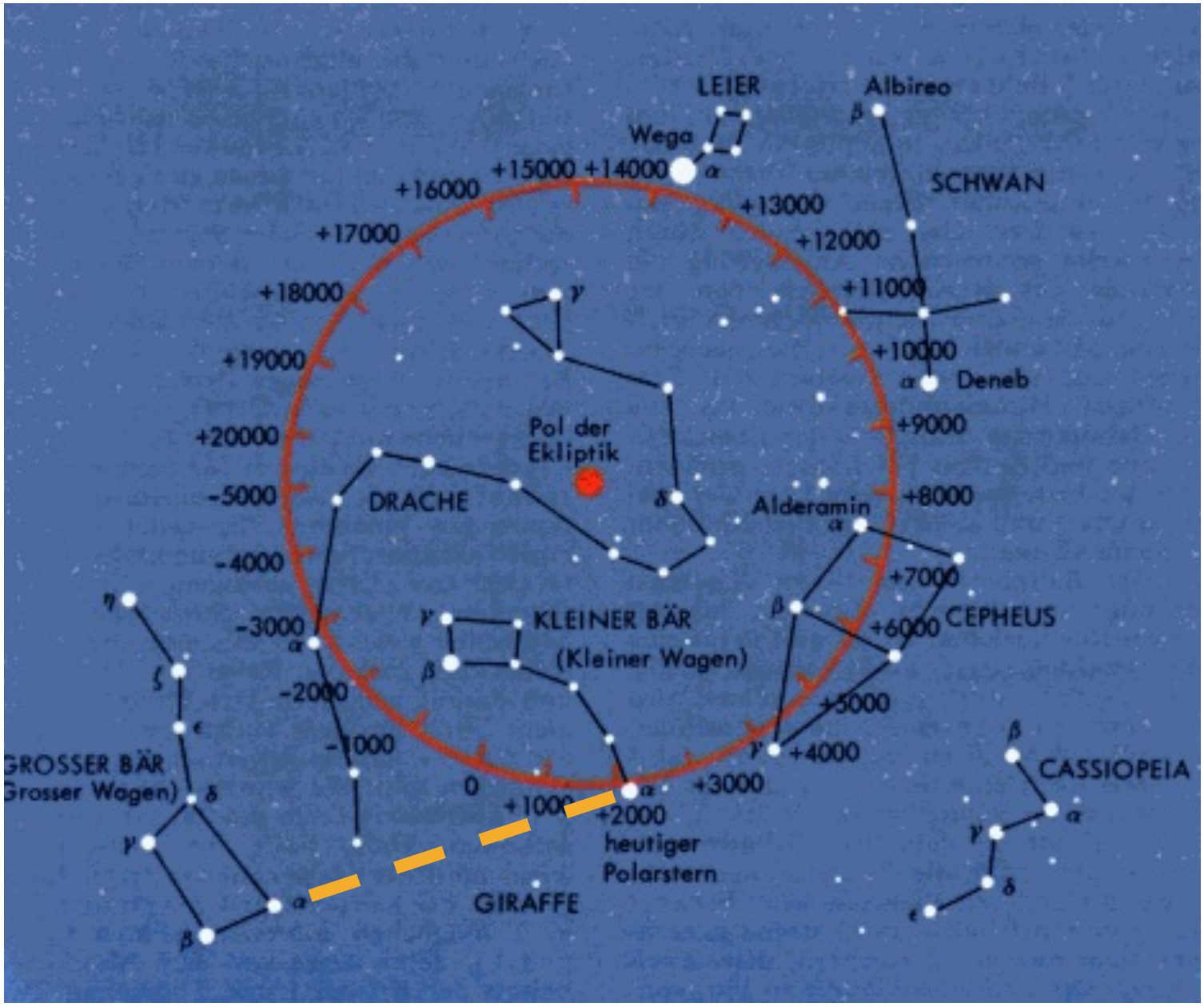
Global deep-sea O-18
(Zachos et al. 2001)



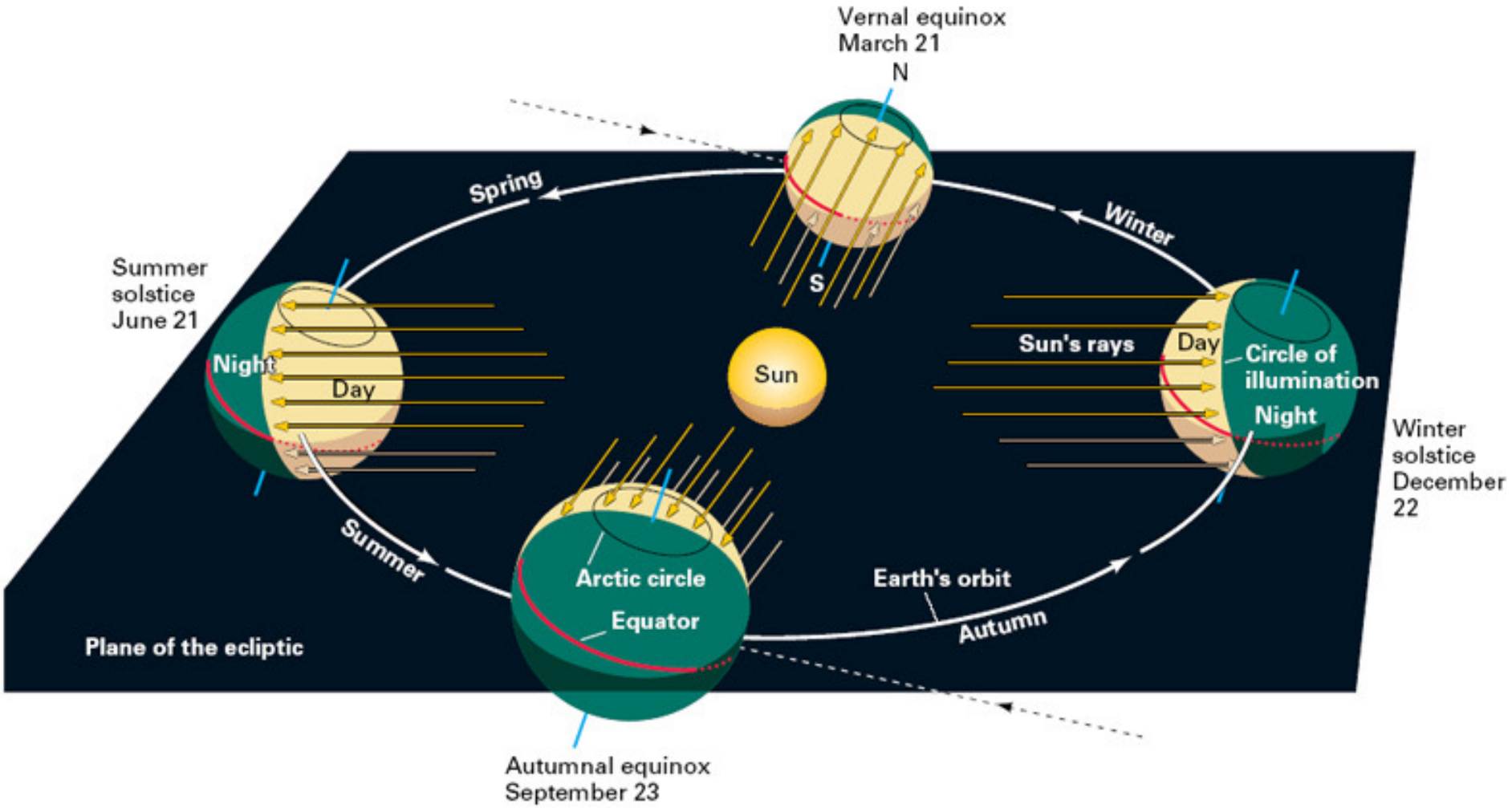
Proxy estimates of atmospheric pCO2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

Integrative approach
Data-Modelling


Precession of the
axis of the earth
Year: 2000 n.Chr.
Lyra
Corona
Borealis
Vega
Cygnus
+14000
+12000
+16000
+10000
Deneb
+18000
+8000
Pol der Ekliptik
-4000
Ursa Minor
+6000
Cepheus
-2000
+4000
Ursa Major
0
Polaris
+2000
Cassiopeia


LEIER
Wega
α
Albireo
β
SCHWAN
+15000
+14000
+16000
+13000
+17000
+12000
+18000
+11000
γ
+19000
+10000
α
Deneb
+20000
+9000
Pol der
Ekliptik
-5000
DRACHE
δ
Alderamin
α
+8000
-4000
+7000
η
γ
KLEINER BÄR
(Kleiner Wagen)
β
-3000
α
β
+6000
CEPHEUS
ζ
-2000
ε
+5000
-1000
γ
+4000
GROSSER BÄR
(Grosser Wagen)
δ
0
α
+3000
+1000
+2000
heutiger
Polarstern
γ
α
β
GIRAFFE
β
CASSIOPEIA
α
γ
δ
ε

The 4 seasons



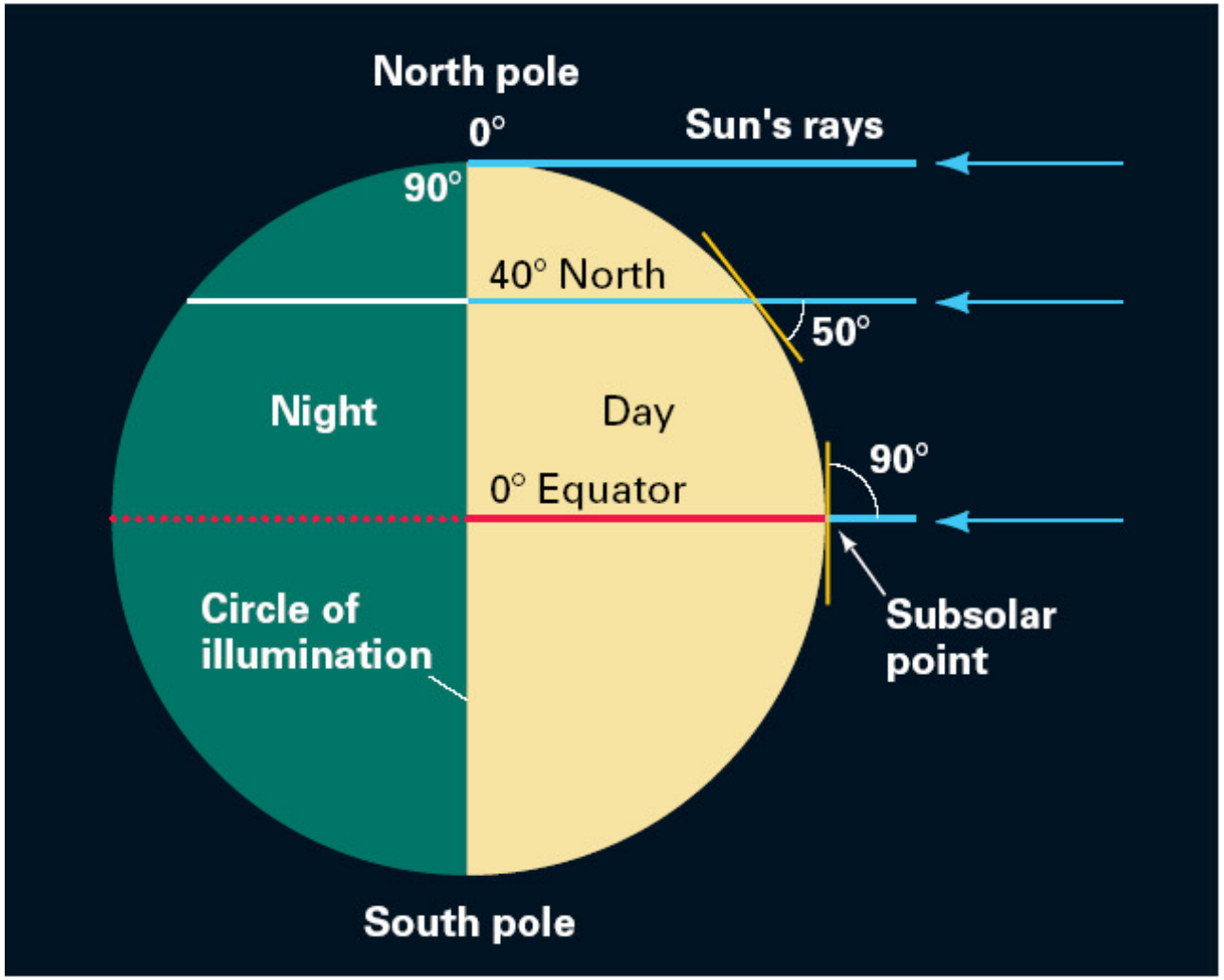
BQuelle: **Strahler: „Physical Geography“**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.16,p.55

Equinox

at equinox, the circle of illumination passes through both poles

the subsolar point is the equator

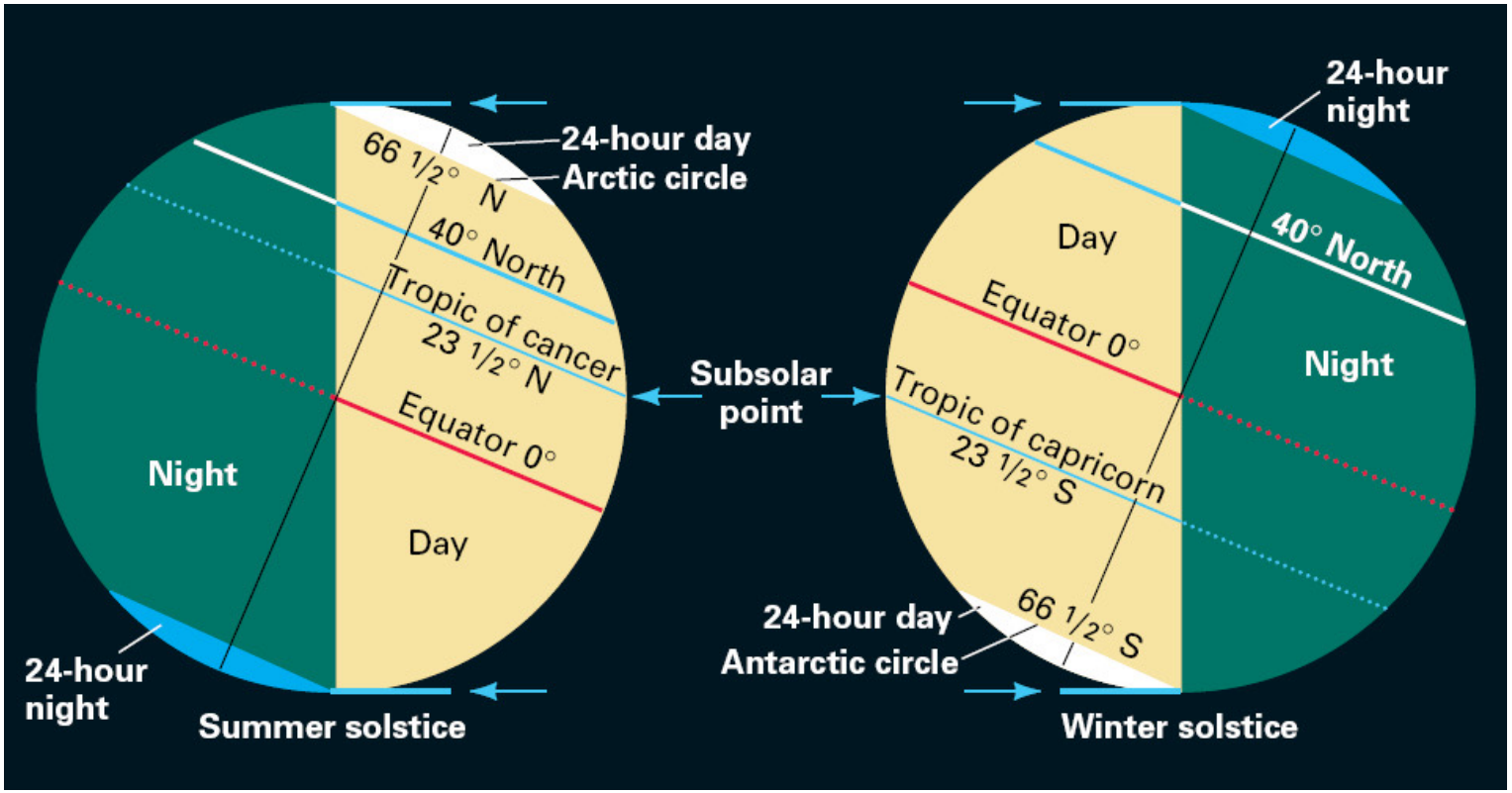
each location on Earth experiences 12 hours of sunlight and 12 hours of darkness



BQuelle: **Strahler: „Physical Geography“**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.17,p.56 (bzw. Fig.1.18,p.41 in neuerer Auflage)

Solstice

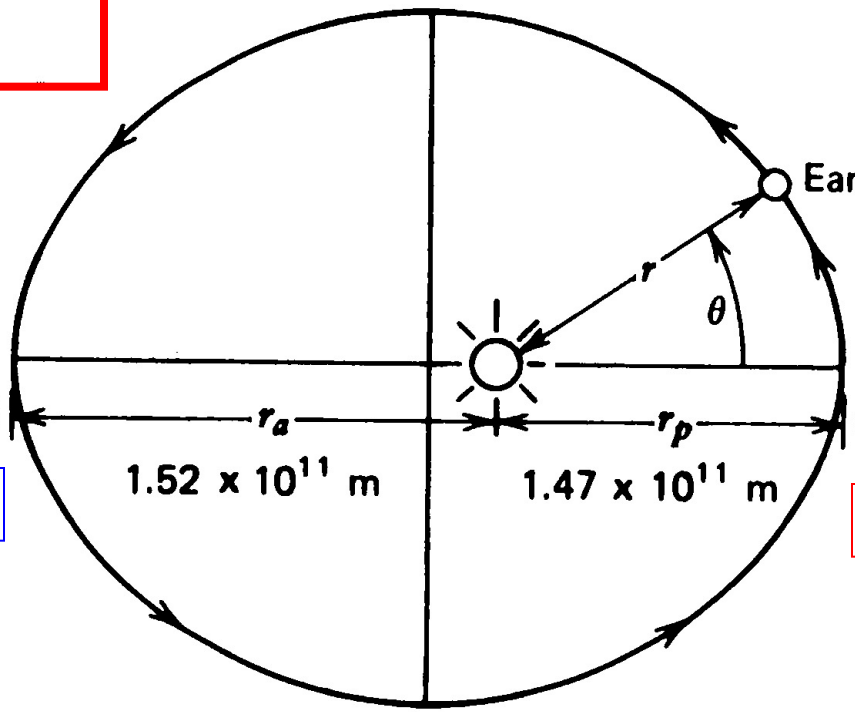
Solstice ("sun stands still")
On June 22, the subsolar point is 23½° N (Tropic of Cancer)
On Dec. 22, the subsolar point is 23½° S (Tropic of Capricorn)



BQuelle: **Strahler: „Physical Geography"**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.18,p.56 (bzw. Fig.1.19,p.41 in neuerer Auflage)

The earth‘s orbit (shown with an exaggerated eccentricity ε)

$$r = \frac{a(1-\epsilon^2)}{1+\epsilon\cos\theta}$$



cos θ = -1

(Aphelion ~ July 4)

θ =0 ; cos θ =+ 1

(Perihelion ~ Jan. 4)

$r_a = r_{Aphelion} = a\,(1+\varepsilon)$

$r_p = r_{Perihelion} = a\,(1-\varepsilon)$

the mean orbital distance is **a = 149,7 [Gm]** = 149,7 Mio km
and the eccentricity is **ε = 0.0167**

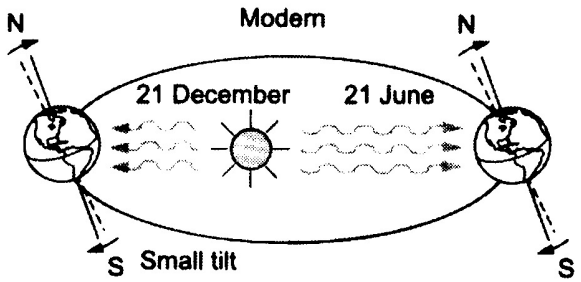
also ca. :: r = a +/- 2%

Quelle:/ Wieder82, Fig 2.1; p.20

Configuration of the earth‘s orbit 9000 years ago

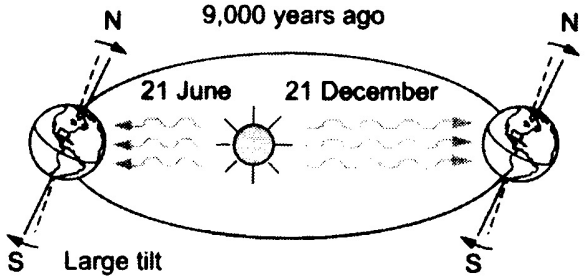
Today:
Perihelion in January

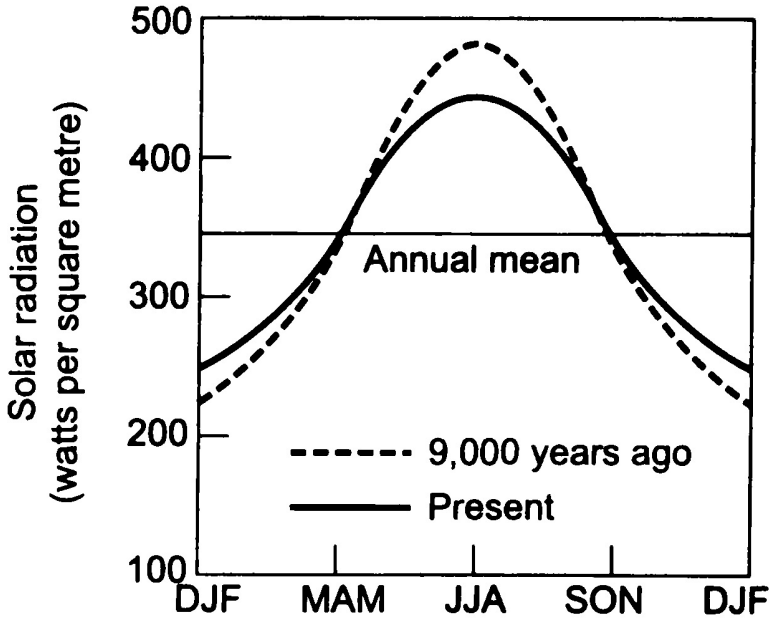
Tilt of the earth‘s axis:
23.5°



9000 years ago::
Perihelion in July

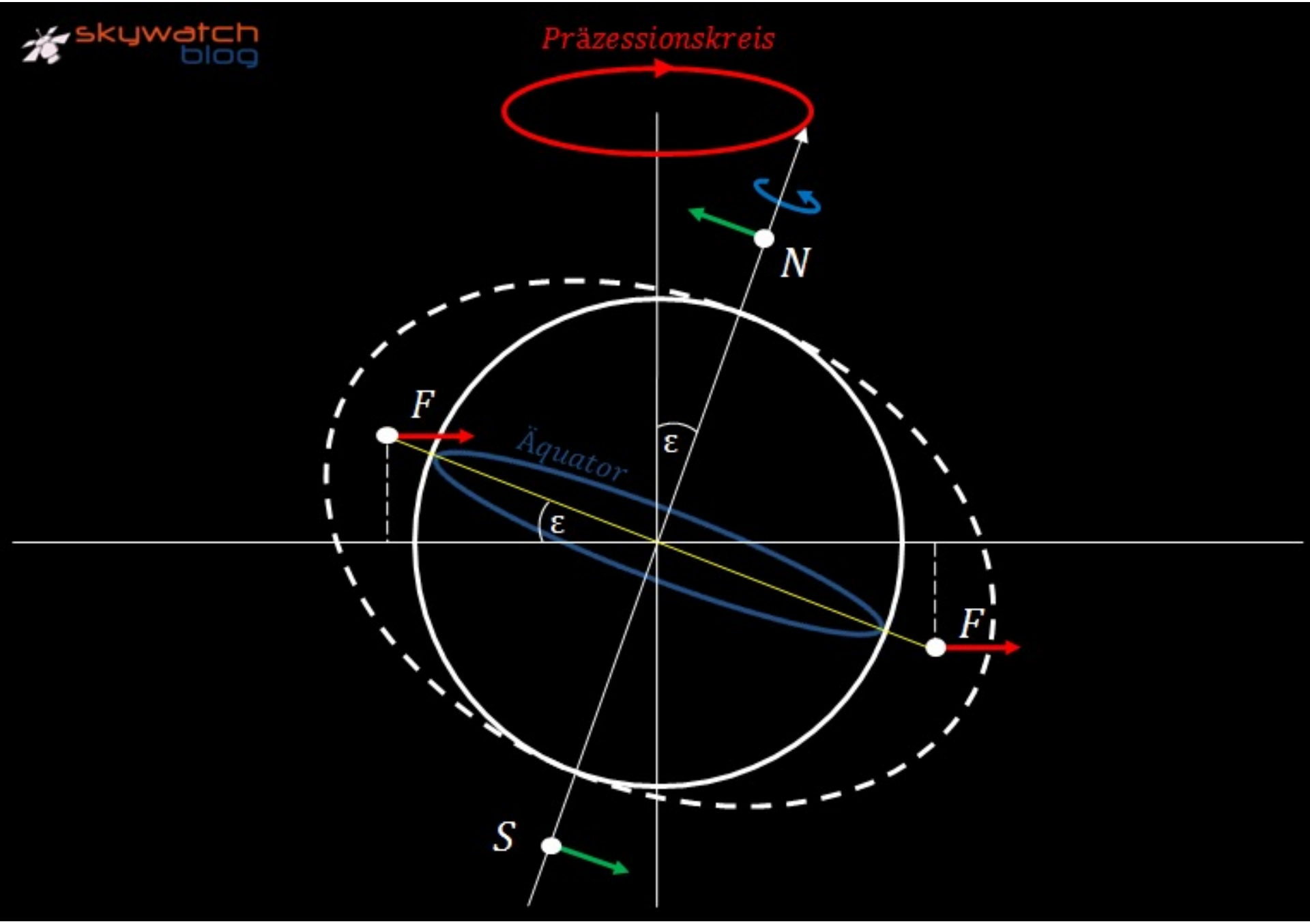
Tilt of the earth‘s axis:
24.0°



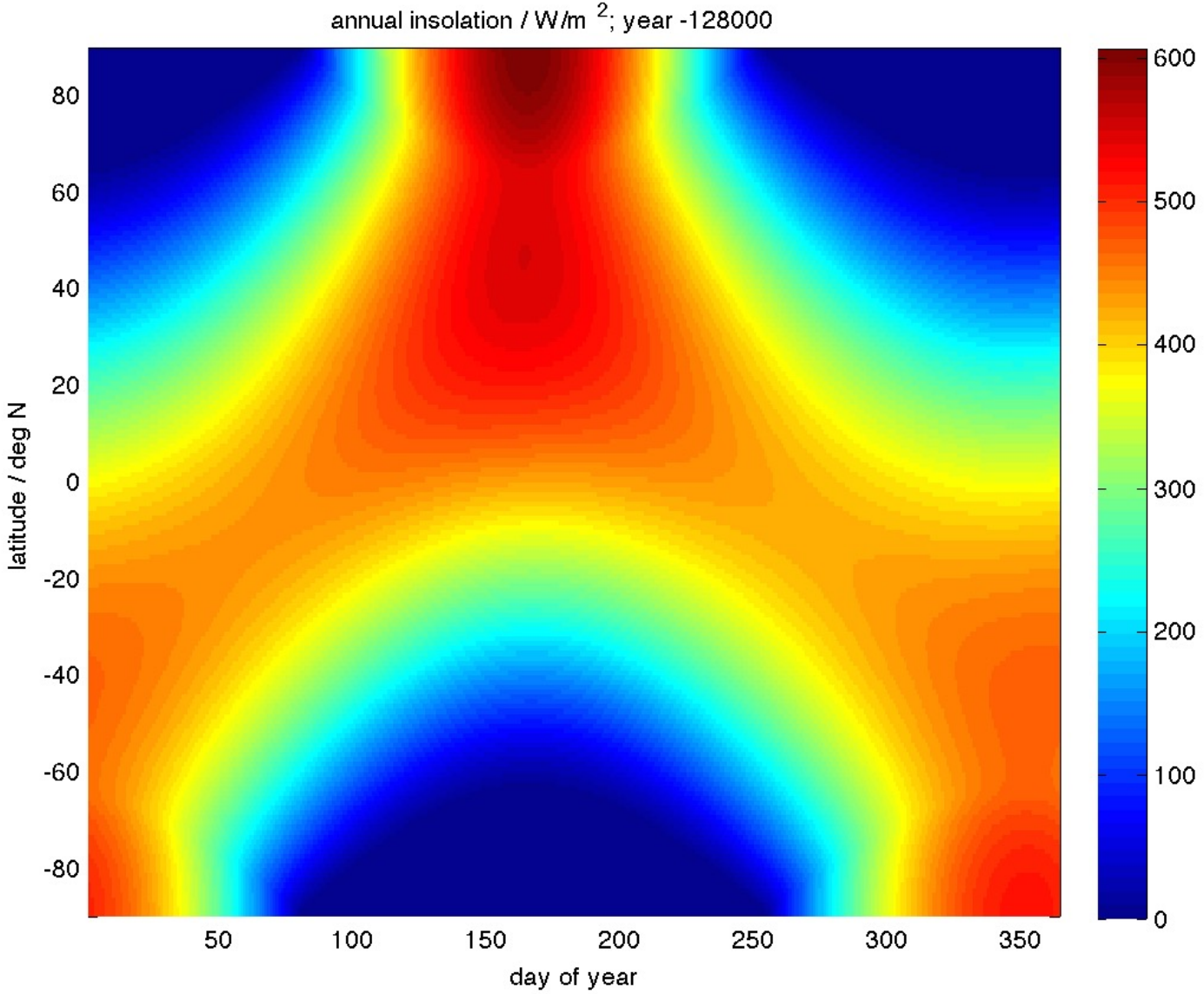


Changes in the average **solar radiation during the year** over the **northern hemisphere** (right). The incoming solar energy averaged over the northern hemisphere was ca. 7 % greater in July and correspondingly less in January.

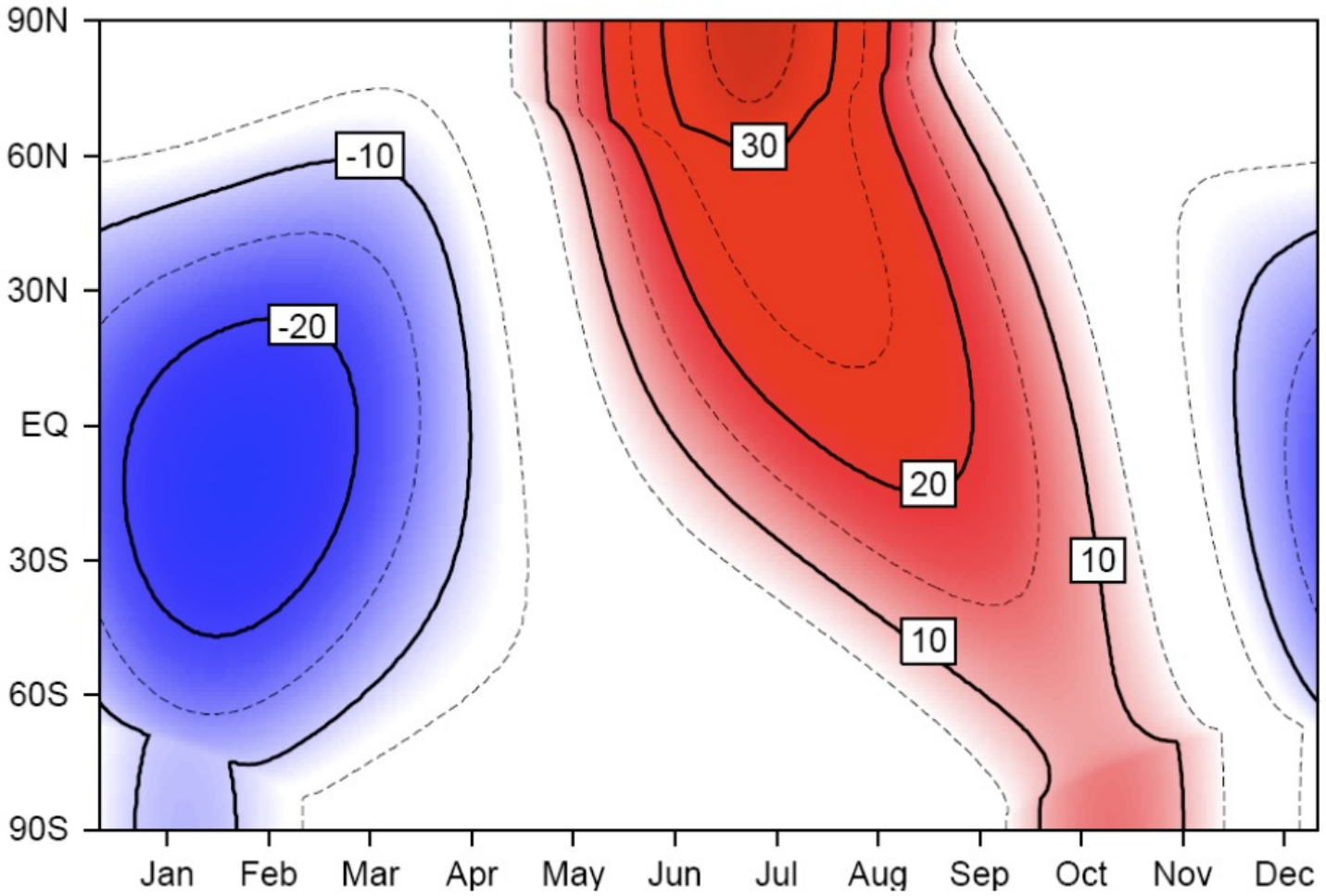
J.E. Kutzbach in „Climate System Modelling“ (1992).

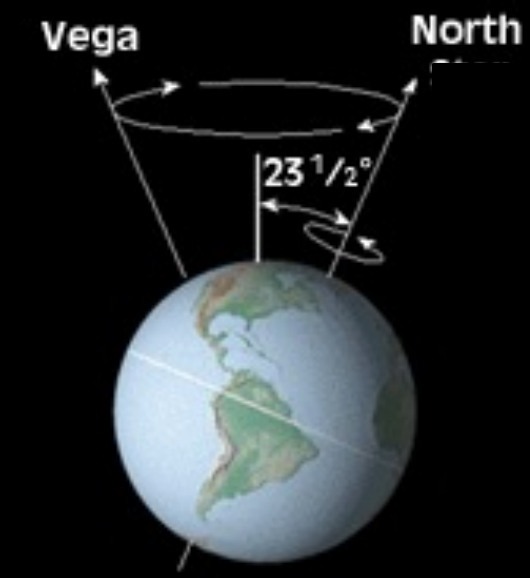

skywatch blog
Präzessionskreis
N
F
Äquator
ε
ε
F
S

Insolation


annual insolation / W/m 2; year -128000
80
60
40
20
0
-20
-40
-60
-80
latitude / deg N
50
100
150
200
250
300
350
day of year
600
500
400
300
200
100
0

Insolation (6k minus present)





Precession

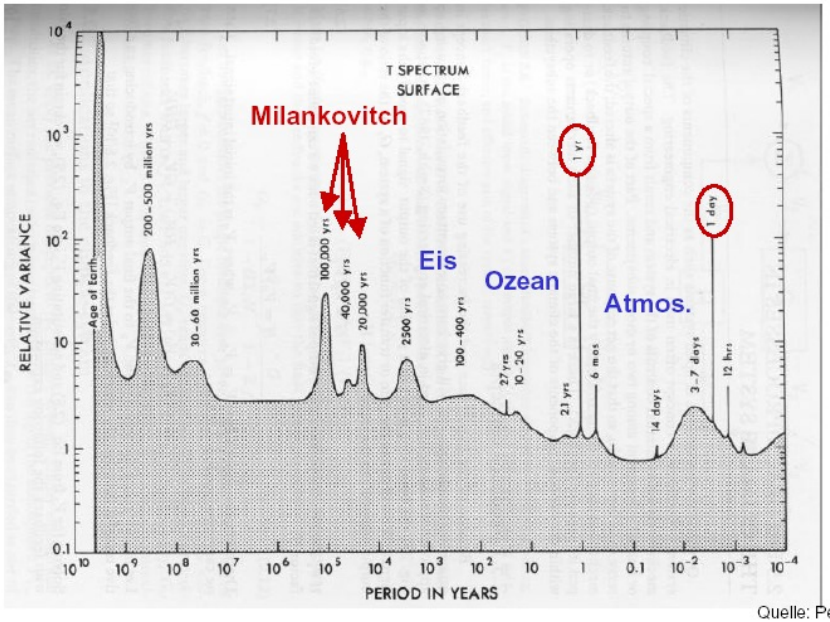
Obliquity

Eccentricity

Orbital focing

- ~20.000, ~40.000, ~100.000 years
- 0.5, 1 year

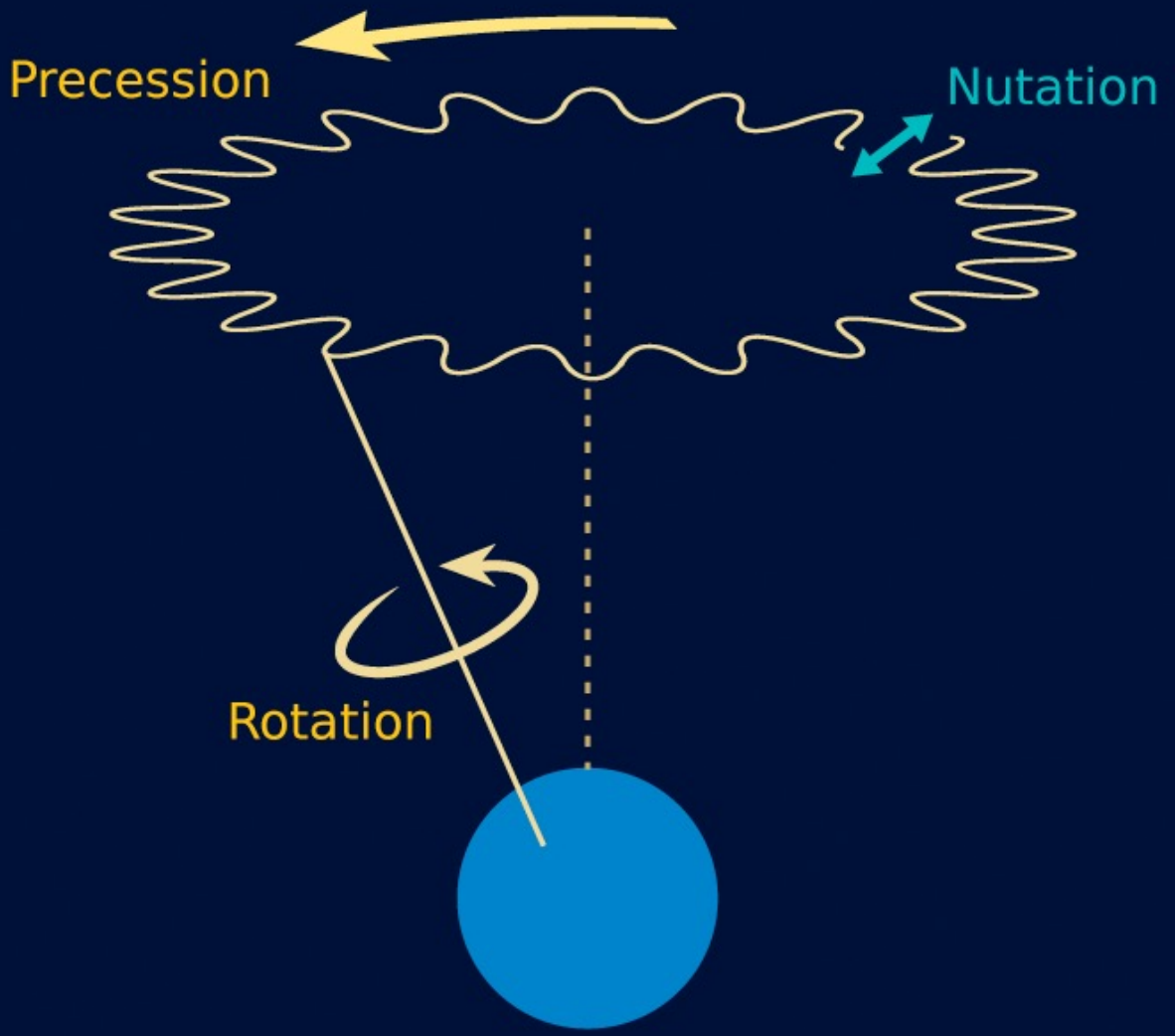
- **Geometry of the Sun-Earth configuration**



Quelle: Peixoto & Oort

Precession, Nutation

(Not to scale)



Sunspots Photo: Nasa

https://www.awi.de/fileadmin/user_upload/AWI/Forschung/Klimawissenschaft/Dynamik_des_Palaeoklimas/OrbitalTheoryOfIceAges/index.html

https://paleodyn.uni-bremen.de/study/climate2021_22.html

Glacial-Interglacial variability

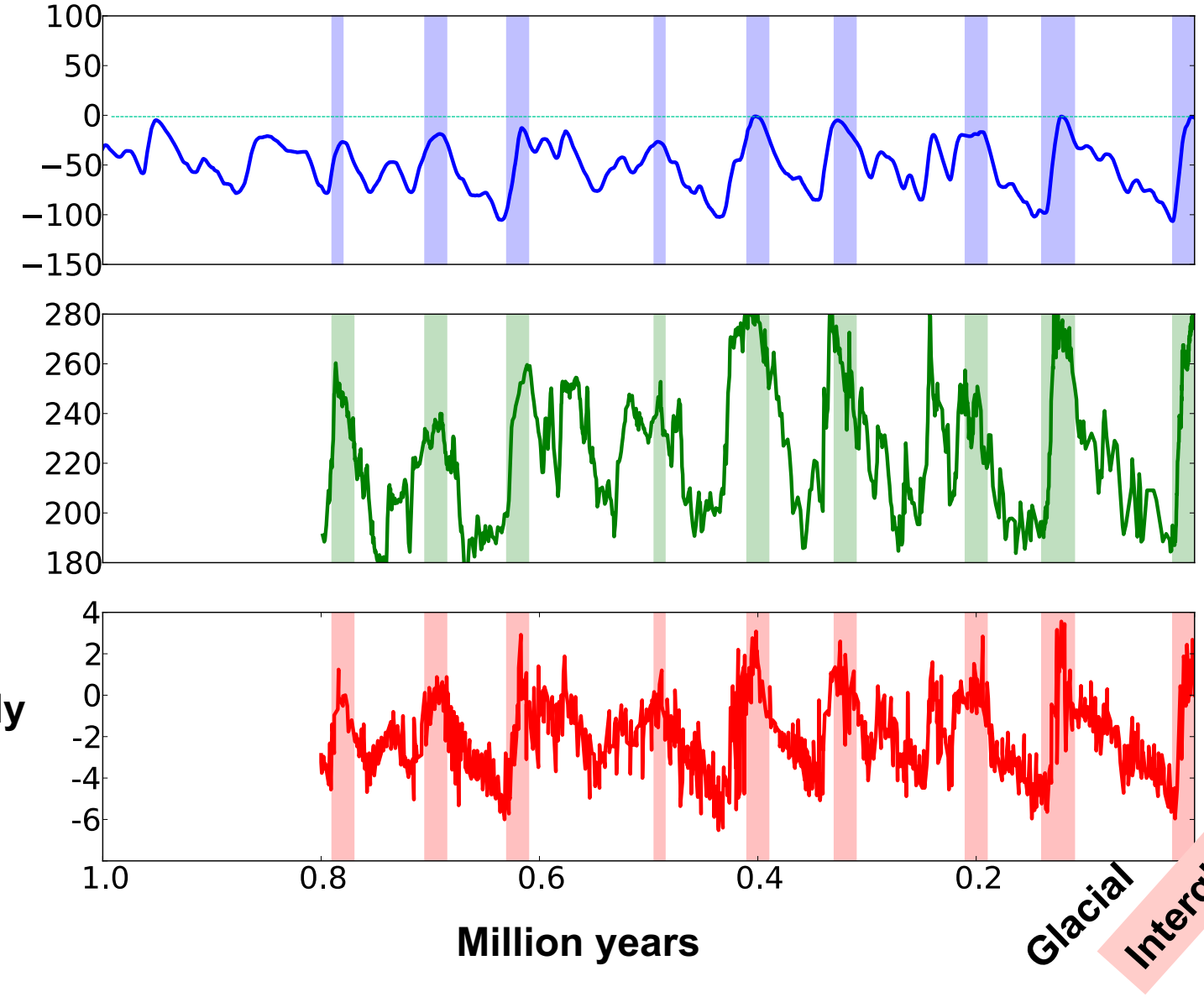
Global Sea Level [m]

(Bintanja et al., 2005)

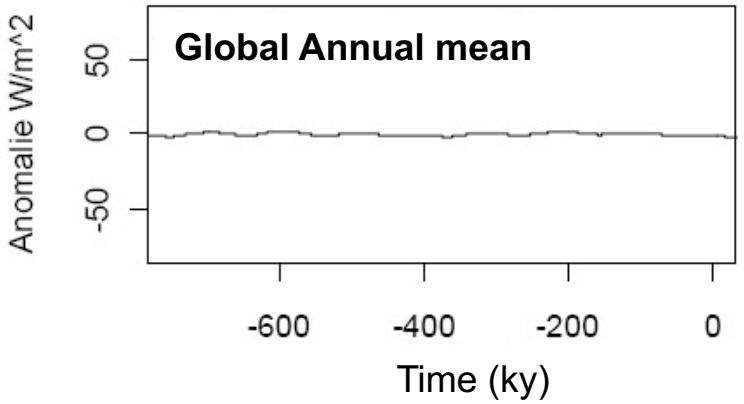
CO_2 [ppmv]

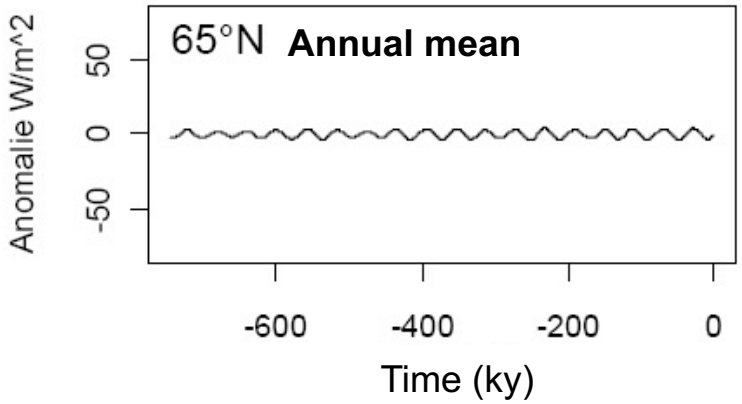
From ice cores (EPICA, 2009)

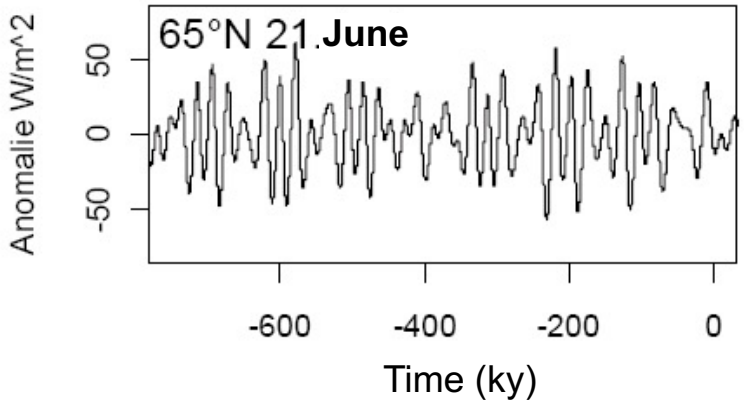
Temp. anomaly "O-18" [° C]



Insolation: Resulting Effect



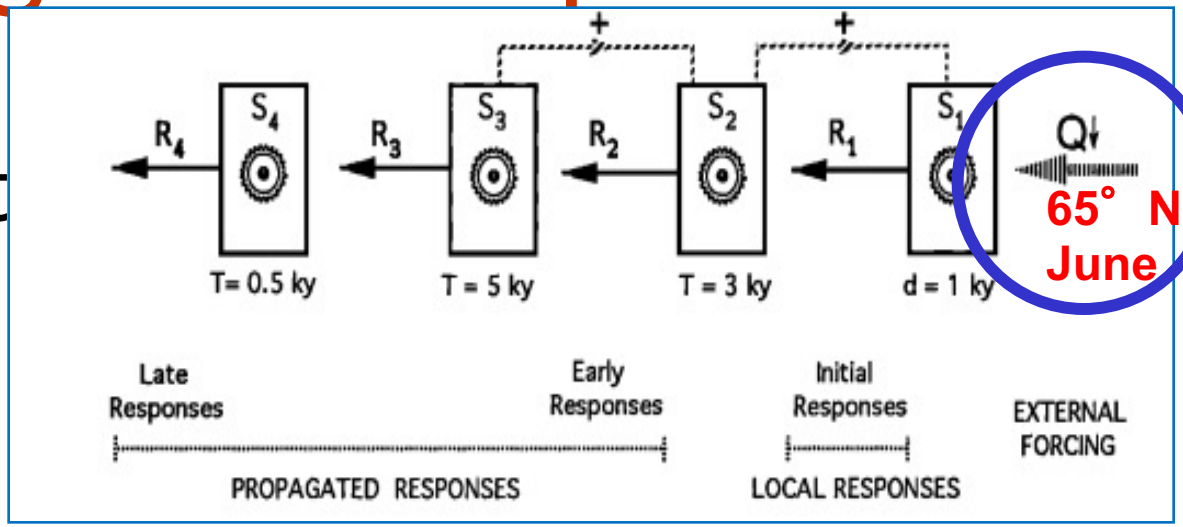




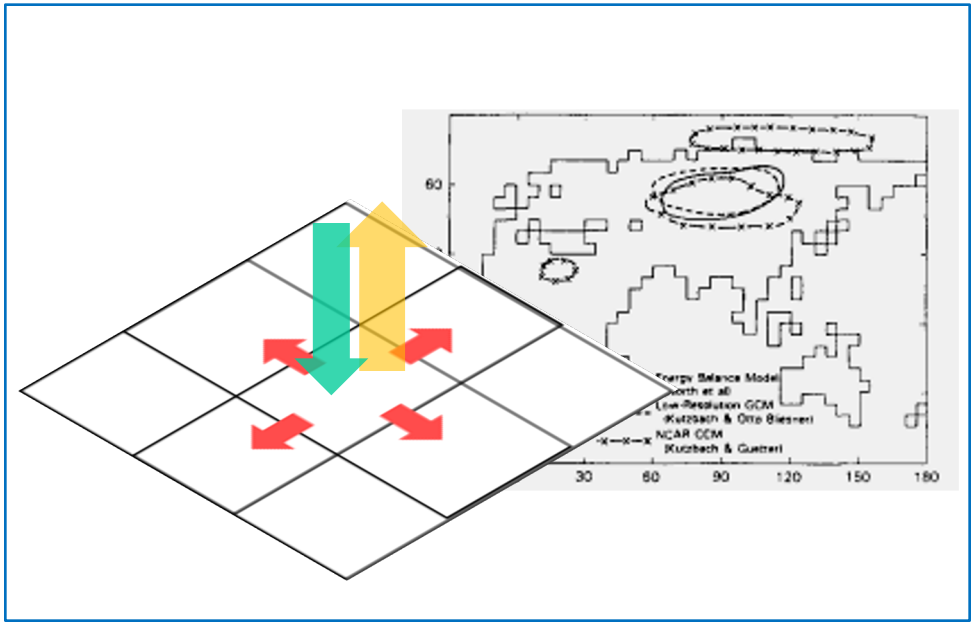
Non-linearities are important

Ice Ages: Concepts

- Global Concept (Imbrie 92)



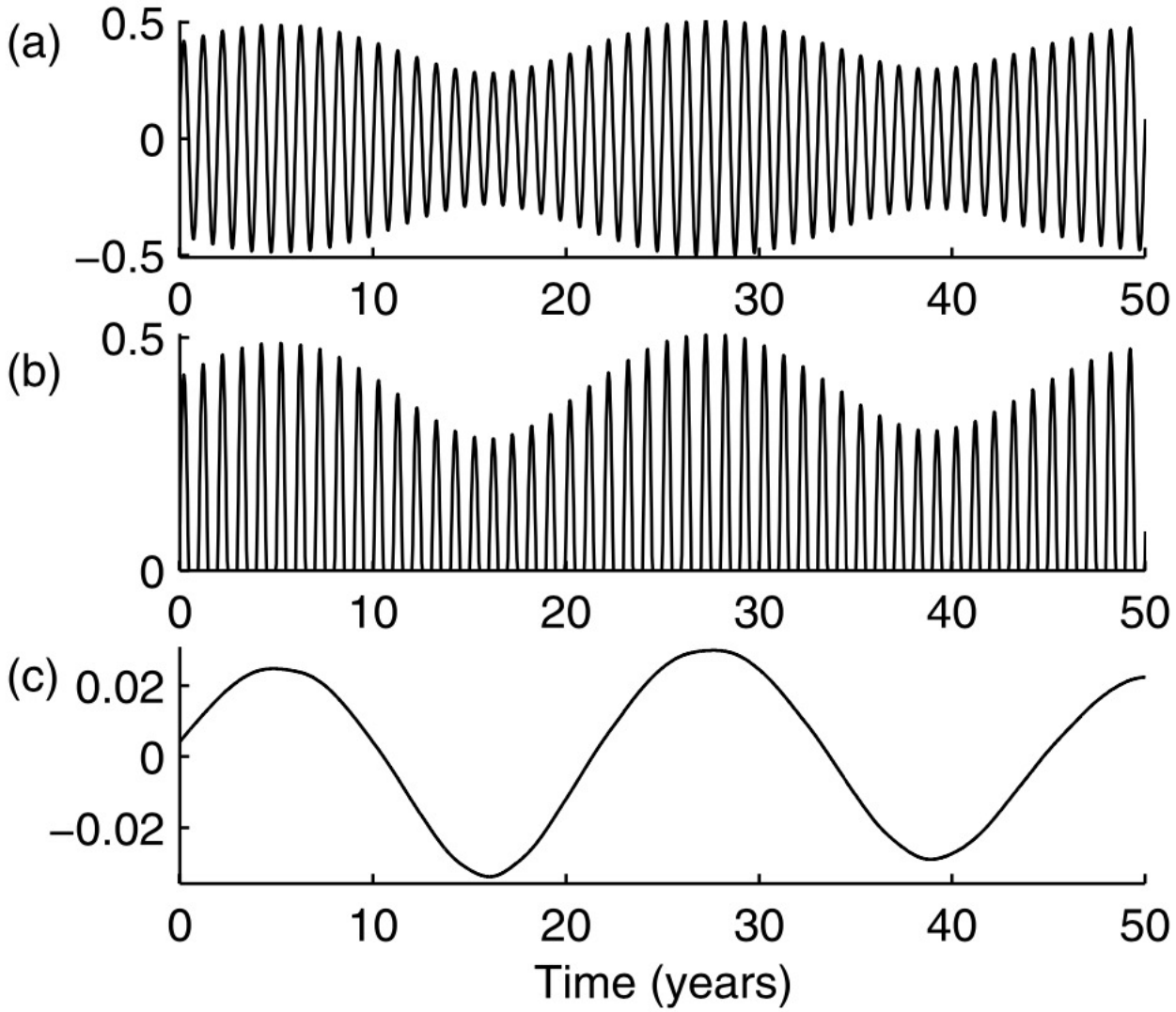
- Local Model (Short et al., 91) 2D linear EBM



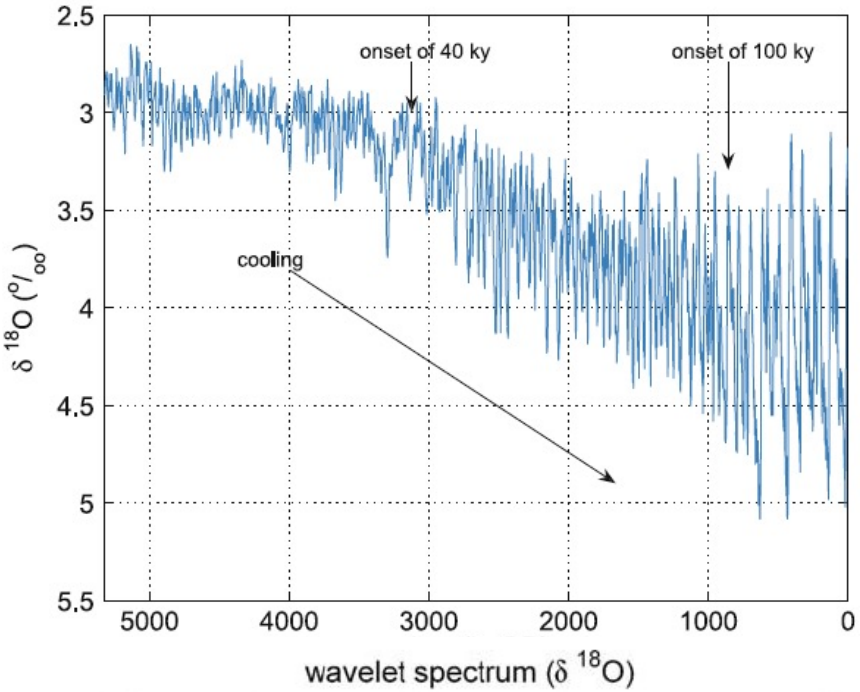
- Complex Models

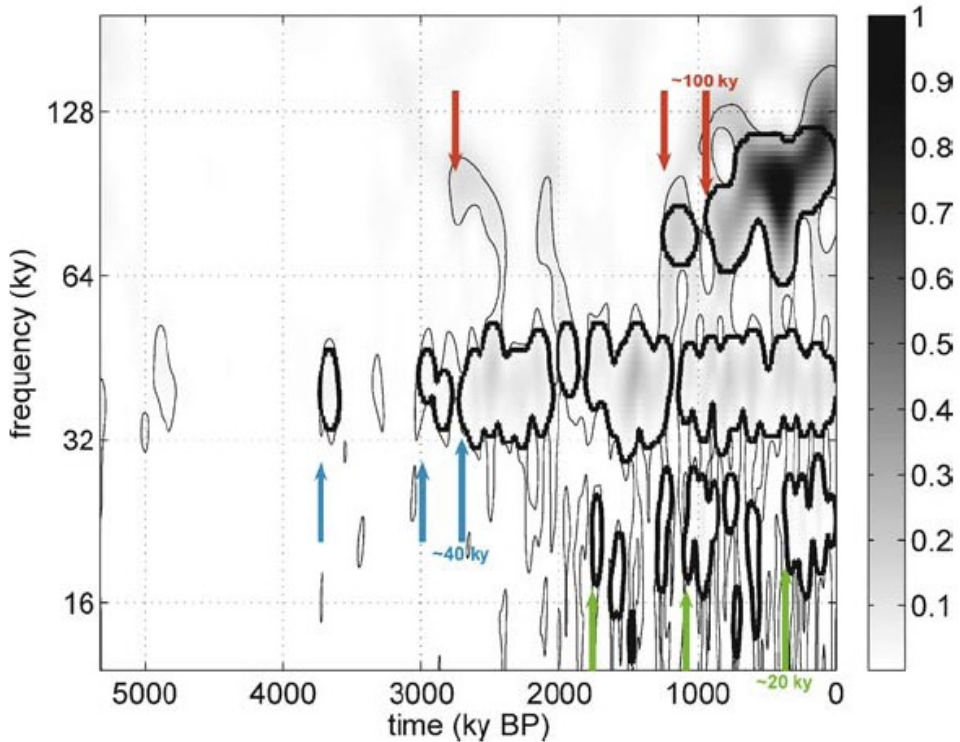
  Computer

Theory of ice ages: Rectification

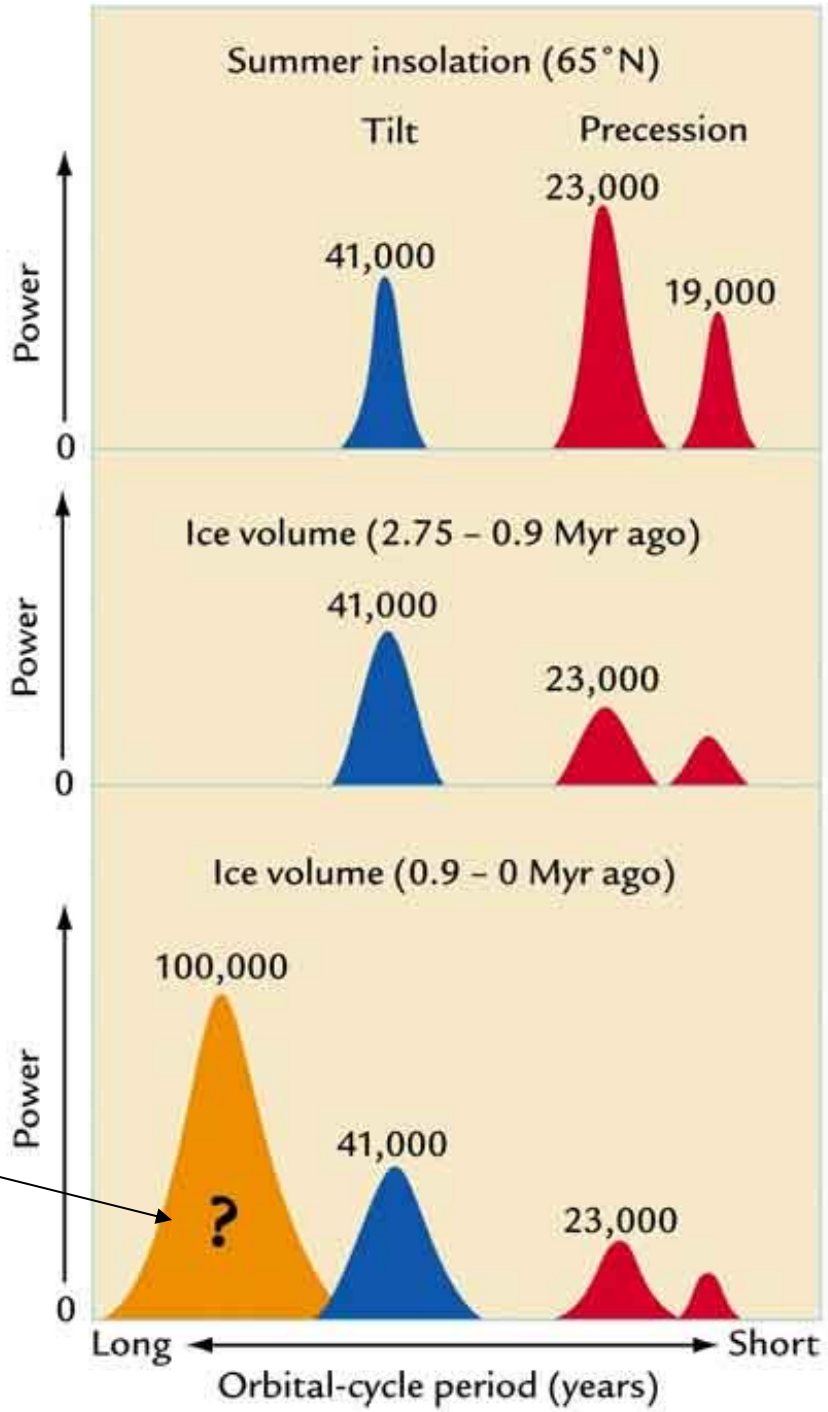


Ice ages


onset of 40 ky
onset of 100 ky
cooling
δ 18O (‰)
2.5
3
3.5
4
4.5
5
5.5
5000
4000
3000
2000
1000
0
wavelet spectrum (δ 18O)


~100 ky
~40 ky
~20 ky
frequency (ky)
128
64
32
16
5000
4000
3000
2000
1000
0
time (ky BP)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

A holy grail


Summer insolation (65°N)
Tilt
Precession
23,000
41,000
19,000
Power
0
Ice volume (2.75 – 0.9 Myr ago)
41,000
23,000
Power
0
Ice volume (0.9 – 0 Myr ago)
100,000
41,000
23,000
?
Power
0
Long
Short
Orbital-cycle period (years)