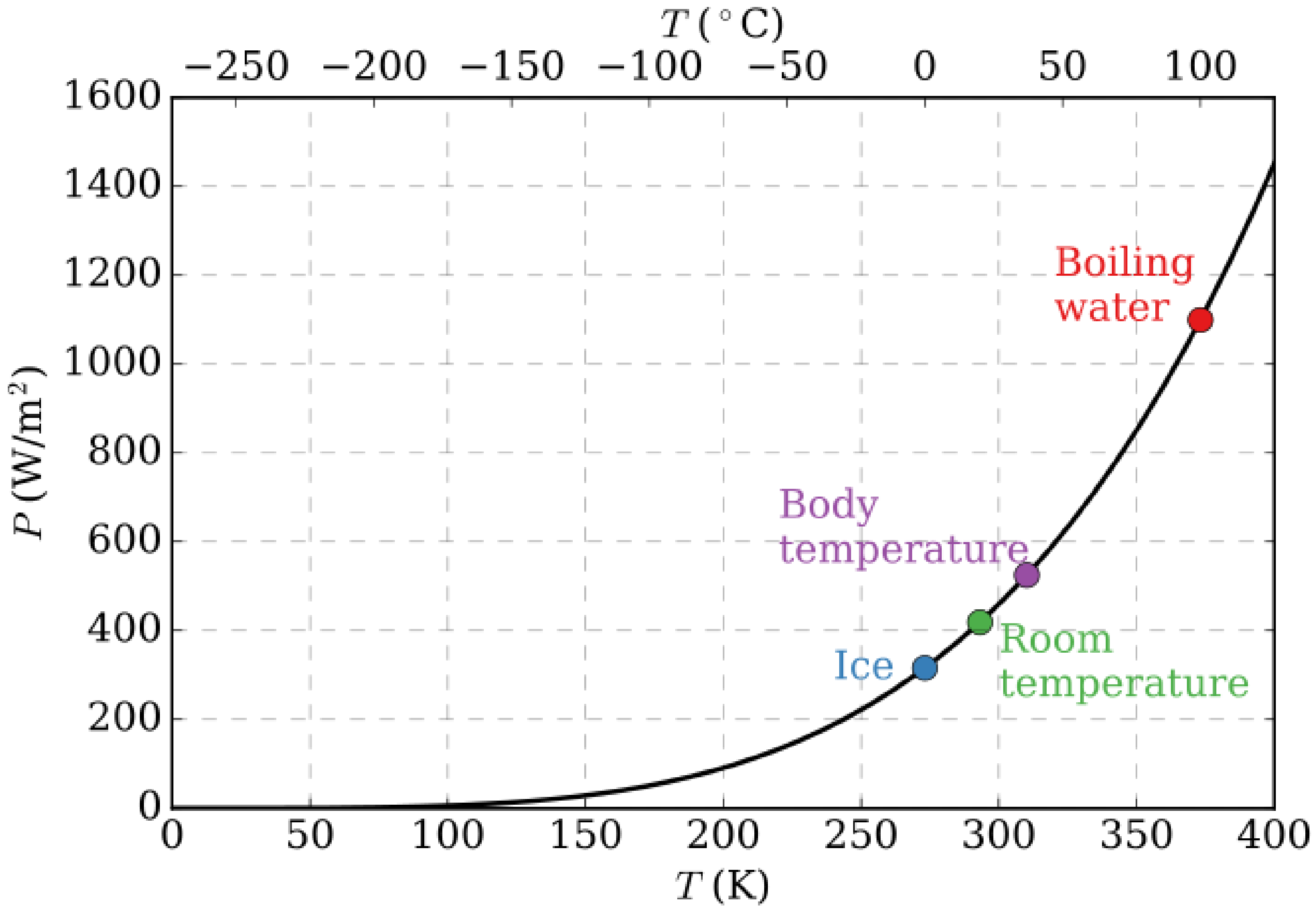
Wärmestrahlung – Stefan-Boltzmann Gesetz



By Nicoguaro - wikipedia

Thermodynamik

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial p}{\partial T}\right)_V - p$$

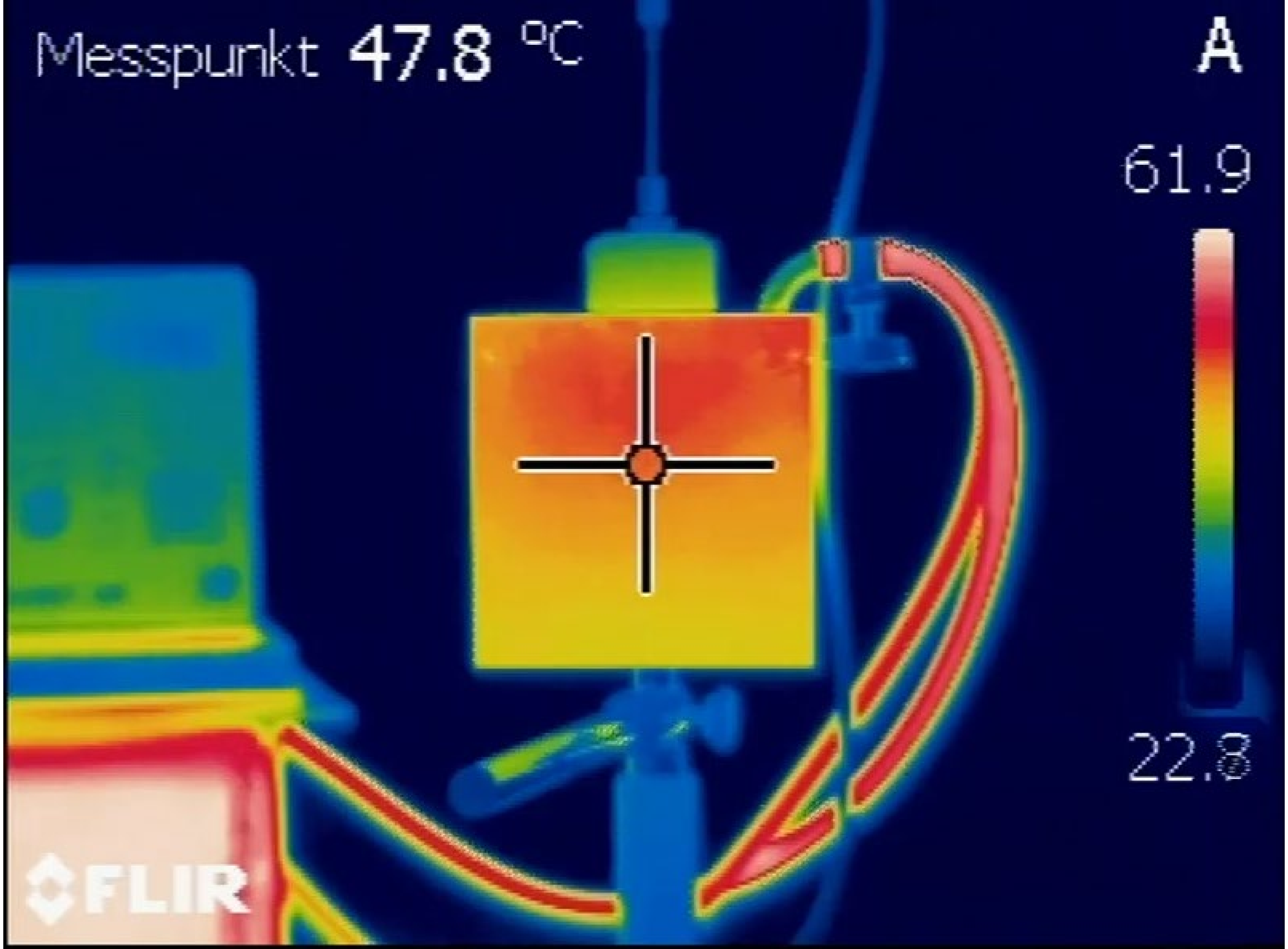
Elektrodynamik

$$p = \frac{u}{3}$$

ergibt zusammengenommen

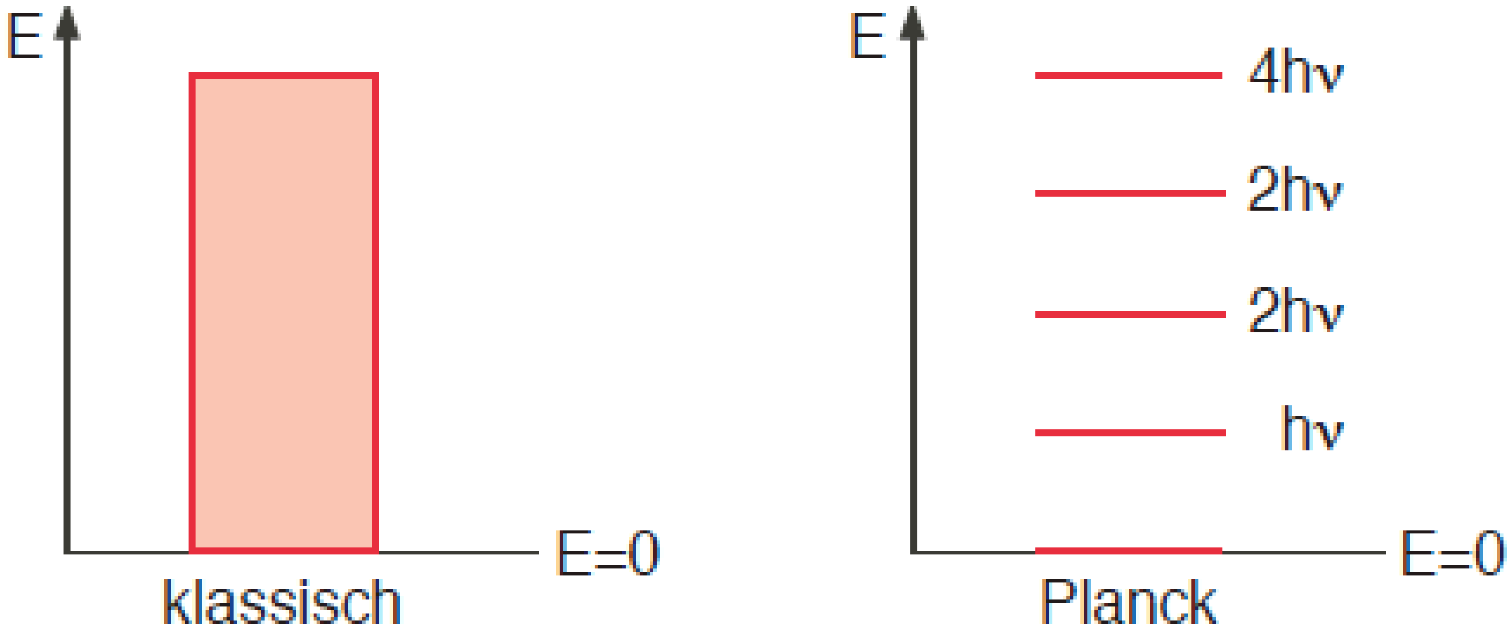
$$P = \sigma \cdot A \cdot T^4$$


Messpunkt
°C
A
77.5
22.9

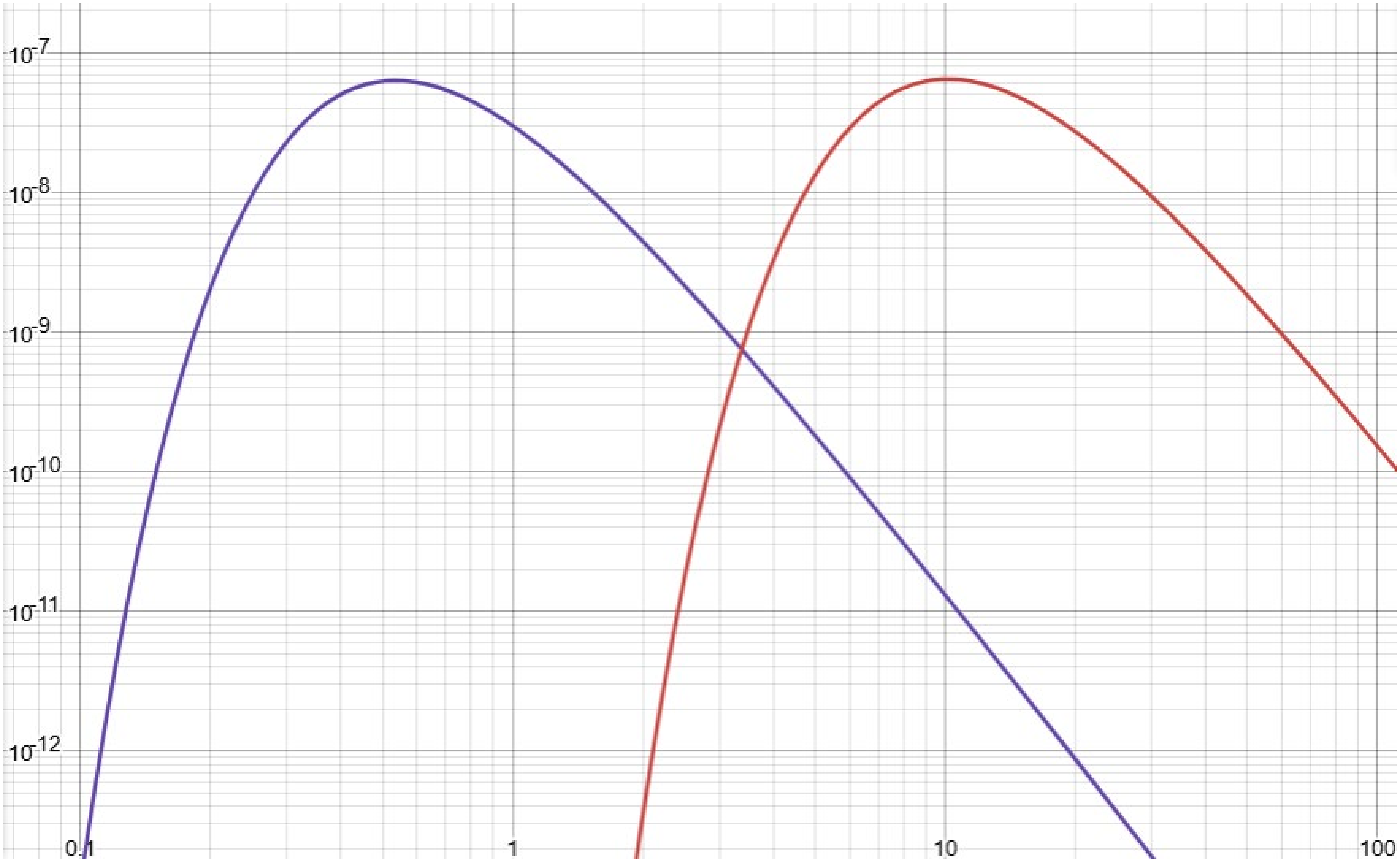

Messpunkt 47.8 °C
A
61.9
22.8

Was wenn die Strahlung nur bestimmte Energien annehmen kann?

$$E_n = n \cdot h\nu \ , n = 0, 1, 2, 3, \ldots$$



Plancksche Konstante: $h = 6.626176 \times 10^{-34}$ Js



10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
0.1
1
10
100

Das ergibt das Planck’sche Strahlungsgesetz für einen schwarzen Körper

-

$$u(\nu, T)d\nu = (8\pi h\nu^3)/c^3\,[\exp(h\nu/k_BT) - 1)]^{-1}d\nu$$

$$u(\lambda, T)d\lambda = (8\pi hc)/\lambda^5\,[\exp(hc/\lambda k_BT) - 1)]^{-1}d\lambda$$

Plancksche Konstante: $h = 6.626176 \times 10^{-34}$ Js

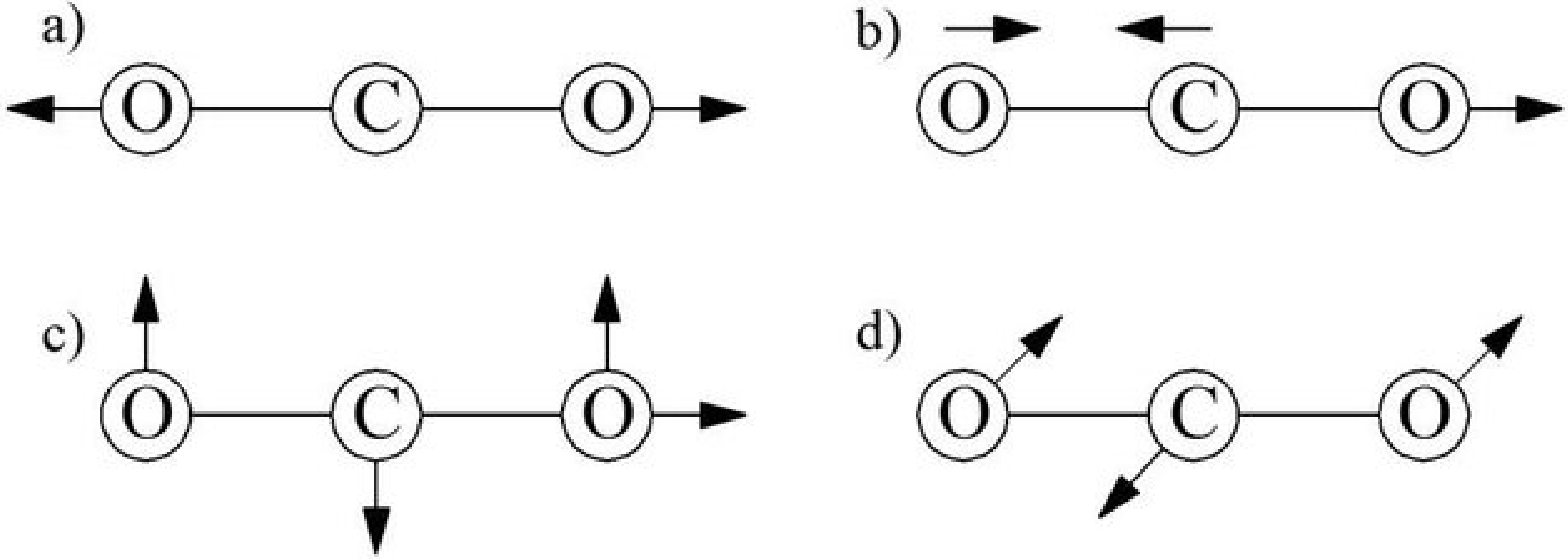
Und daraus folgt auch das Stefan-Boltzmann’sche Gesetz

Damit können wir die Stefan-Boltzmann Konstante direkt aus dem Planck‘schen Gesetz bestimmen

$$\sigma = \frac{2\pi^5 k_B^4}{15c^2h^3} = 5.67051(19) \cdot 10^{-8} \frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}^4}$$

Wir können also aus den fundamentalen konstanten h, k und c, sowie der Solarkonstanten eine mittlere Gleichgewichtstemperatur der Erde ausrechnen (inkl Albedo), was 253 K ergäbe.

Mit den Bindungseigenschaften erhalten wir die Absorptionseigenschaften



Mit den Bindungseigenschaften erhalten wir die Absorptionseigenschaften

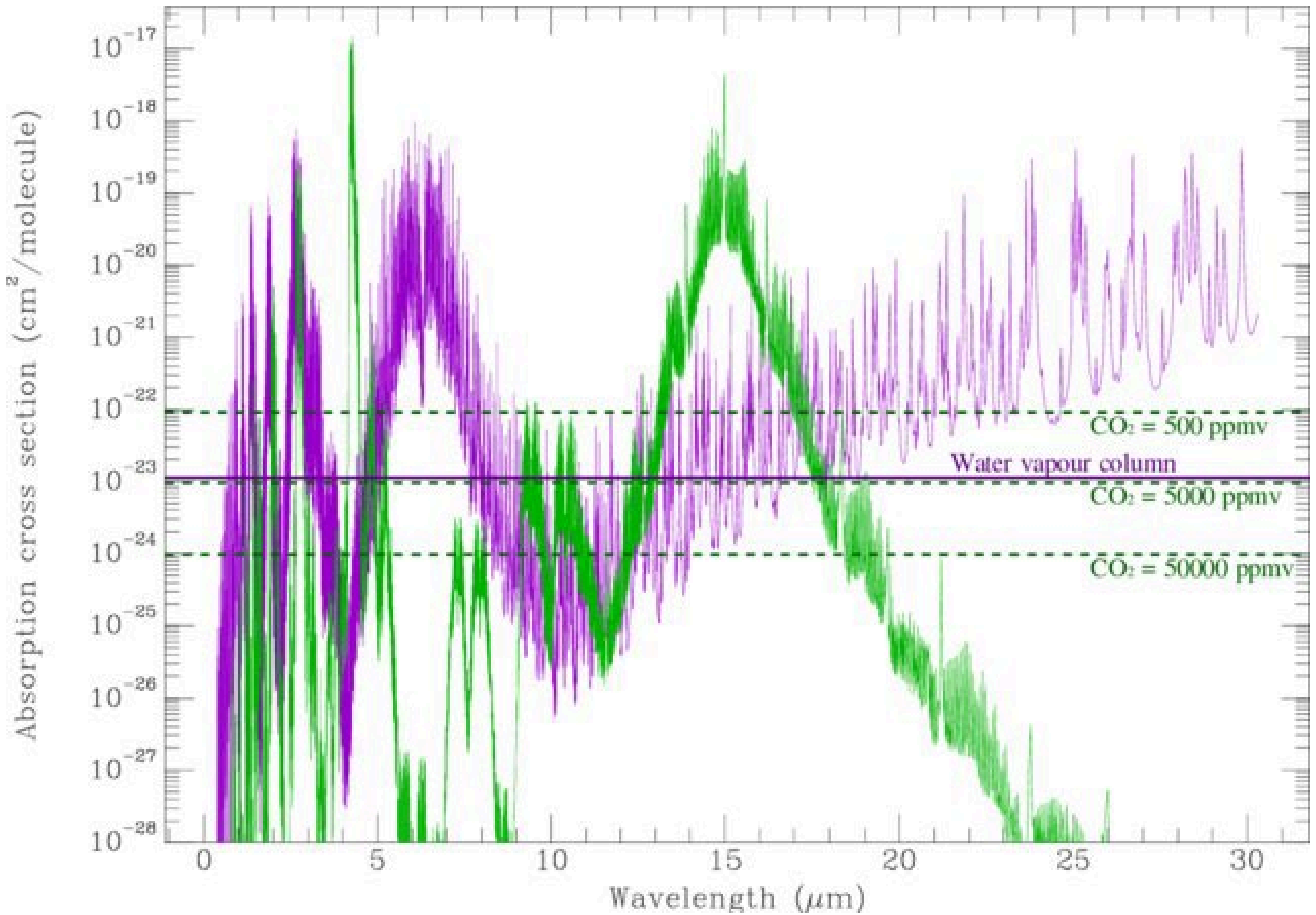
*Bond Lengths, *pm*			
Multiple	**Bonds**		
C=C	134	O=O	121
C≡C	120		
C=N	127	N=N	122
C≡N	115	N≡N	113
C=O	121		
C≡O	113	S=O	133

*Bond Energies, *D*, (kJ/mol)			
Multiple	**Bonds**		
C=C	611	O=O	498
C≡C	837		
C=N	615	N=N	418
C≡N	891	N≡N	946
C=O	799		
C≡O	1072	S=O	523

$$\lambda = \frac{2\pi c}{\omega} = \sqrt{\frac{4\pi^2 c^2 m}{k}} = \sqrt{\frac{4\pi^2 c^2 x^2 m}{2E}} = 2\pi x \sqrt{\frac{mc^2}{2E}}$$

$$\lambda = 20\sqrt{\frac{12}{16}} 10^{-6} m \simeq 15 \mu m$$

Mittlere freie Weglänge und Absorptionsquerschnitt



$$\ell = (\sigma n)^{-1}$$

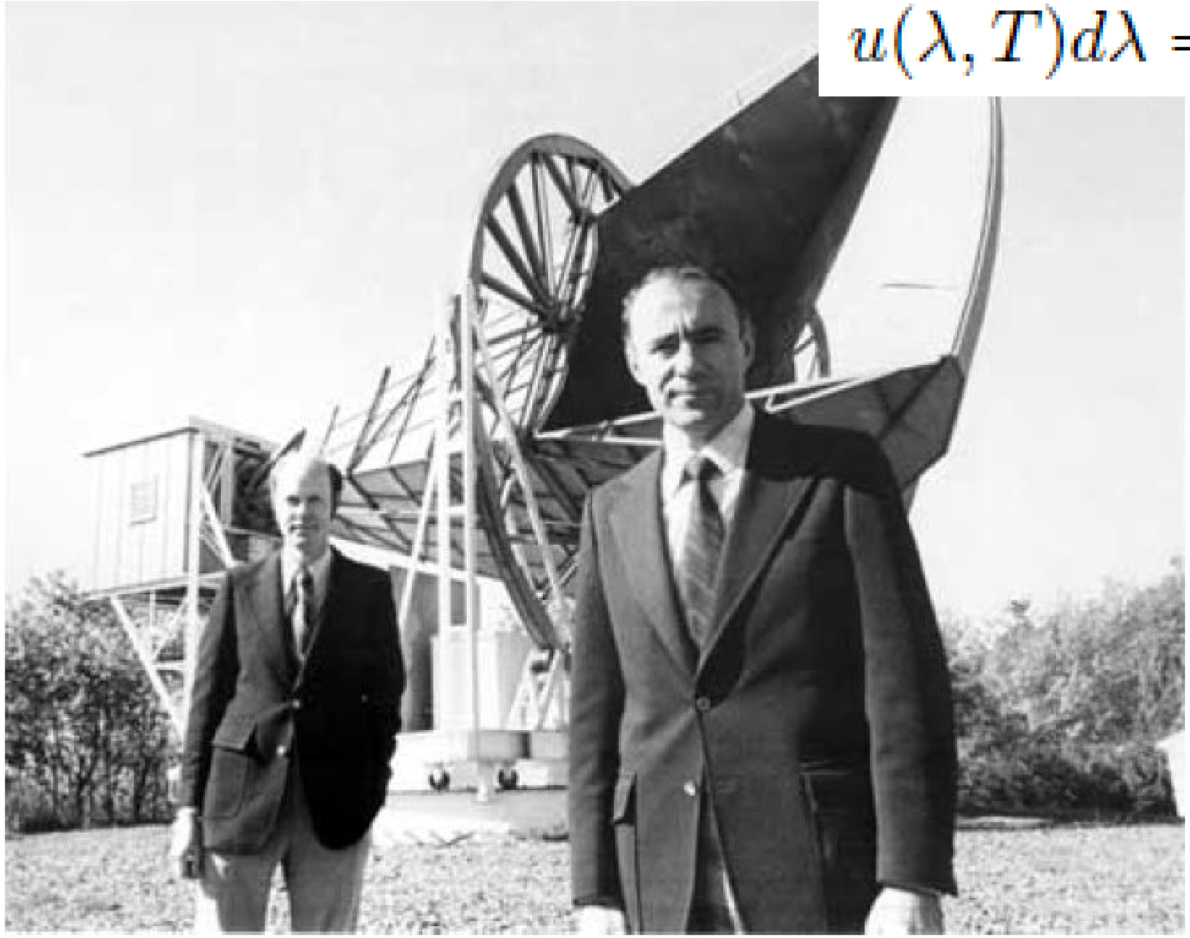
$$dI = -In\sigma\, dx$$

Die Absorptions-länge in der Atmosphäre ist also etwa 30 m

File:Absorption-cross-sections-for-CO2-green-and-water-vapour-purple-from-HITRAN.jpg - Wikimedia Commons

Temperaturen aus Intensitäten (kosmische Hintergrundstrahlung, Wärmebildkamera)

$$u(\lambda, T)d\lambda = (8\pi hc)/\lambda^5 \left[\exp(hc/\lambda k_B T) - 1)\right]^{-1} d\lambda$$



A. Penzias und R. Wilson, Bell Labs, 1965
Nobelpreis 1978

$$T = \frac{hc}{k_B \lambda \ln\left(1 + \frac{2hc^2 \Delta\lambda}{I\lambda^5}\right)}$$

$$T \simeq \frac{\lambda^4}{2k_B c \Delta\lambda} I$$

Gemessene Mikrowellenintensität ohne bekannte Quelle ergibt eine Temperatur von 3.5±1.0 K

$$\sigma = \frac{\mu^2 E_0^2 \delta\omega}{2\hbar\omega I} = 4\pi\alpha q^2 d^2 \frac{\delta\omega}{\omega}$$

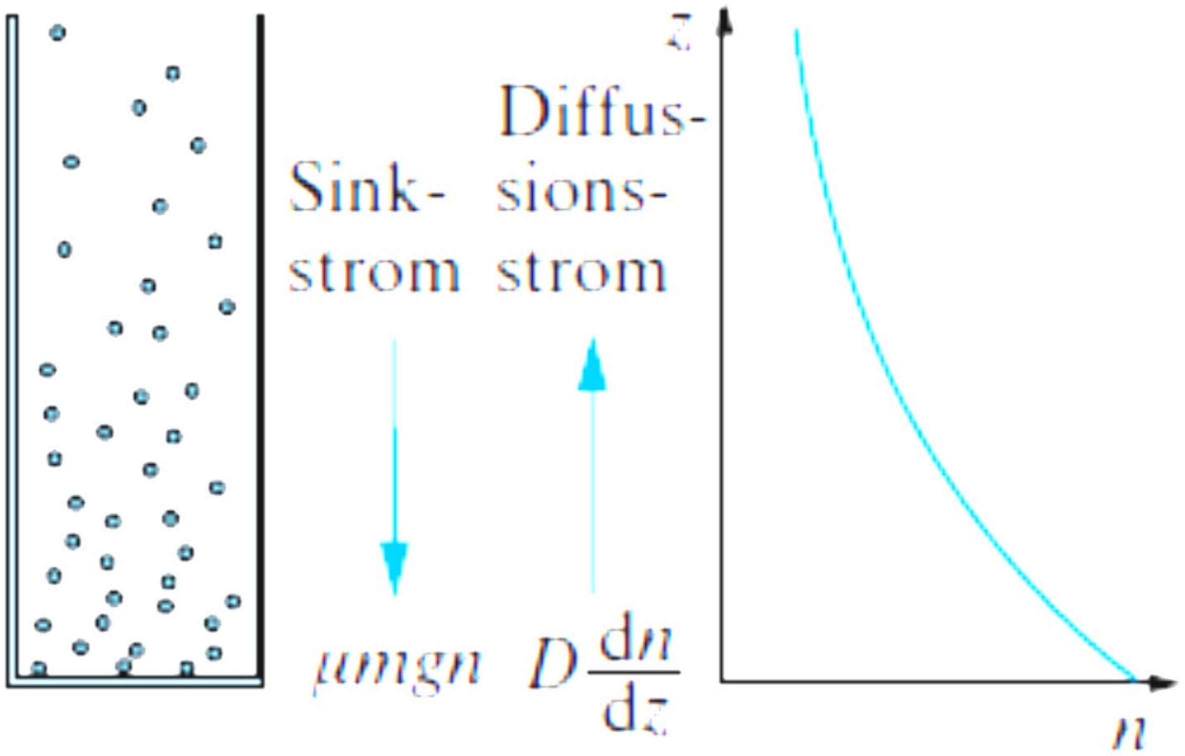
$$\sigma = \frac{4\pi}{137} 0.2^2 0.5^2 10^{-20} m^2 \frac{1}{3} = 2 \cdot 10^{-24} m^2$$

$$\ell = \frac{1}{n\sigma} = \frac{k_B T}{\rho p_0 \sigma} = \frac{4 \cdot 10^{-21} J}{4 \cdot 10^{-4} 10^5 Pa 2 \cdot 10^{-24} m^2} = 50m$$

Wie nimmt der Druck mit der Höhe ab?

$$\frac{\mathrm{d}p}{\mathrm{d}h} = -g\frac{\varrho_0}{p_0}\,p$$

$$p(h) = p_0 \mathrm{e}^{-g\varrho_0 h/p_0}$$



$$n = n_0 \mathrm{e}^{-mgh/(kT)}$$

Boltzmann Verteilung!

Dadurch nimmt die Absorptionslänge mit der Höhe zu!

Was macht die Temperatur in der Atmosphäre?

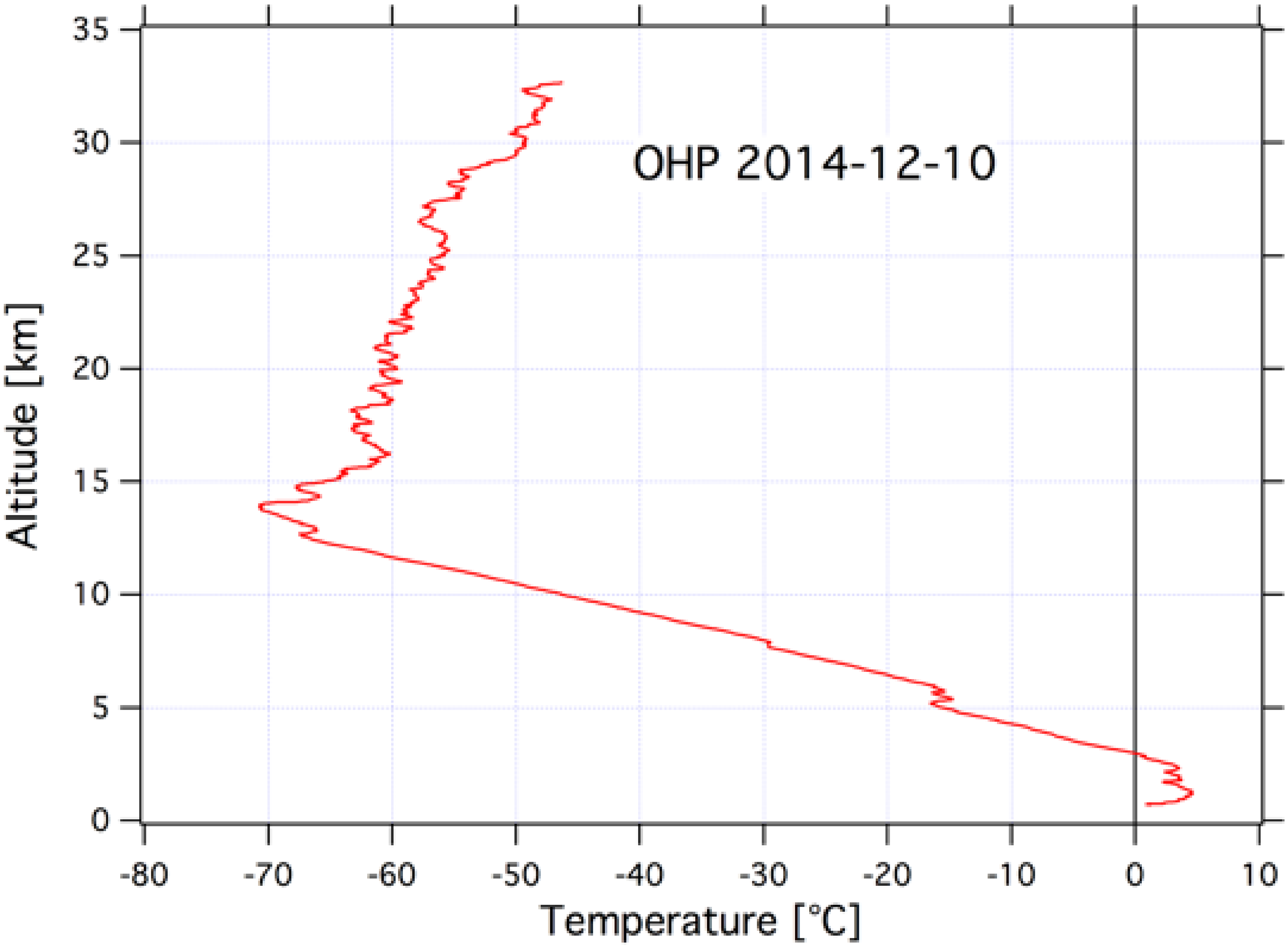
$$P\mathrm{d}V = -\frac{V\mathrm{d}P}{\gamma}$$

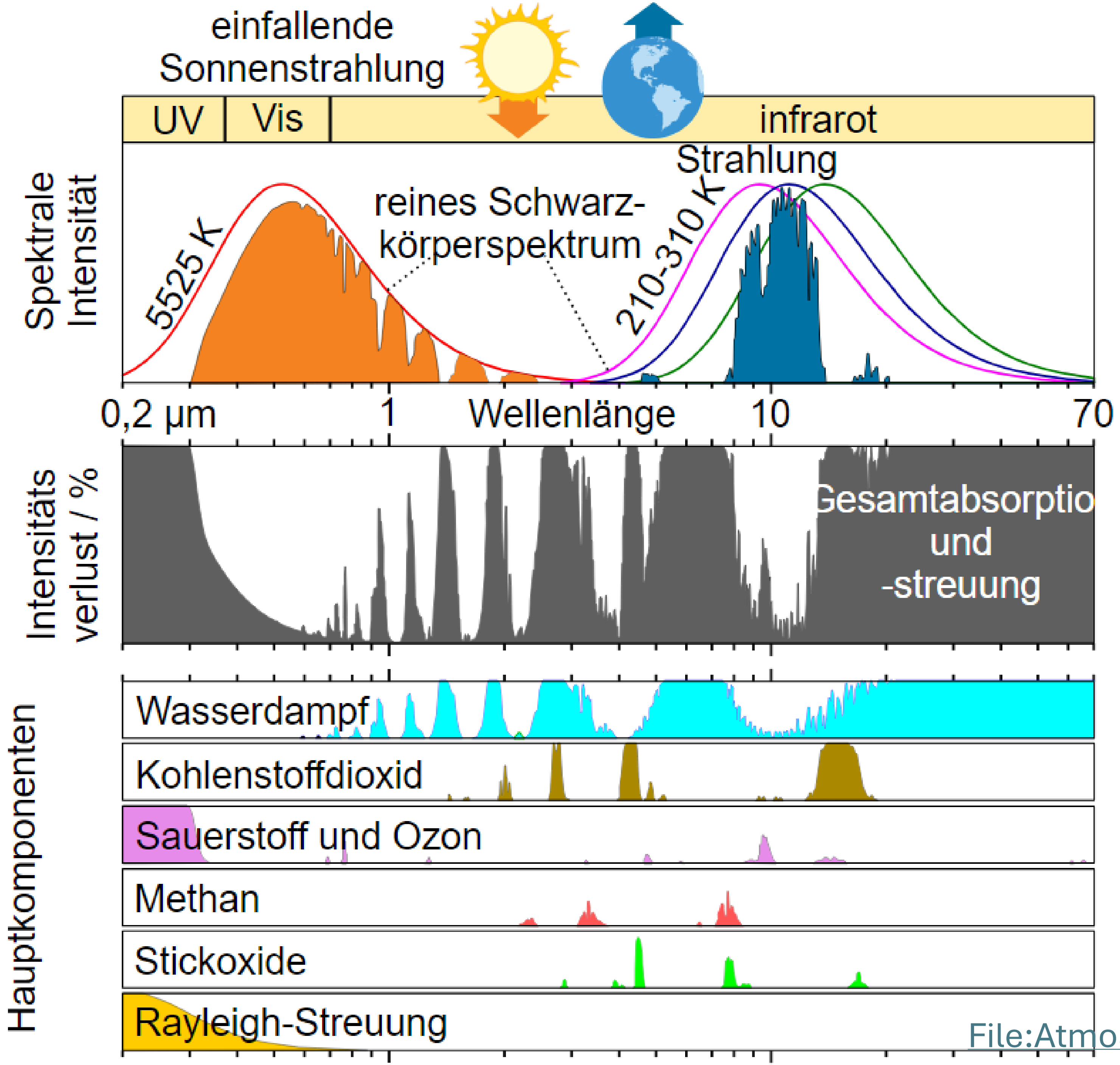
$$\rho c_\mathrm{p}\mathrm{d}T - \mathrm{d}P = 0$$

$$mc_\mathrm{v}\mathrm{d}T - \frac{V\mathrm{d}P}{\gamma} = 0$$

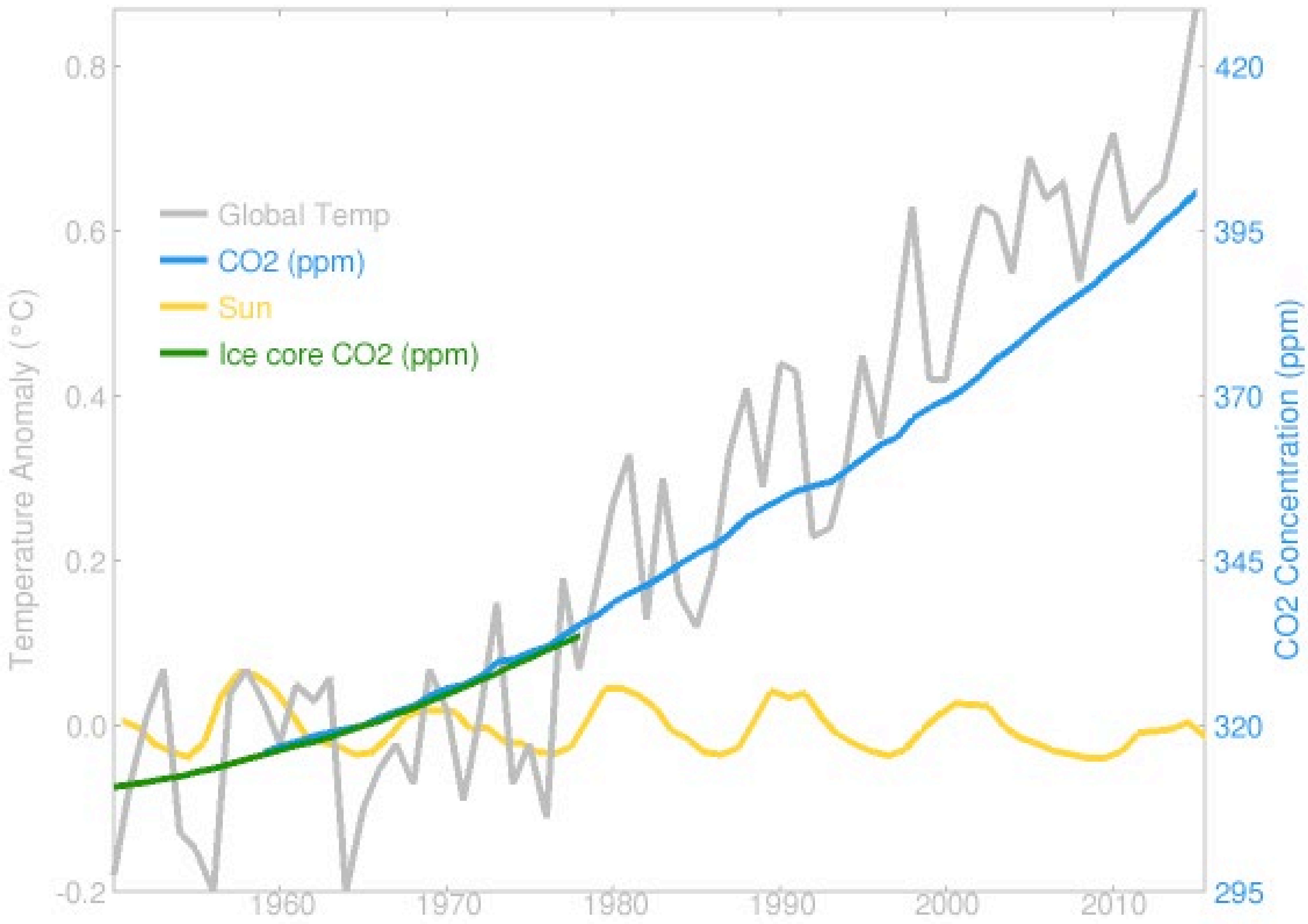
$$\mathrm{d}P = -\rho g \mathrm{d}z$$

$$-\frac{\mathrm{d}T}{\mathrm{d}z} = \frac{g}{c_\mathrm{p}}$$

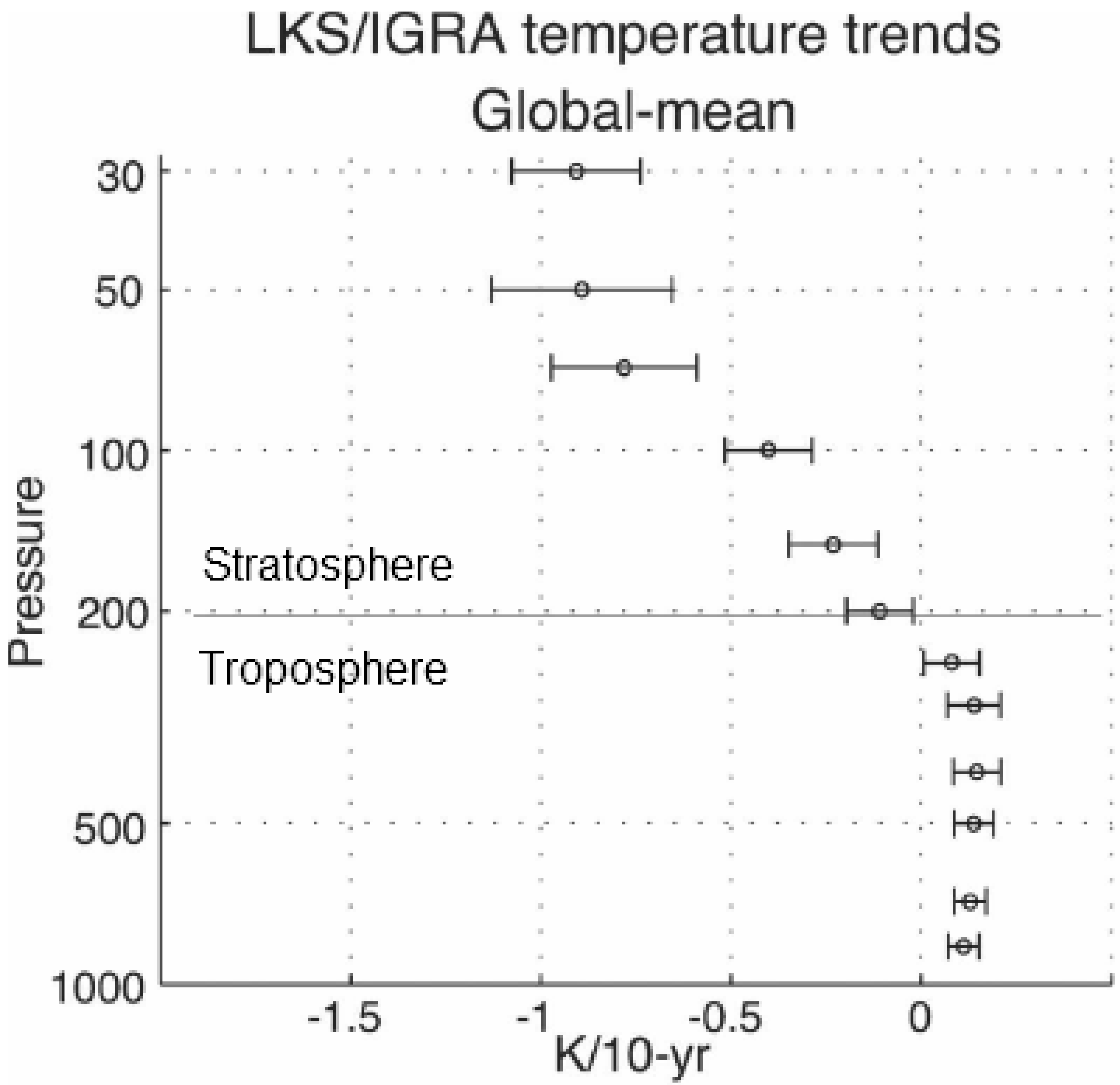

OHP 2014-12-10
Altitude [km]
Temperature [°C]
0
5
10
15
20
25
30
35
-80
-70
-60
-50
-40
-30
-20
-10
0
10



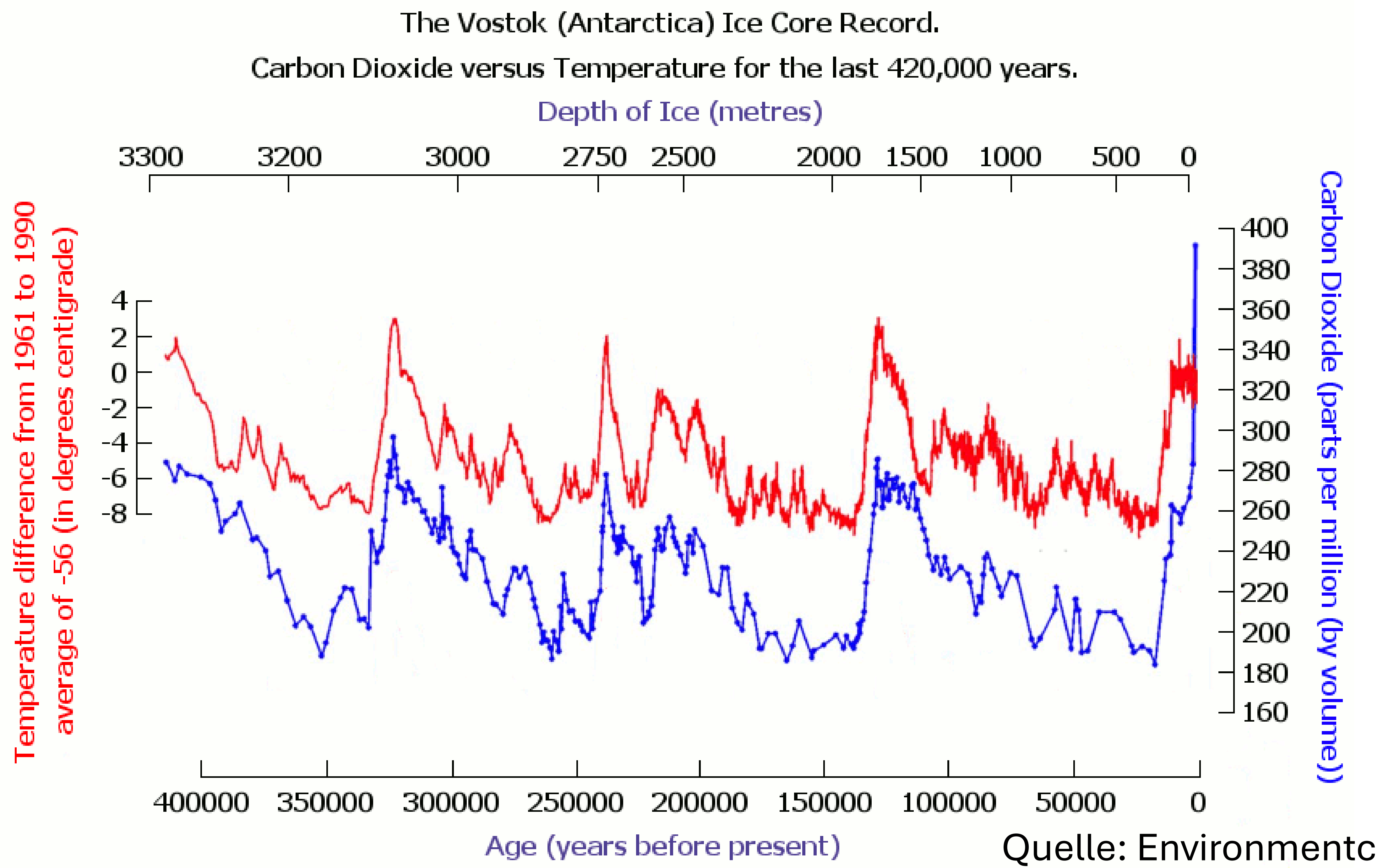
File:Atmospheric Transmission.svg - Wikimedia Commons



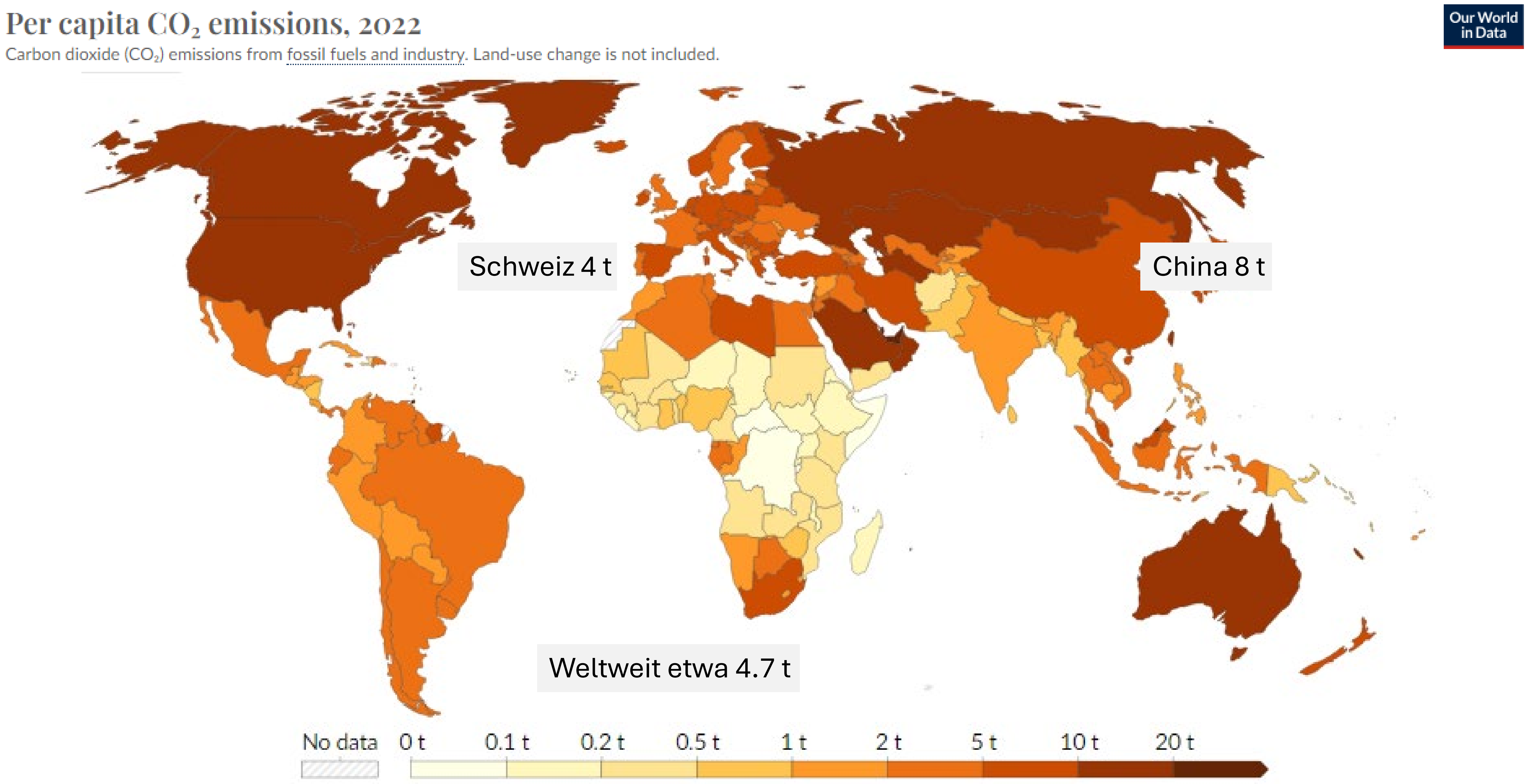
Quelle:
Realclimate.org



LKS/IGRA temperature trends
Global-mean
Pressure
30
50
100
200
500
1000
Stratosphere
Troposphere
-1.5
-1
-0.5
0
K/10-yr

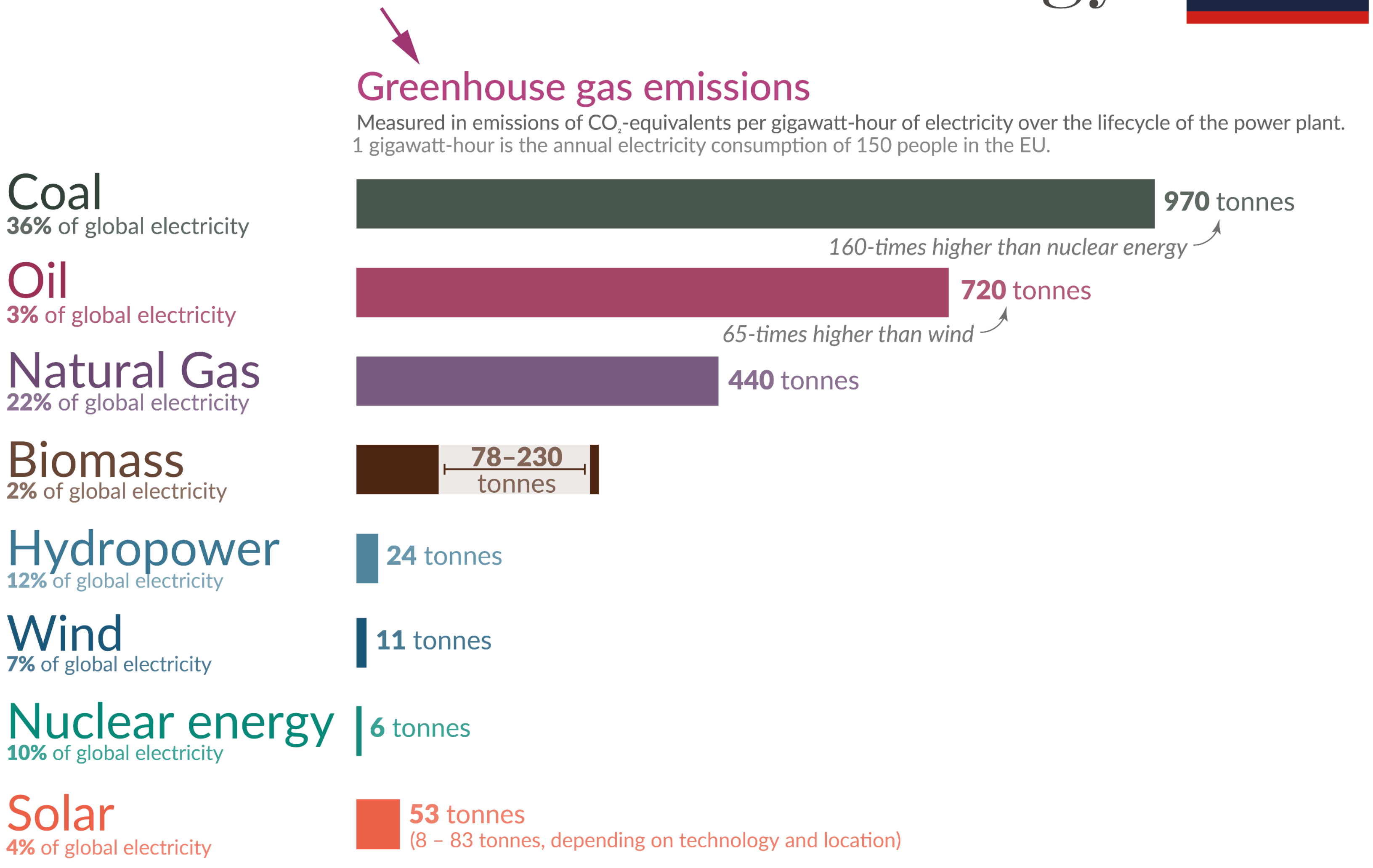


Quelle: Environmentcounts.org


Per capita CO_2 emissions, 2022
Carbon dioxide (CO_2) emissions from fossil fuels and industry. Land-use change is not included.
Our World in Data
Schweiz 4 t
China 8 t
Weltweit etwa 4.7 t
No data
0 t
0.1 t
0.2 t
0.5 t
1 t
2 t
5 t
10 t
20 t

What are the cleanest sources of energy?

Our World in Data



Death rates from fossil fuels and biomass are based on state-of-the art plants with pollution controls in Europe, and are based on older models of the impacts of air pollution on health. This means these death rates are likely to be very conservative. For further discussion, see our article: OurWorldinData.org/safest-sources-of-energy. Electricity shares are given for 2021.
Data sources: Markandya & Wilkinson (2007); UNSCEAR (2008; 2018); Sovacool et al. (2016); IPCC AR5 (2014); UNECE (2022); Ember Energy (2021).

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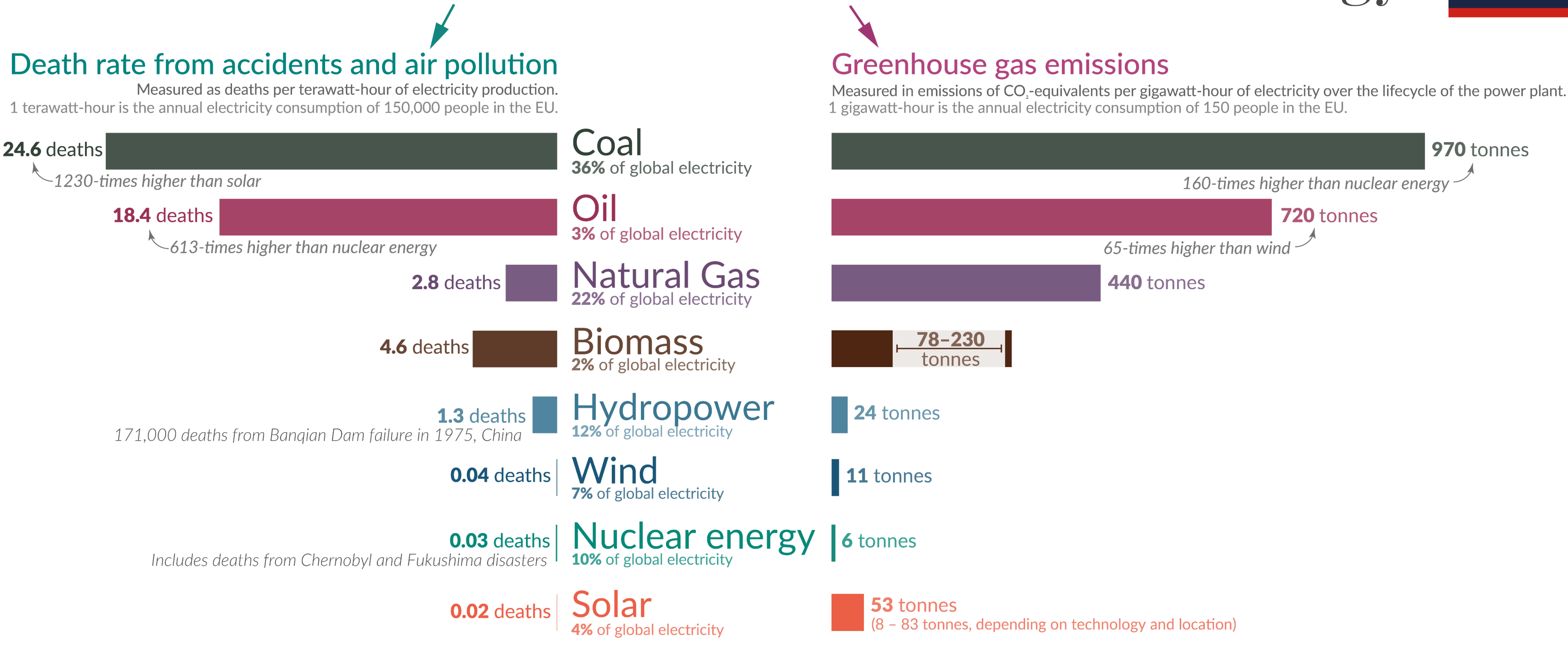
What are the safest and cleanest sources of energy?



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