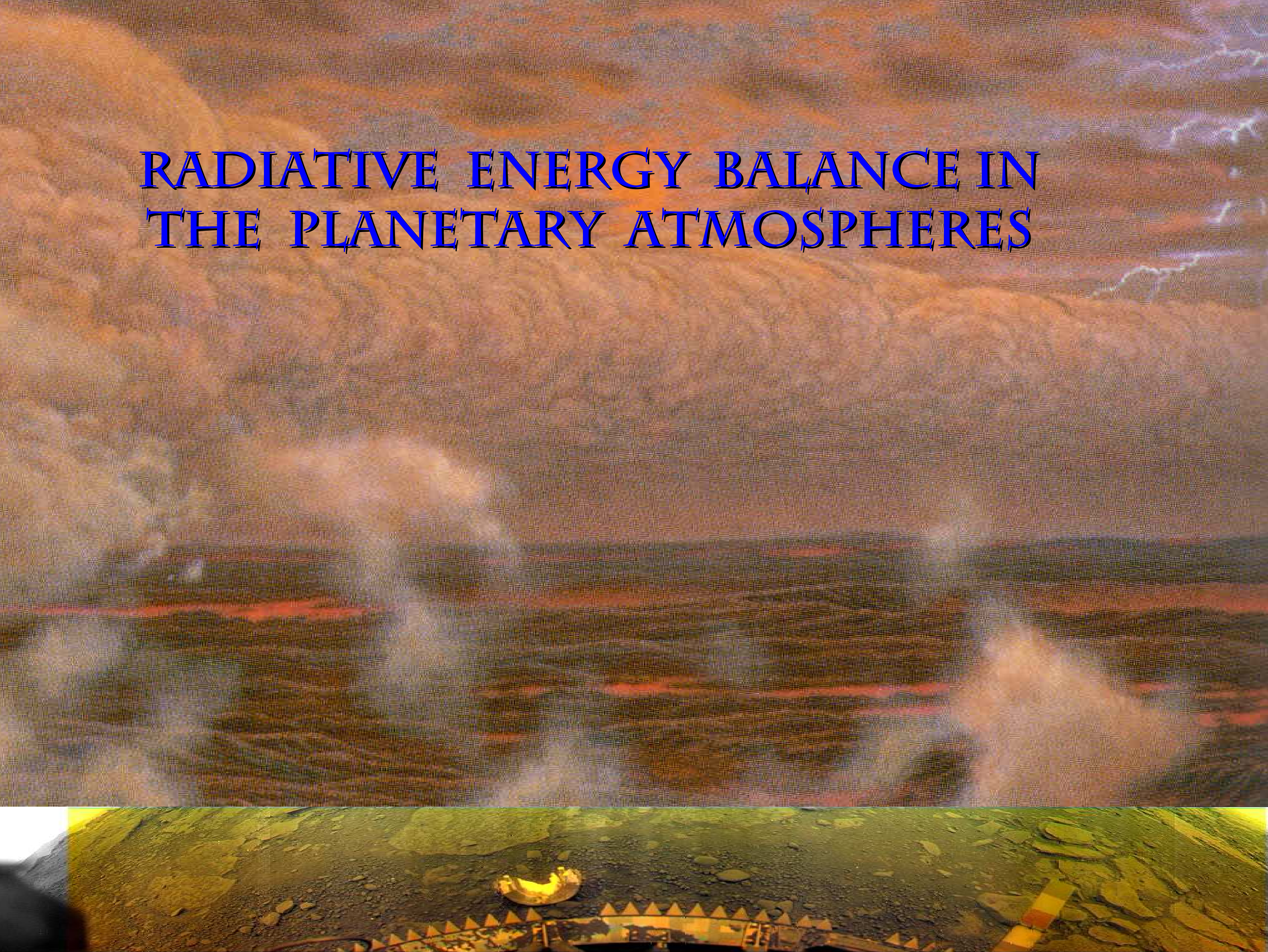
RADIATIVE ENERGY BALANCE IN THE PLANETARY ATMOSPHERES

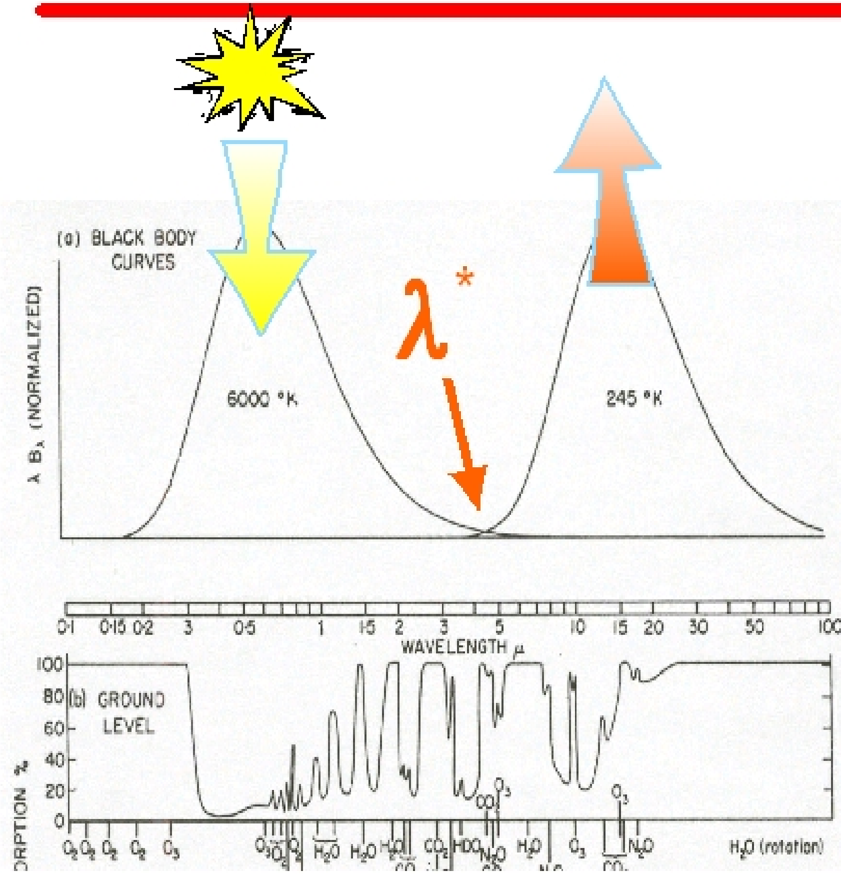


Outline of the talk

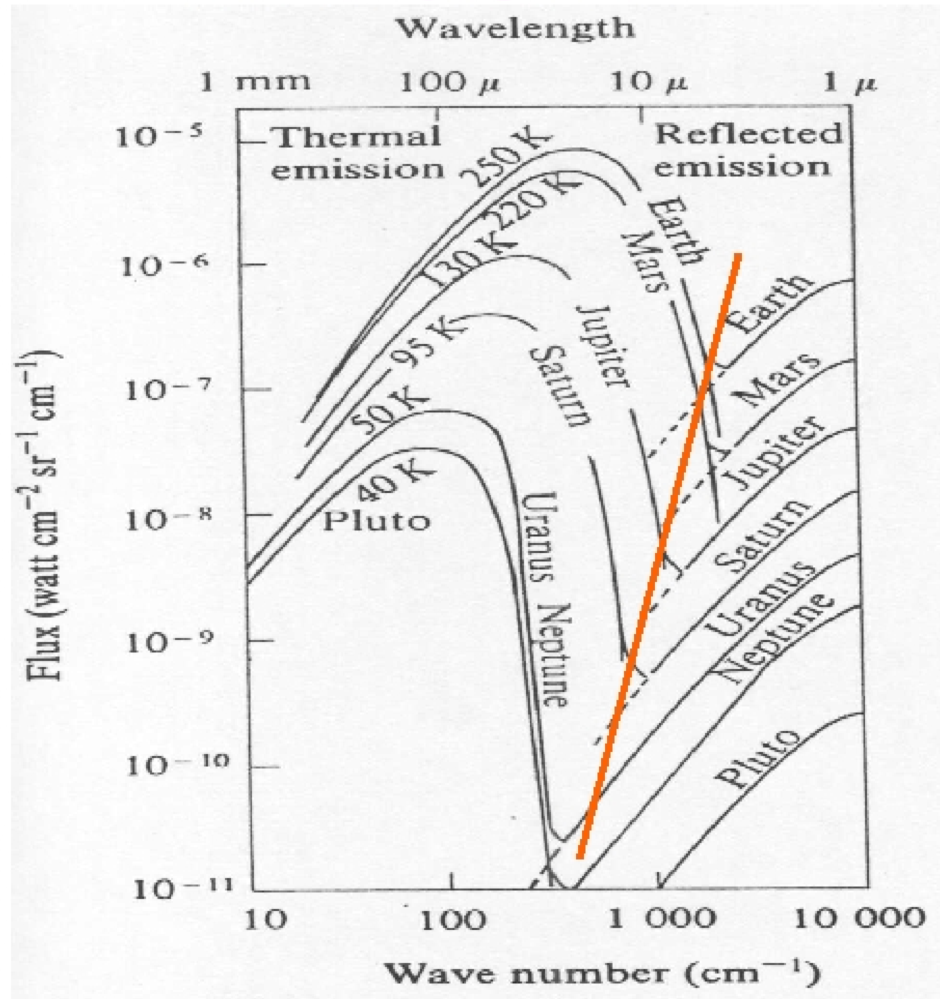
- *radiative energy budget*
- *forcing of the general circulation*
- *greenhouse effect*
- *balance of entropy*

Radiative energy budget

Energy balance of planets



Planetary spectra



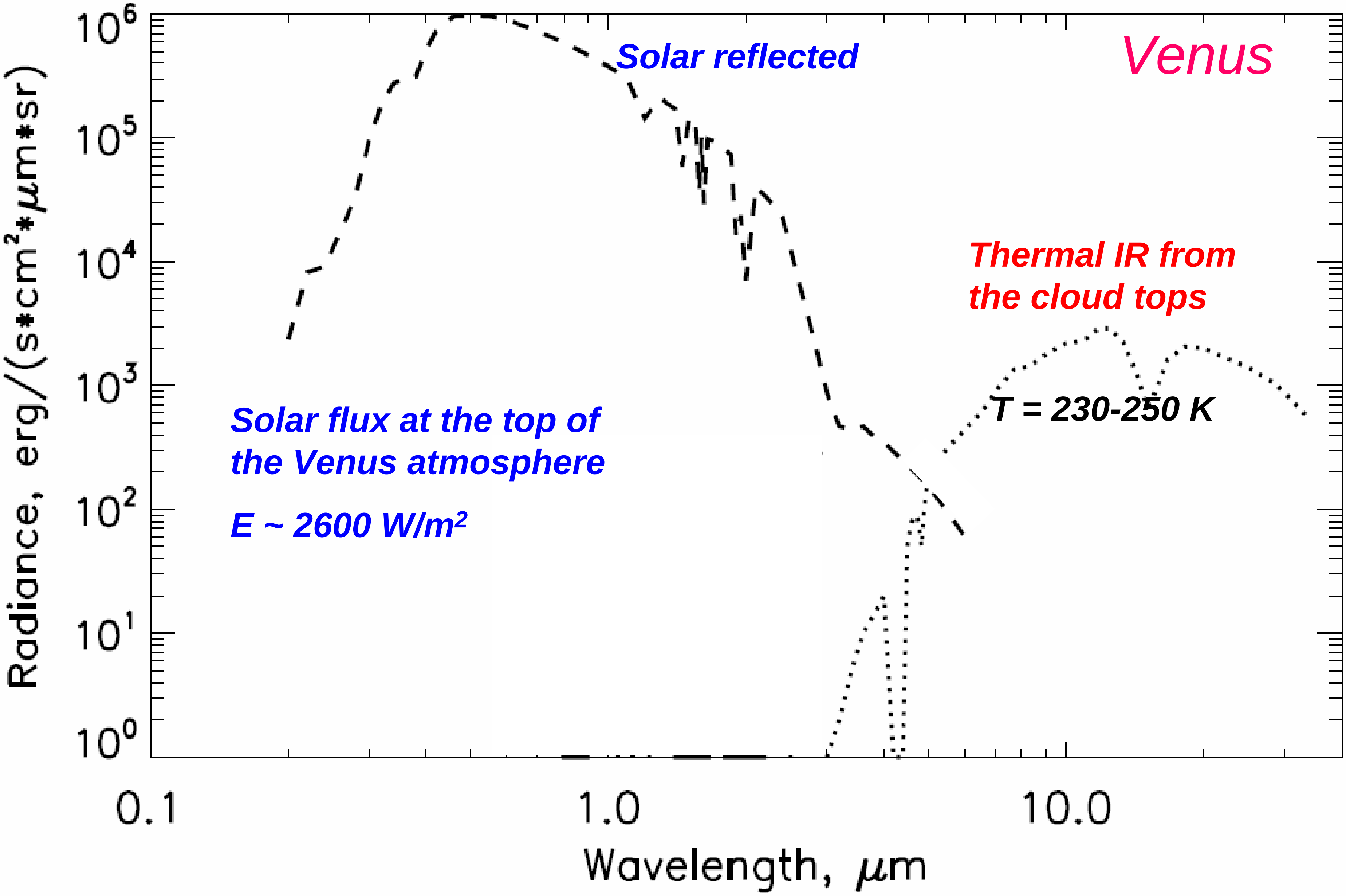
Effective temperature

$$E(1-A) = 4\sigma T^4_{eff}$$

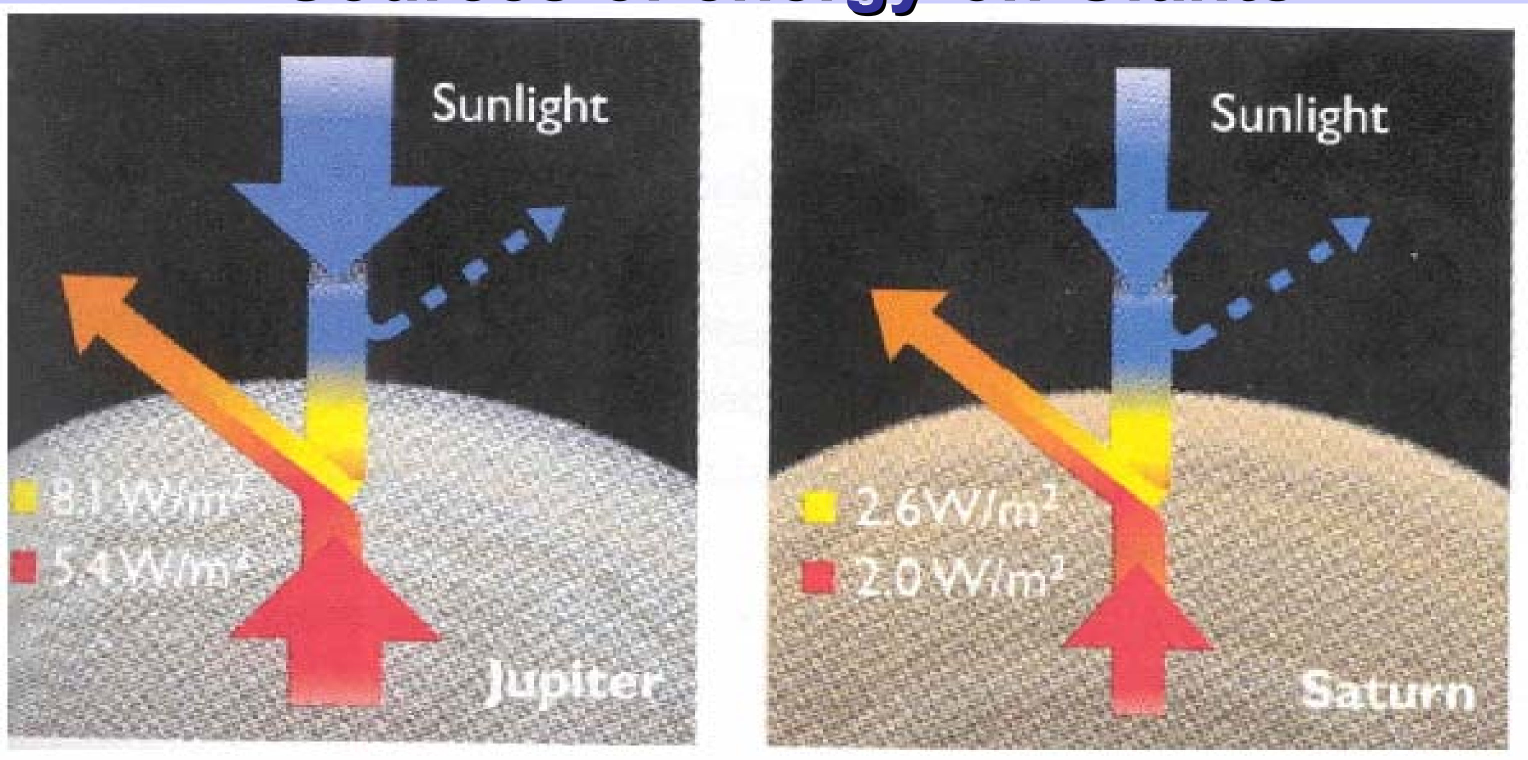
Solar constant

$E_\oplus = 1370\ W/m^2$

Composite spectrum of the outgoing radiation

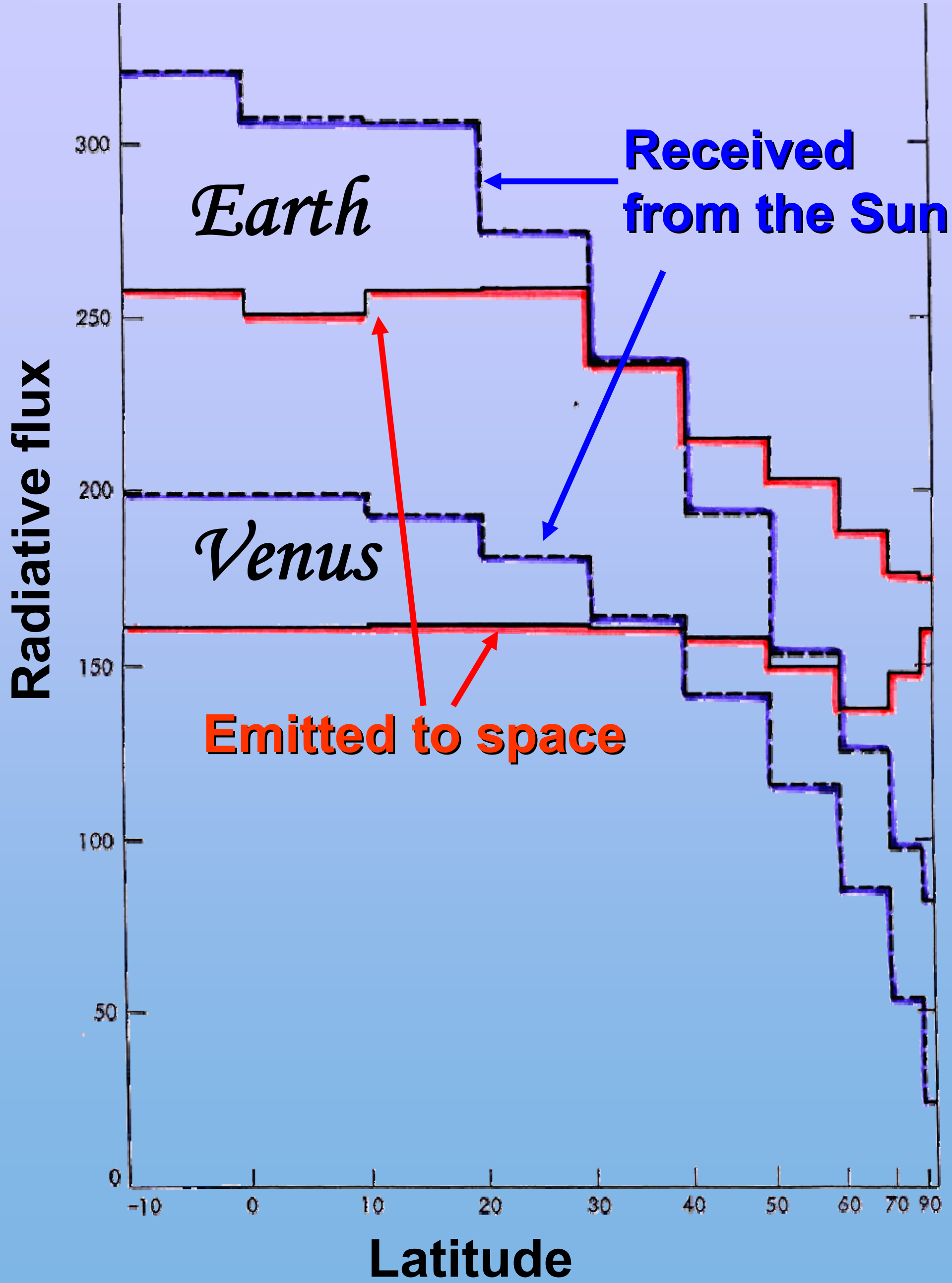


Sources of energy on Giants



	Earth	Jupiter	Saturn	Uranus	Neptune
D, au	1	5.2	9.56	19.22	30.11
Solar flux, W/m^2	1370	50.66	15	3.7	1.51
Energy balance, F_{IR} / F_{abs}	1	1.67	1.78	1.06	2.61

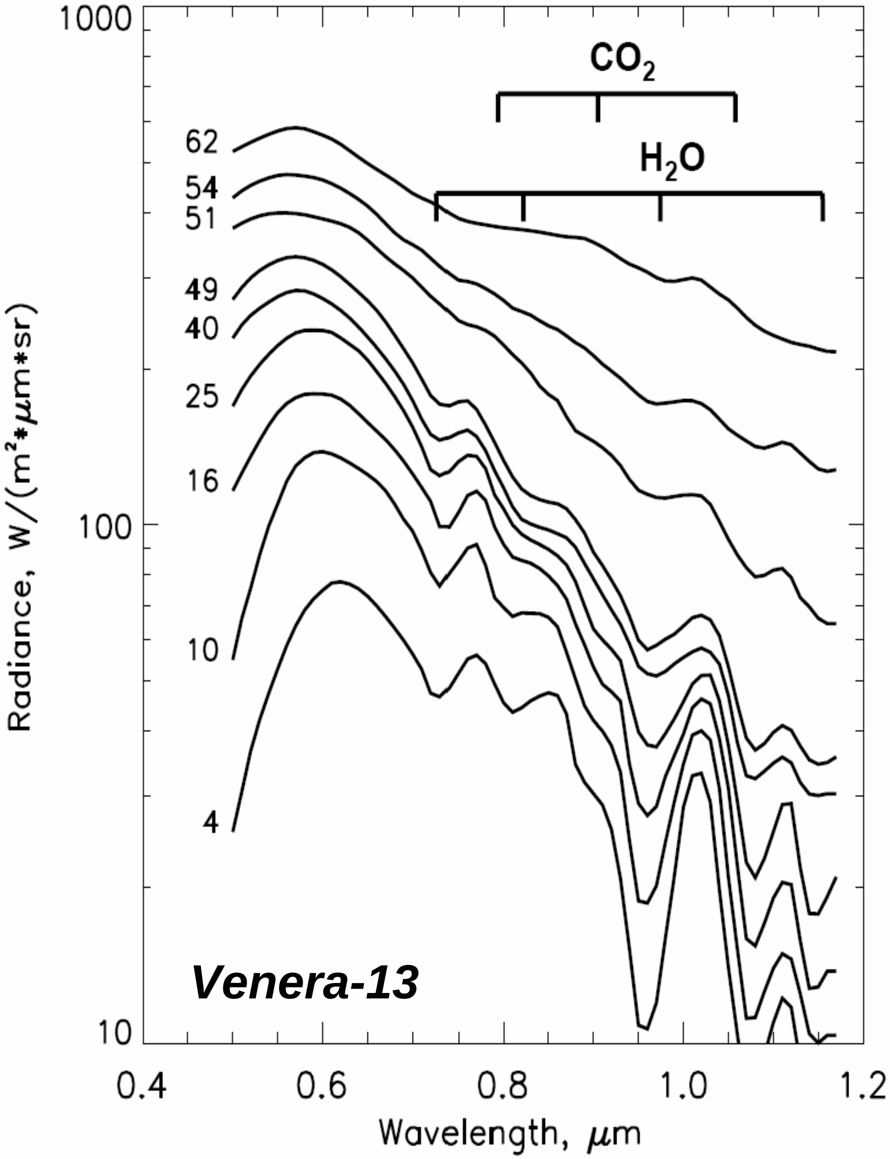
Latitudinal distribution of energy sources and sinks

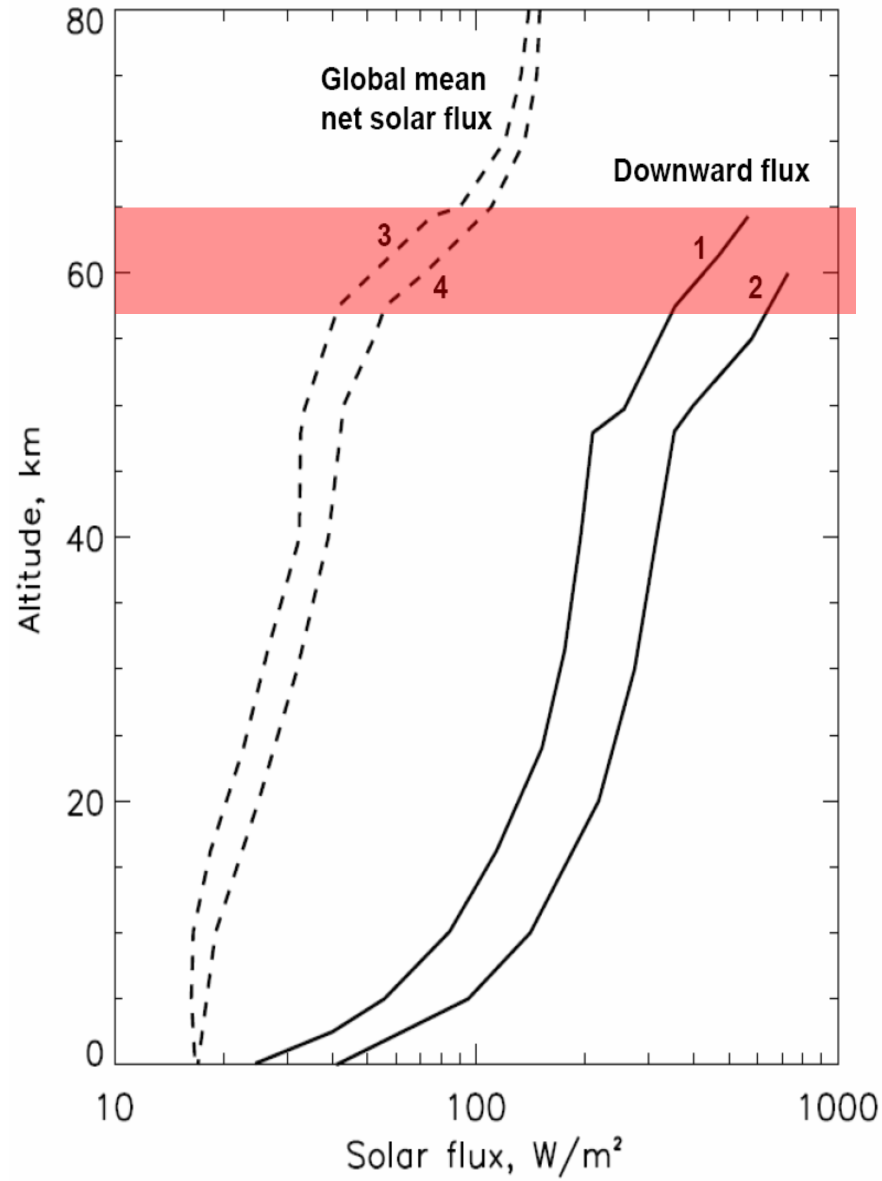


- *Venus gets less energy than the Earth !*
- *Net heating at equator, net cooling on poles*
- *Latitudinal distribution of radiative balance implies energy transport by circulation*

Taylor et al., 1983

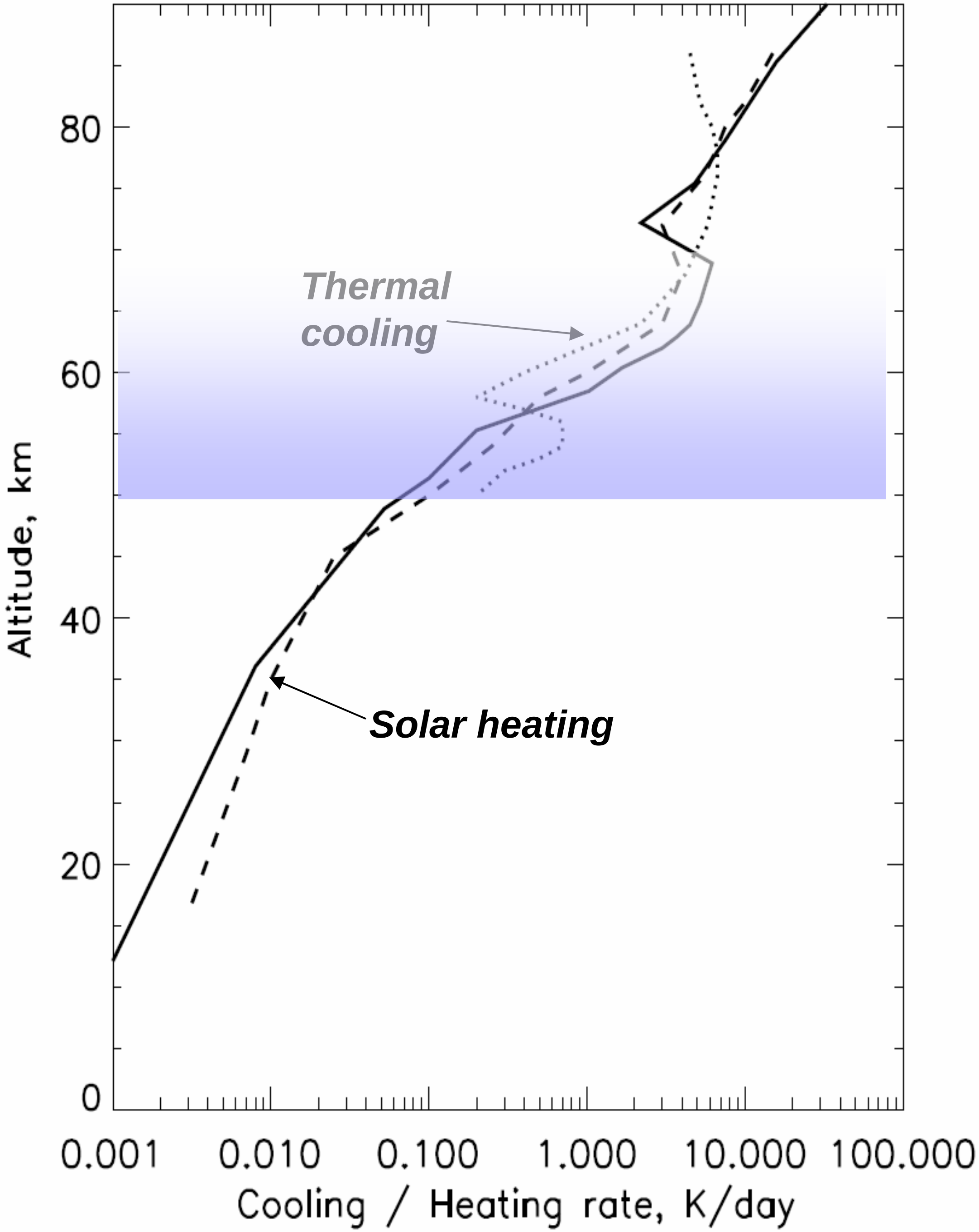
Vertical distribution of deposited solar energy





Ekonomov et al., 1983

Global mean heating and cooling rates



- *half of solar energy deposited on Venus is absorbed by the unknown UV absorber in the cloud layer*

Tomasko et al., 1985

Crisp & Titov, 1997

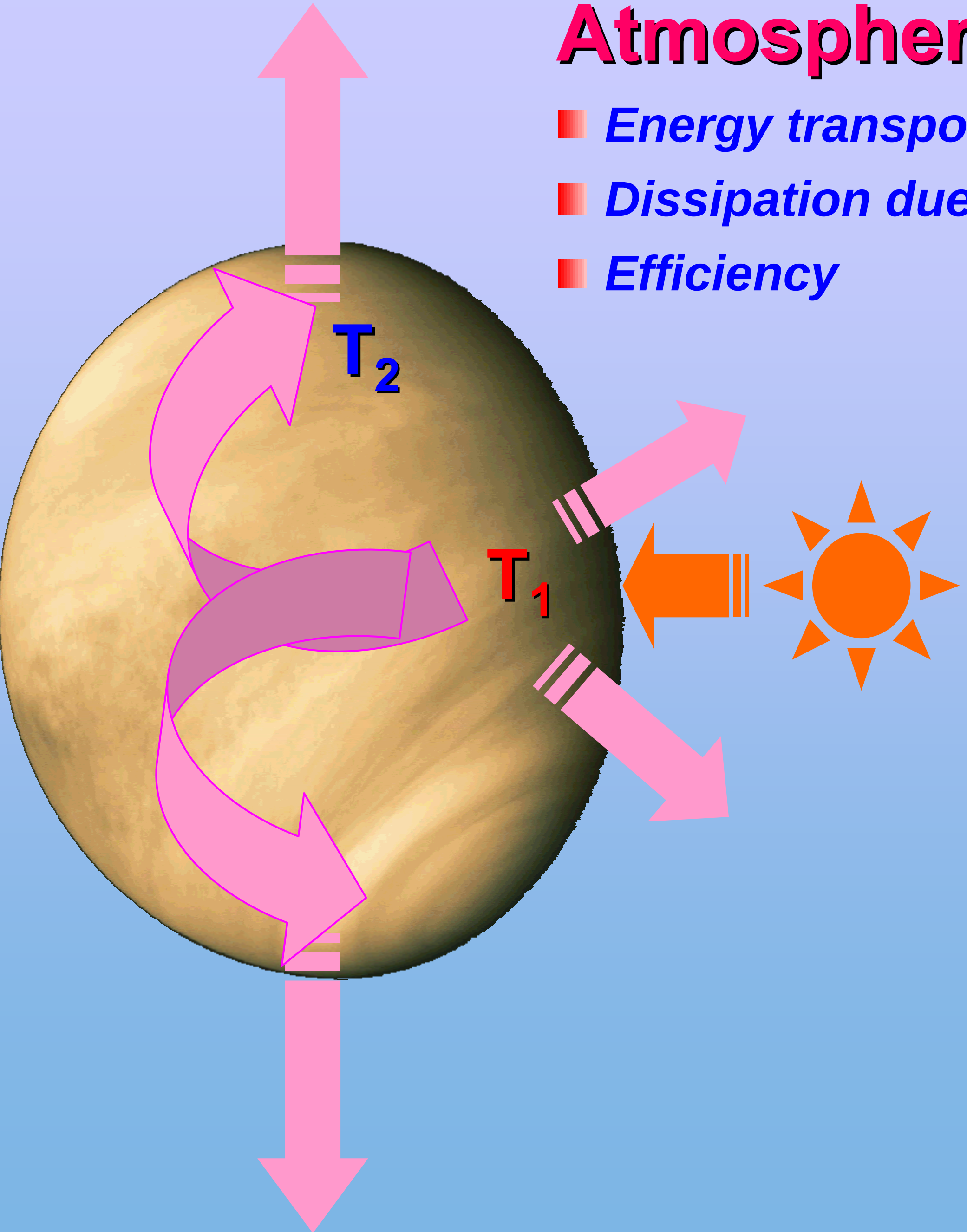
Mean deposition of solar energy on terrestrial planets [W/m^2]

	Venus	Earth	Mars
Atmosphere	130	70	~0
Surface	20	170	125

Atmospheres as heat engines

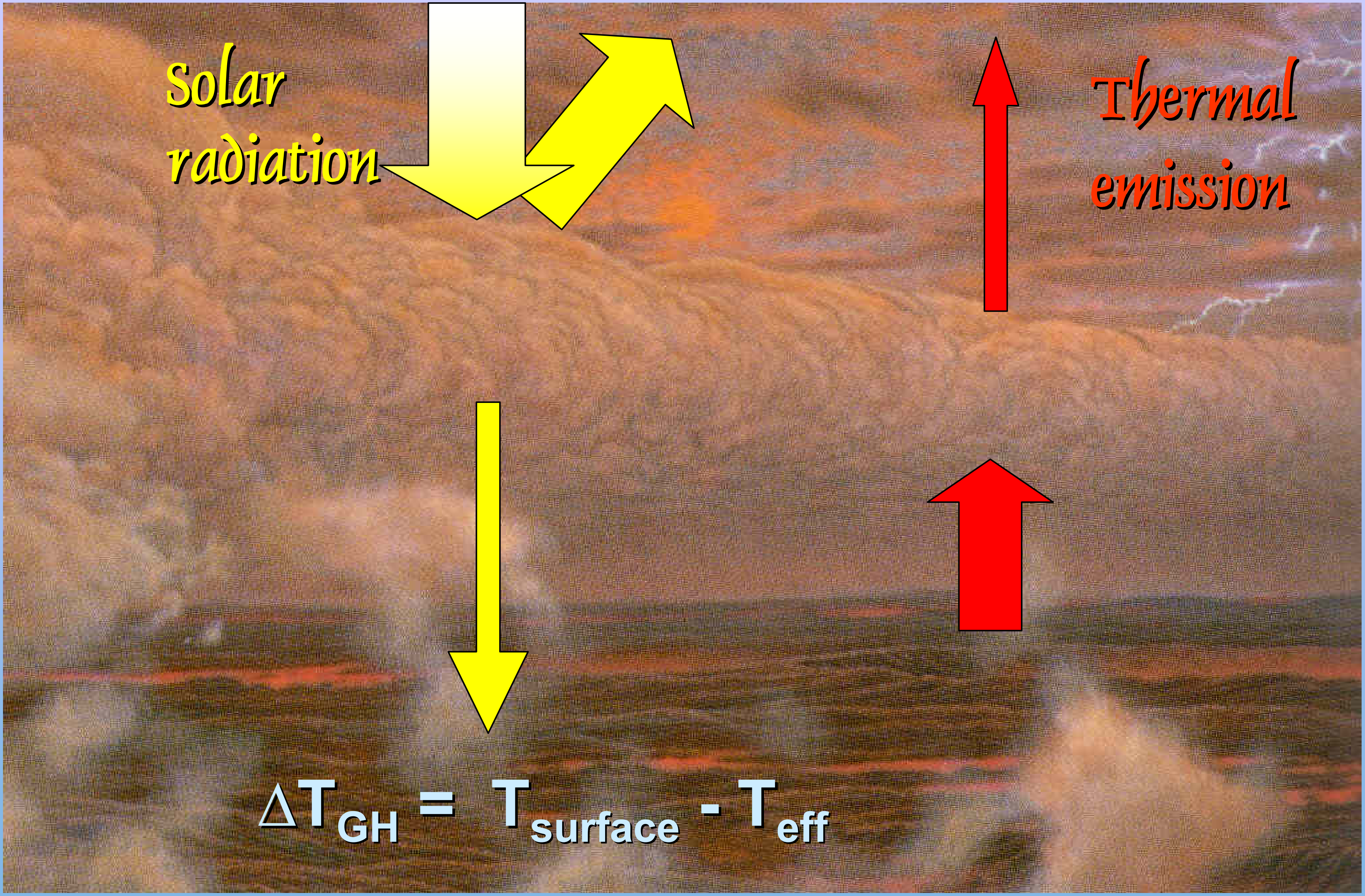
- *Energy transport by atmospheric motions*
- *Dissipation due to friction*
- *Efficiency*

$$\varepsilon \le 1 - \frac{T_2}{T_1}$$



Greenhouse effect

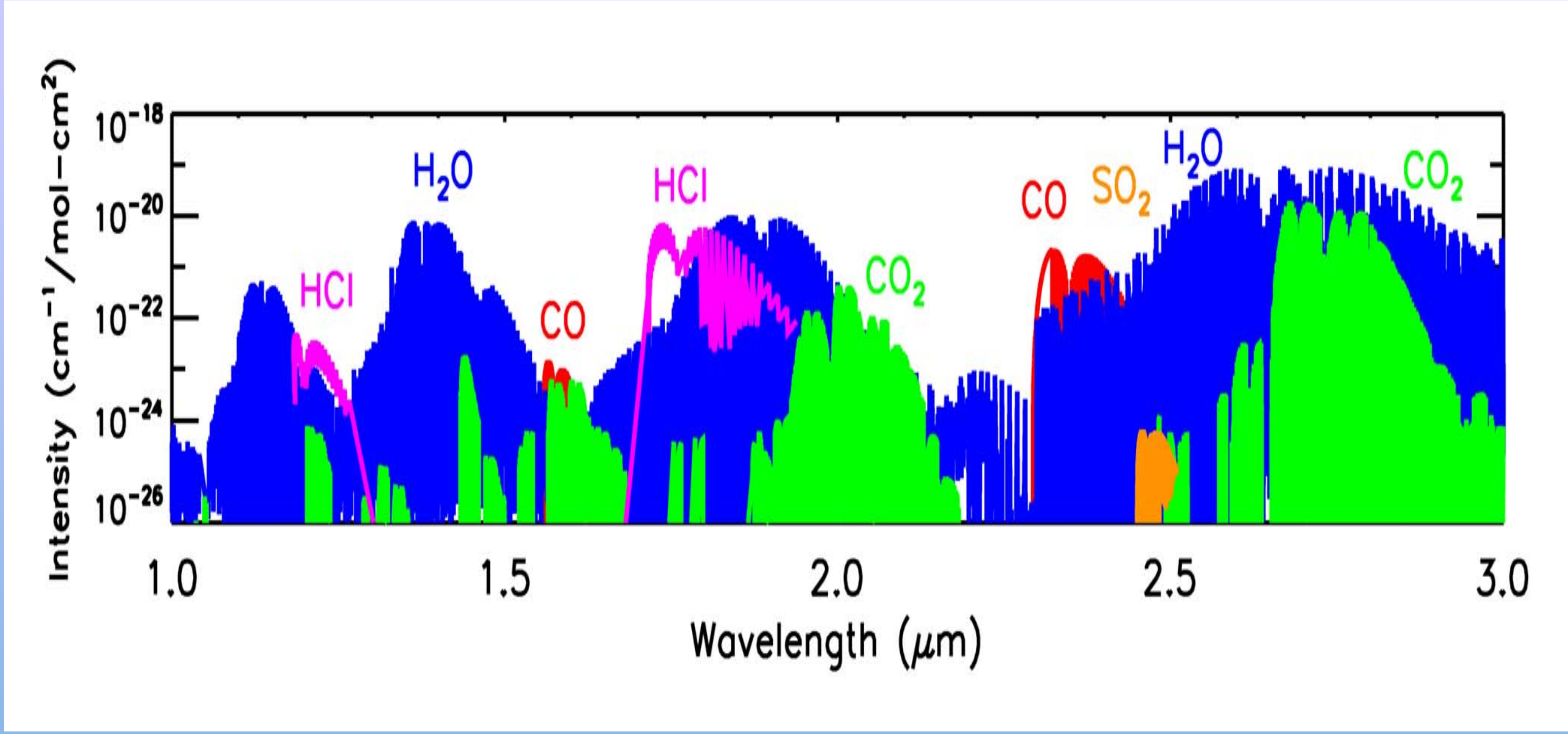
Basics of the greenhouse effect



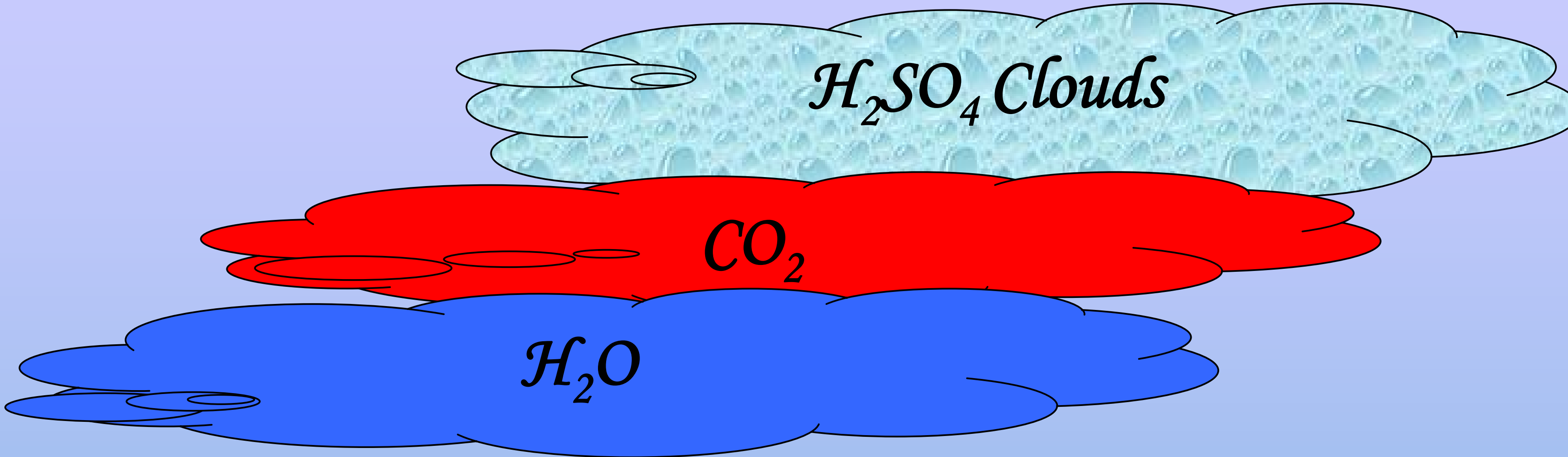
0.5 µm 1 µm 5 µm 10 µm

Wavelength, microns

Absorption bands of the atmospheric gases



Venus – the queen of greenhouse



CO_2 – 420K

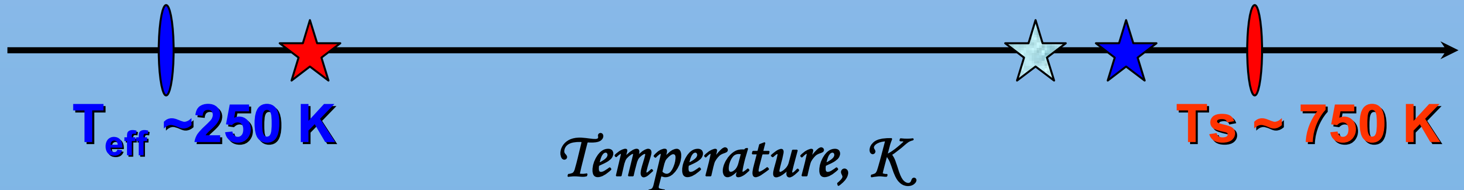
H_2O – 70K

Clouds – 140K

COS – 12K

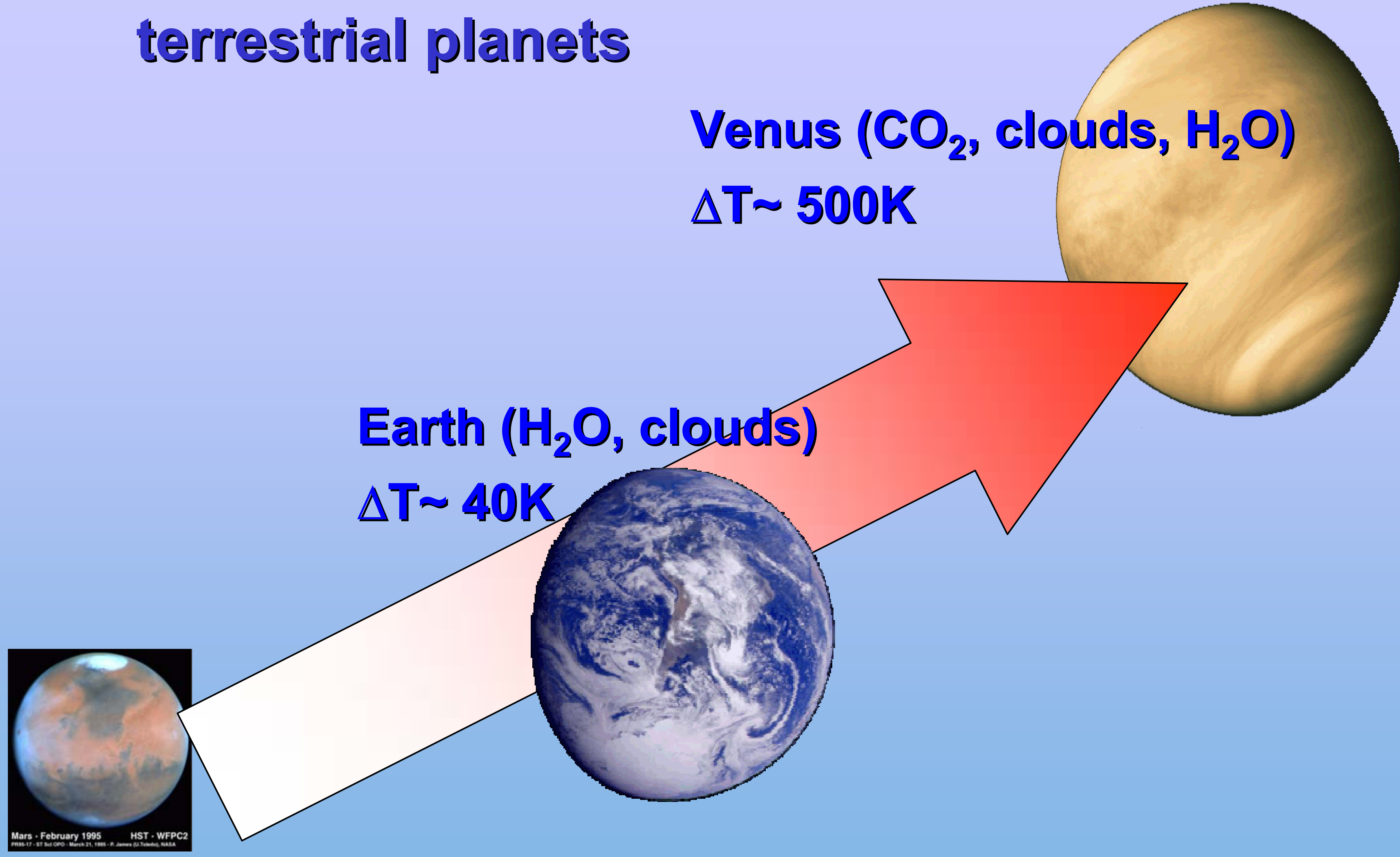
CO – 3K

SO_2 – 3K



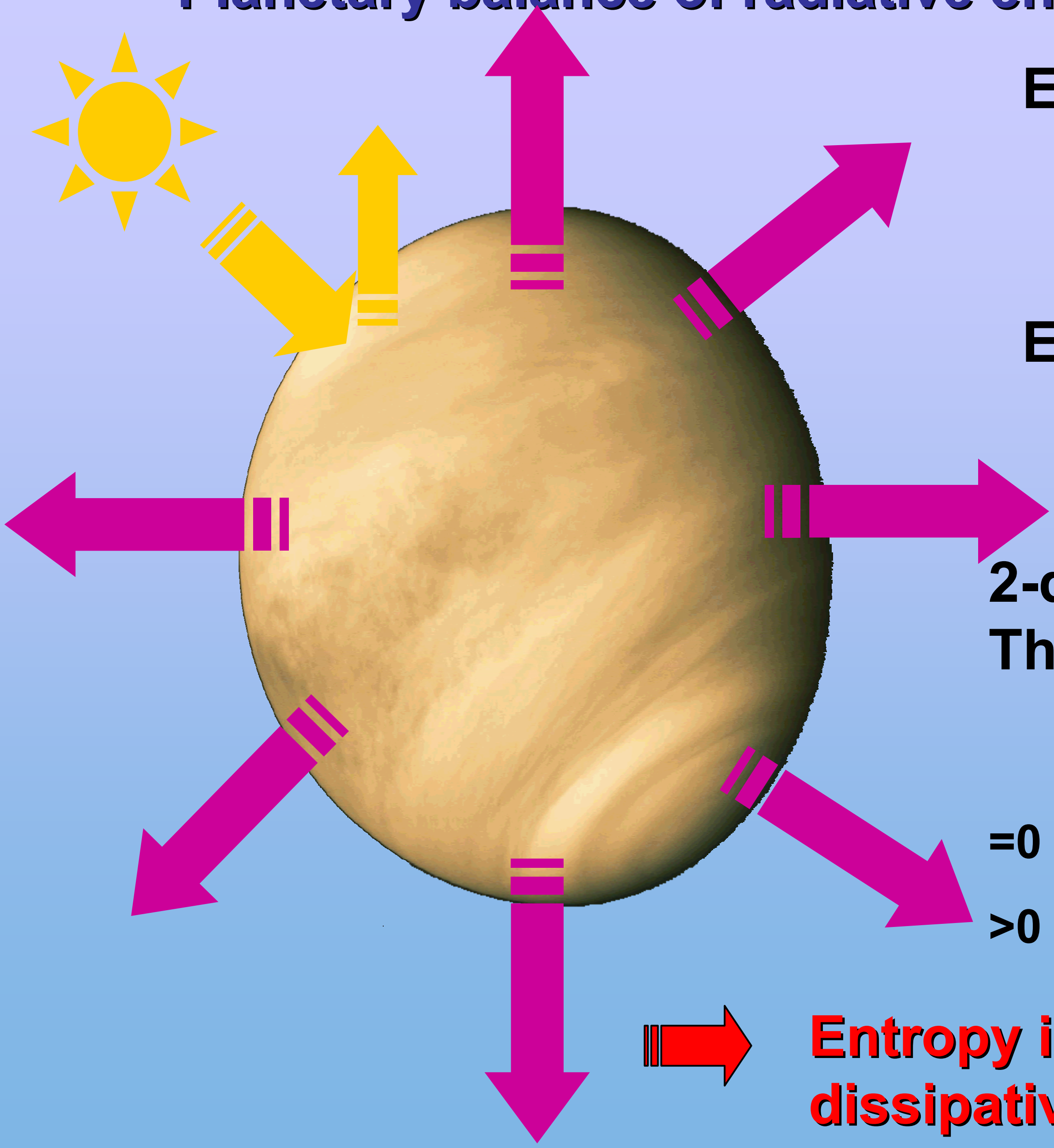
Bullock, 2007

Greenhouse effect on the terrestrial planets



Entropy balance

Planetary balance of radiative energy and entropy



Energy balance:

$$E_{Solar} - E_{ThIR} = 0$$

Entropy:

$$\Delta S = E/T$$

2-d Law of Thermodynamics:

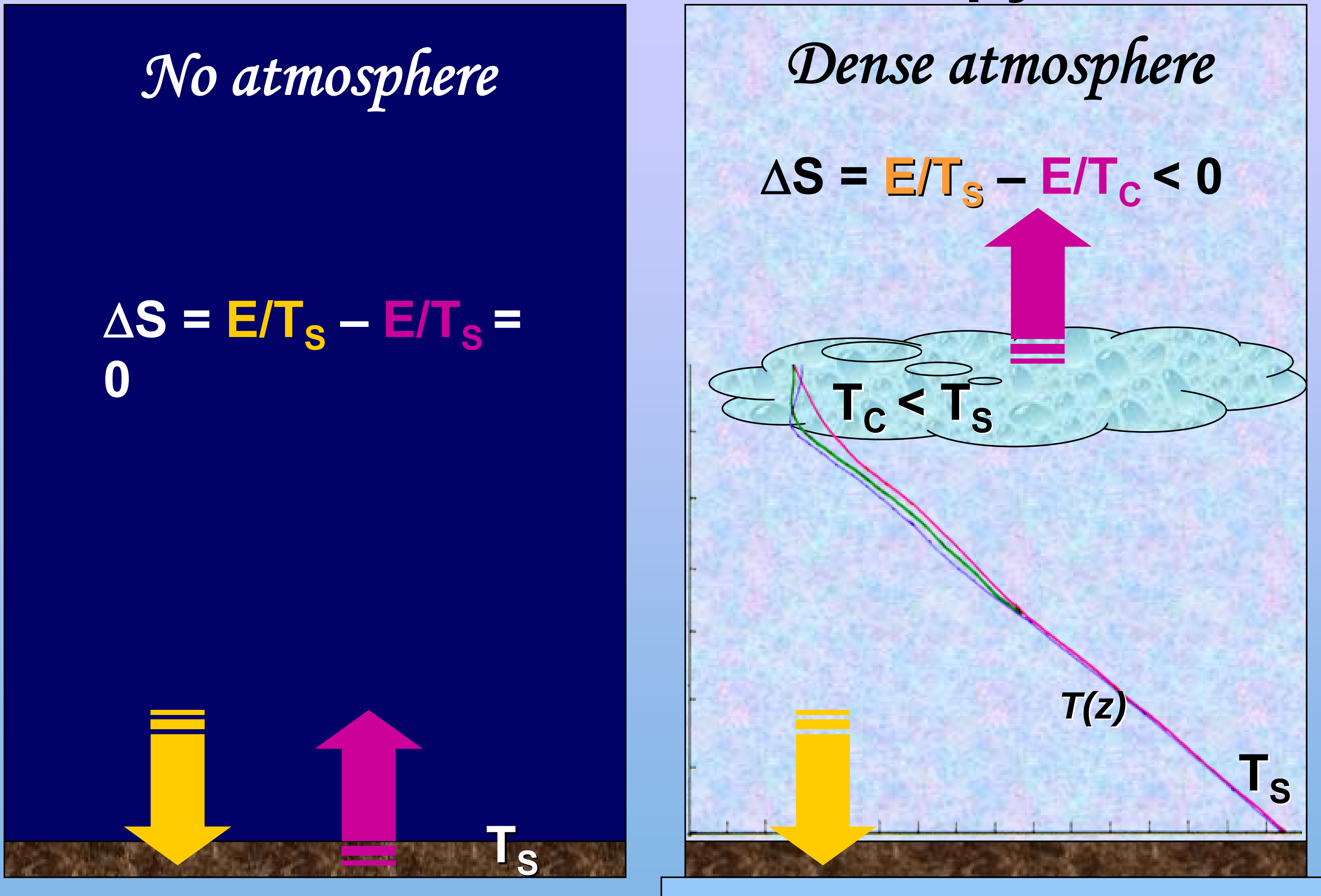
$$\Delta S \geq 0$$

=0 - reversible processes

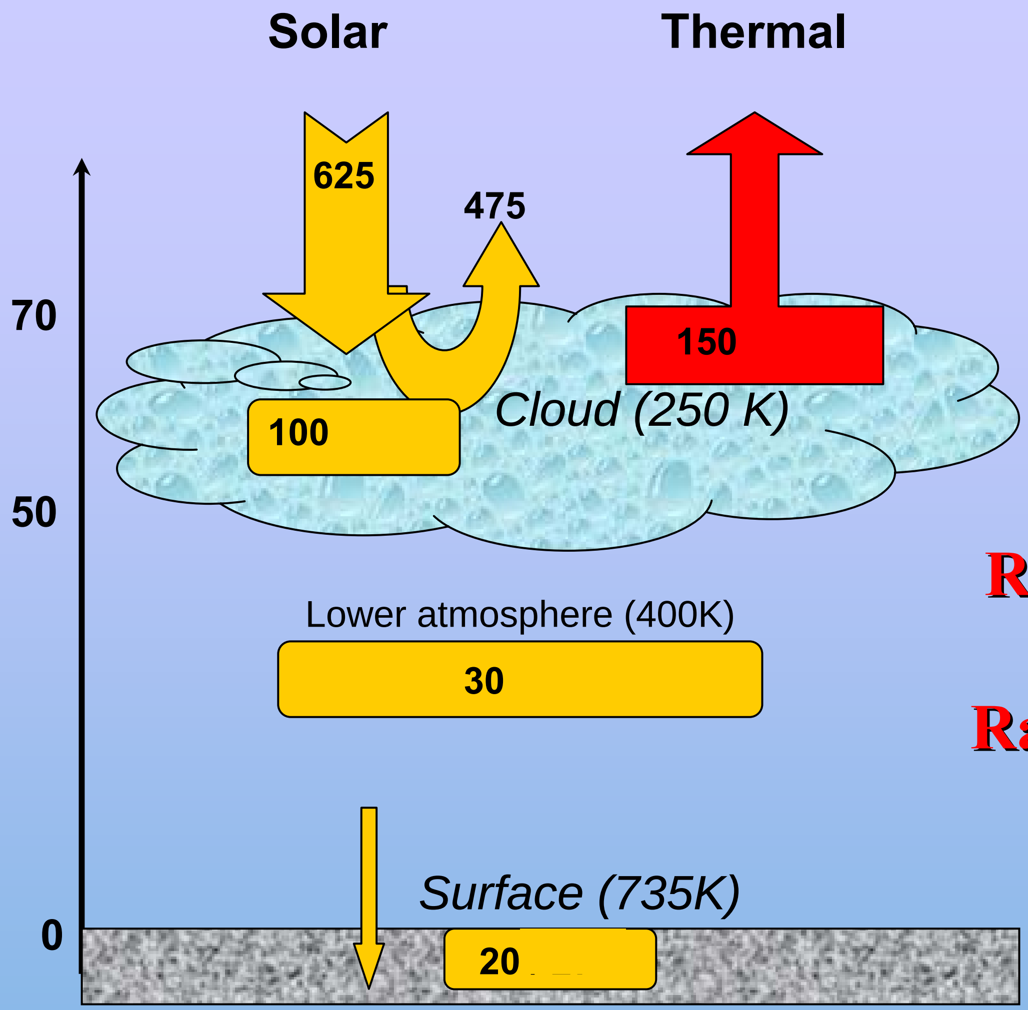
>0 – irreversible processes

Entropy is a measure of dissipative processes

Flux of radiative entropy



Planets receive negative entropy from the Sun



Radiative Energy / Entropy balance on Venus

Radiative energy balance

$\Delta E \approx 0$

Radiative entropy balance

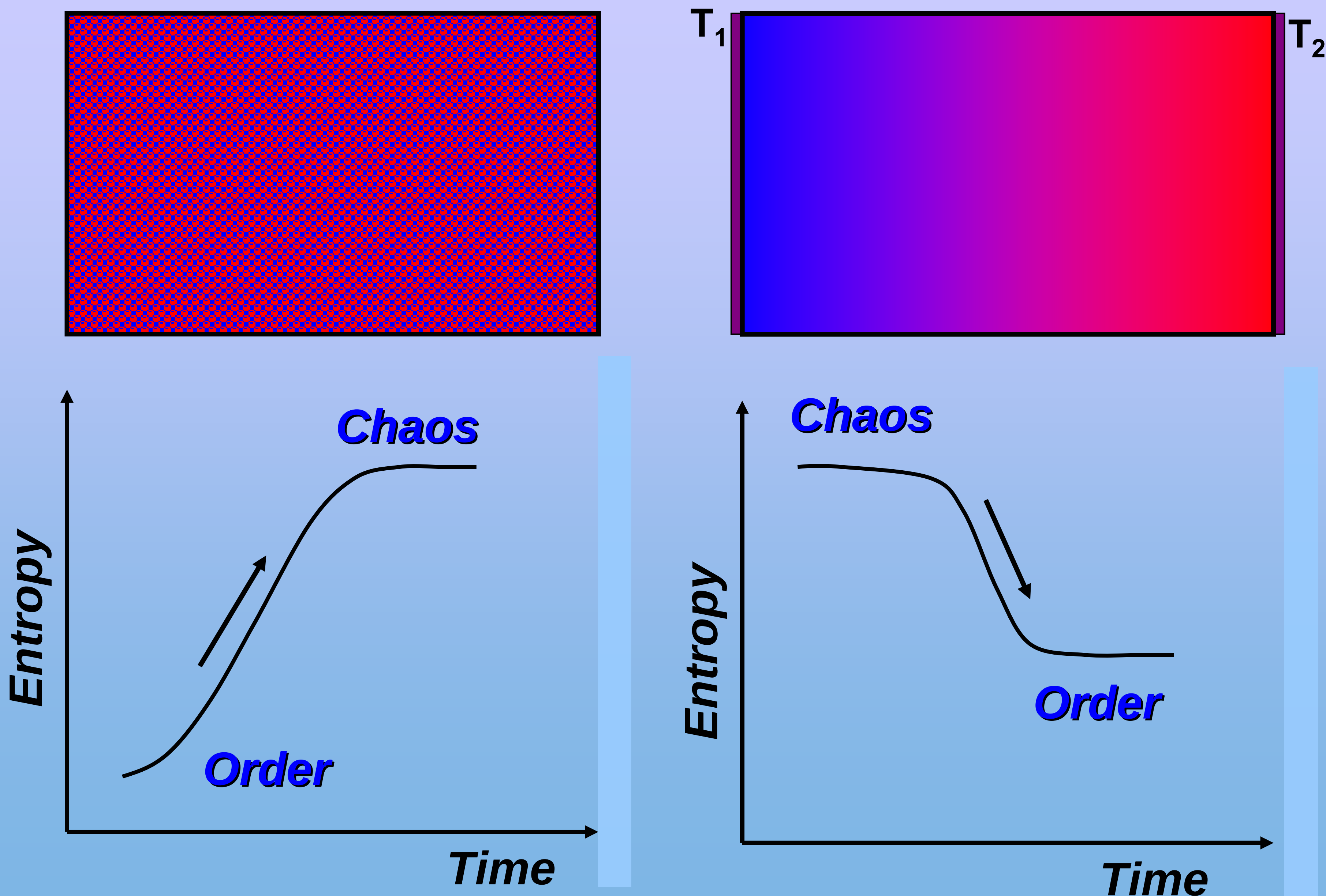
$\Delta S \approx -100\ mW/m^2/K$

Entropy balance on Earth and Venus

	Earth (Goody, 2000)	Venus
Net radiative sink	-70	-100
Moist convection	+55	0
Mechanical dissipation	+12	~1
Net balance	-3	-100

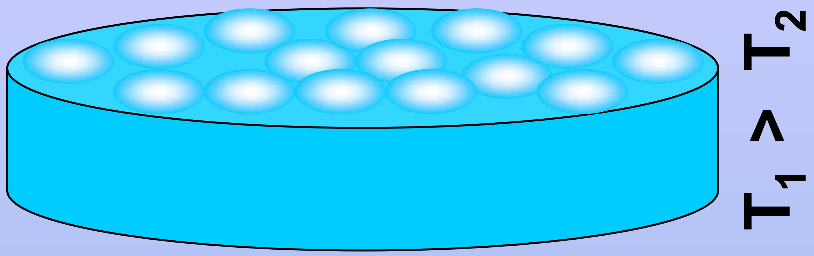
Dissipative processes in the Venus atmosphere - ????

Equilibrium and non-equilibrium thermodynamics



Non-equilibrium dissipative systems

Benard convection



- critical temperature gradient
- high level of order
- high entropy production