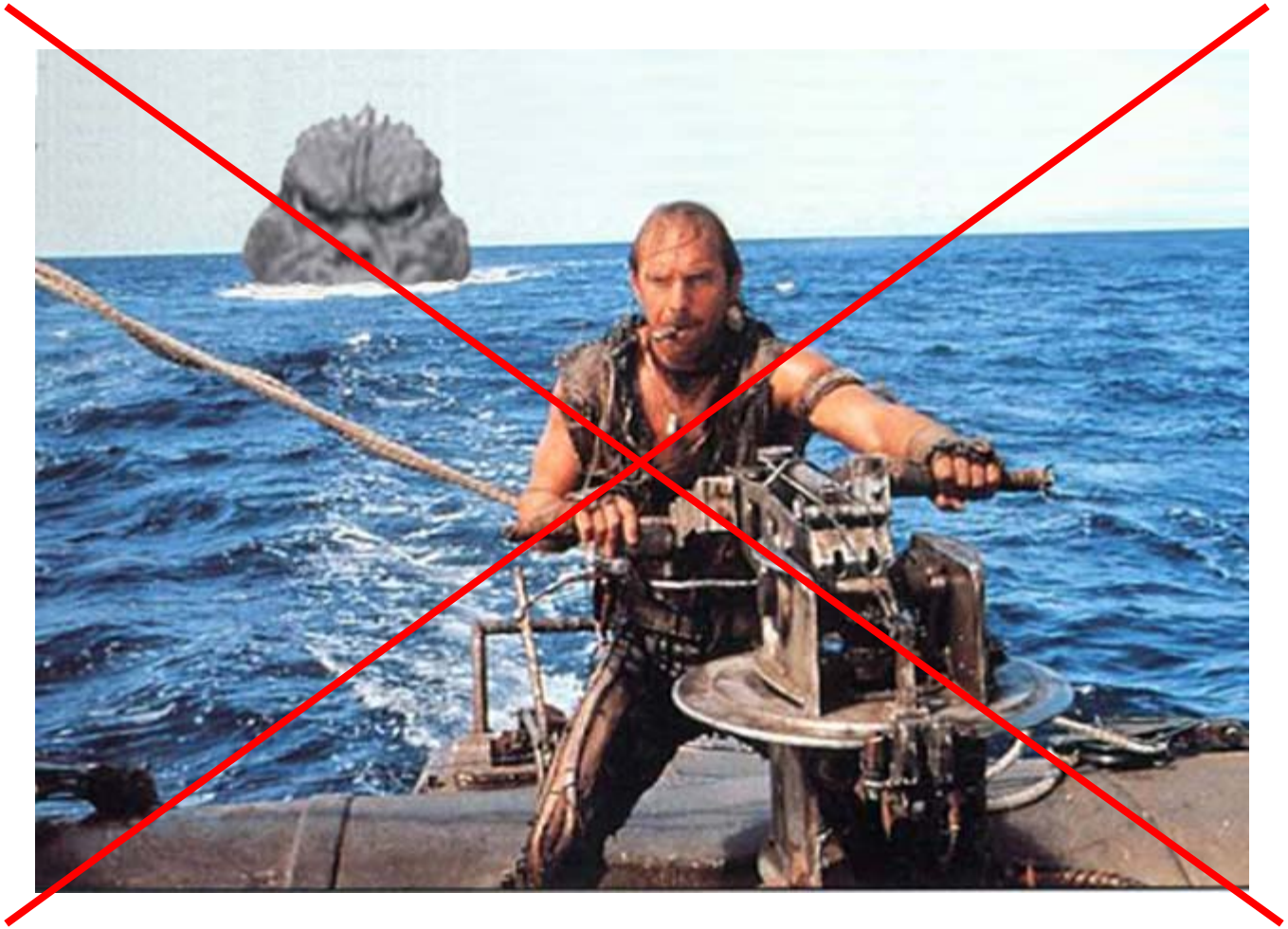
WATER WORLDS?

Dennis Hoening
Cristina Da Lio
Stefano Basso
Youmin Chen
Basudew Biswal
Christian Birkel
Nick Odoni
Stuart Daines
Tim Lenton



IstitutoVeneto diScienzeLettere edArti

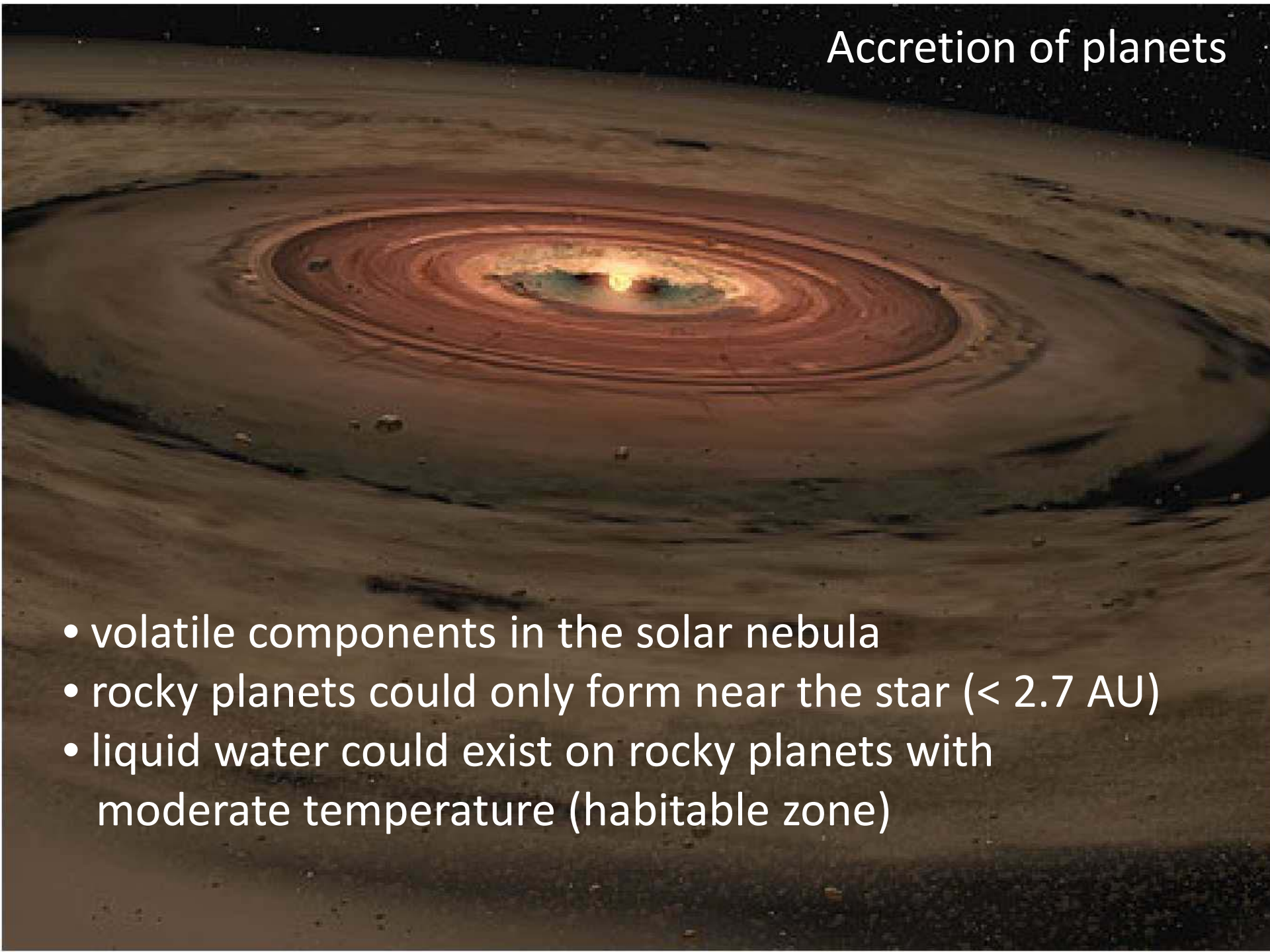
BESS SUMMER SCHOOL ON BIOGEODYNAMICS AND EARTH SYSTEM SCIENCES

VENICE 2011

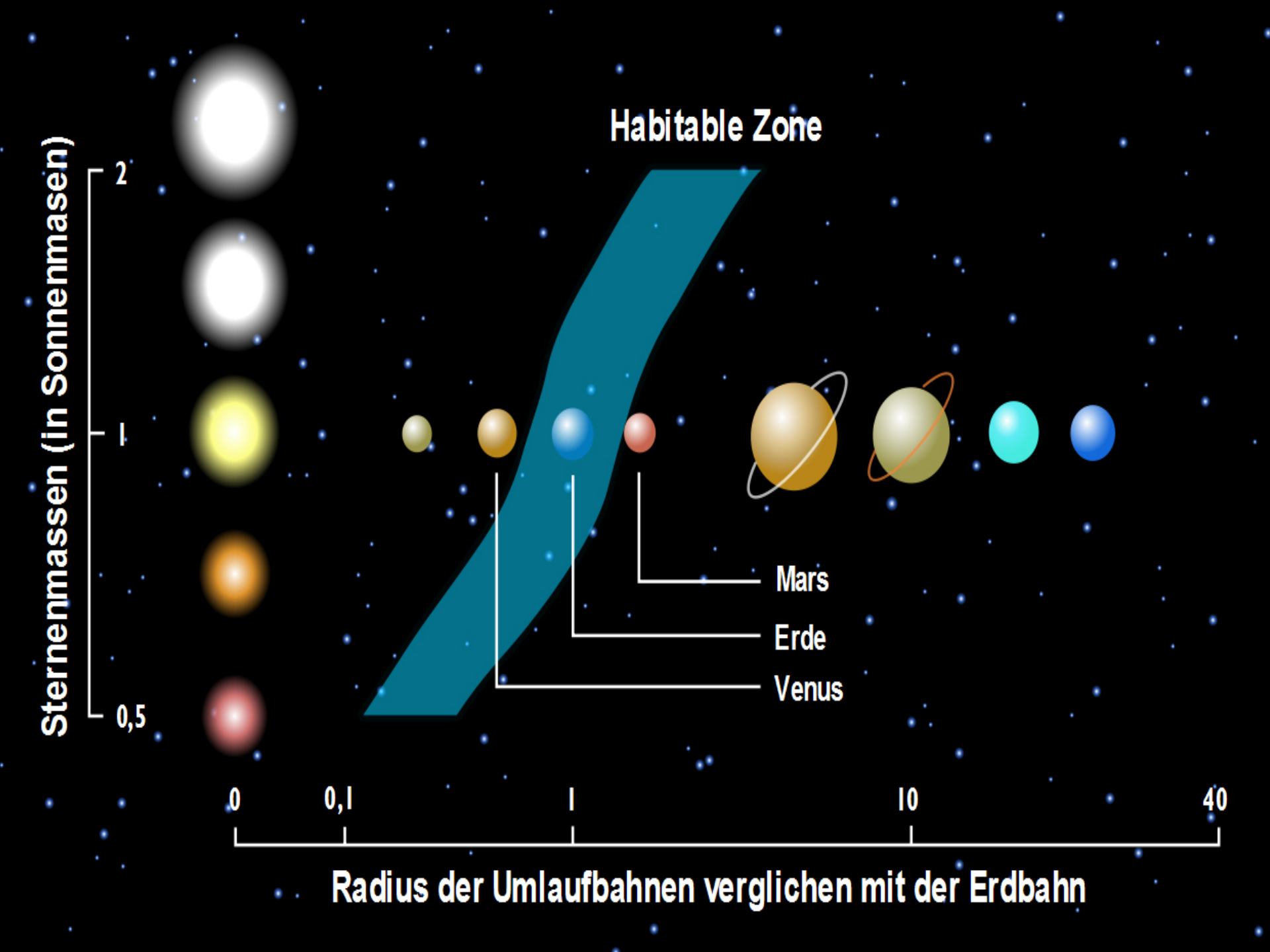
Motivation - Water and Life

- Philosophical question: Is there life on other planets?
- Liquid water is (probably) required for the origin and developement of life (solution, photosynthesis, breathing…)
- Small range for liquid water (0°C to 100°C at 1 bar)
  - Aim: Searching for planets with conditions, where liquid water could exist

Accretion of planets



- volatile components in the solar nebula
- rocky planets could only form near the star (< 2.7 AU)
- liquid water could exist on rocky planets with moderate temperature (habitable zone)


Habitable Zone
Sternenmassen (in Sonnenmasen)
2
1
0,5
Mars
Erde
Venus
0
0,1
1
10
40
Radius der Umlaufbahnen verglichen mit der Erdbahn

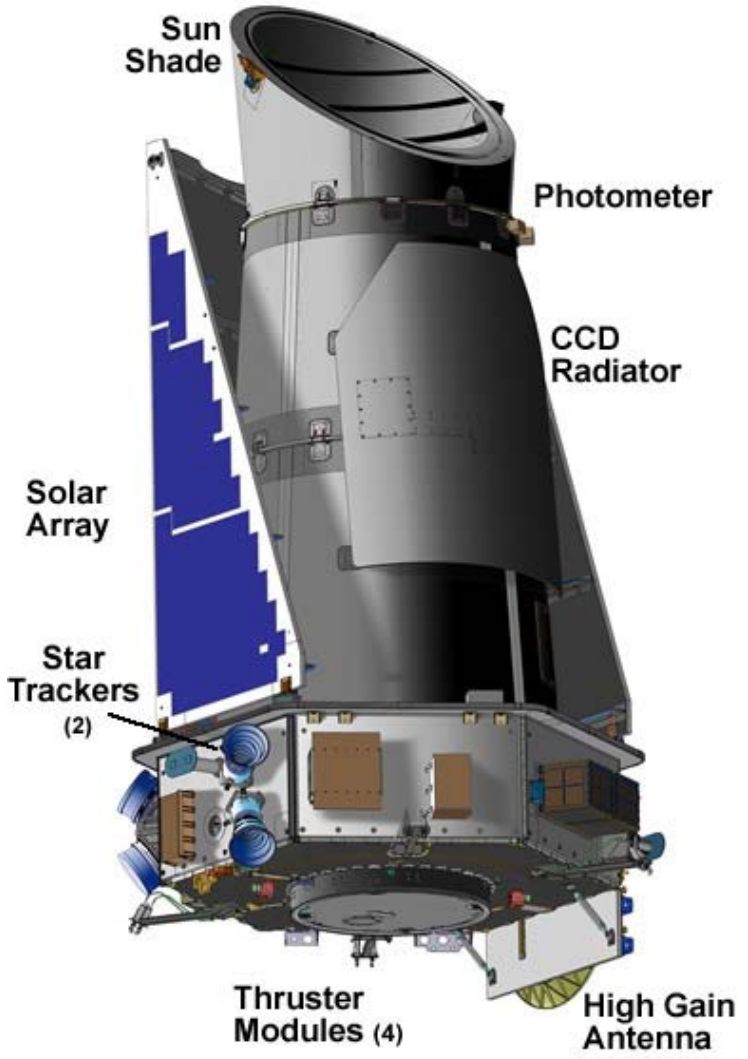
Search for extraterrestrial water

- **1235** possible extra-solar planet candidates detected by NASA's planet-hunting Kepler space telescope during its first four months of operation.

- **54** are orbiting in the parent star's habitable zone where liquid water could exist.

- **5** of these are near Earth-size.

- The remaining **49** candidates range from twice the size of Earth to larger than Jupiter.



Albedo and Temperature

$$T_{surf}{}^4 = (1-a)\frac{E}{4\pi D^2}\frac{1}{4\sigma}\left(1+\frac{3}{4}\tau\right)$$

$$\tau = k_\tau \rho_w{}^{0.5}$$

$$\rho_w = \xi P_0 exp\left(-L/RT_{surf}\right)$$

L = Latent heat of vaporization.

R = Molar gas constant (=8.34 $ml^{-1}K^{-1}$).

P_0 = $1.4*10^{11}$ Pa.

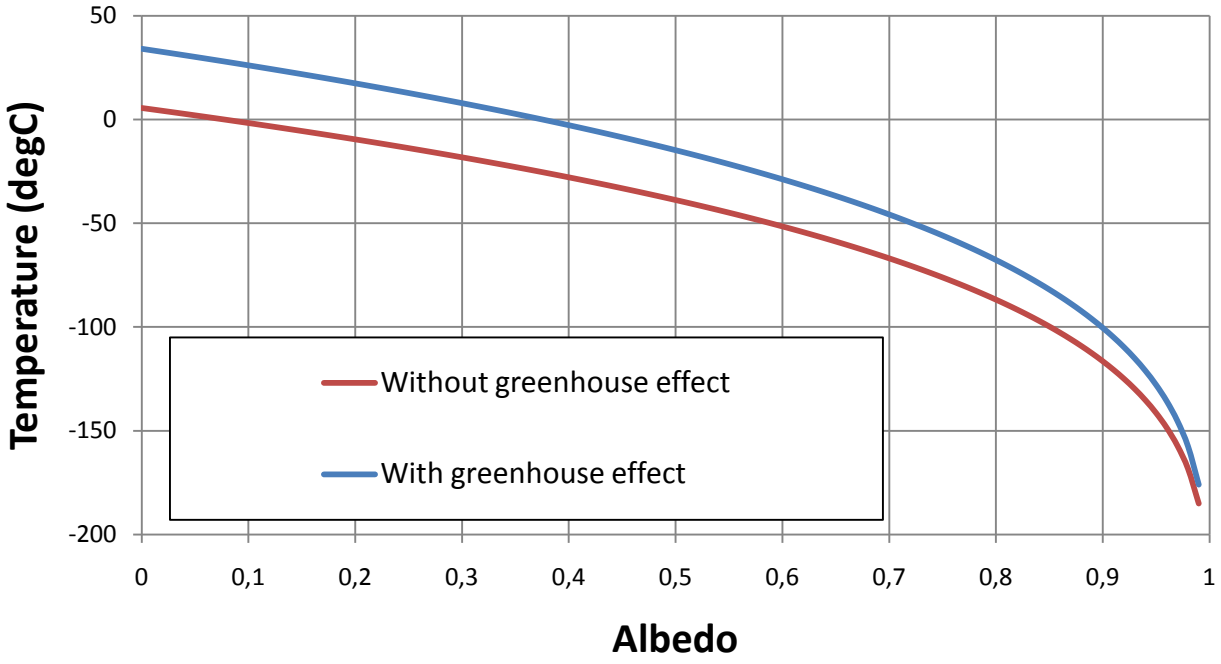
σ = $5.67*10^{-8}$ $Wm^{-2}k^{-4}$.

ξ = relative humidity, equal to 0.62 for earth.

a = albedo, equal to 0.225 for earth.

τ = 0.41 (water) + 0.244 (green house gasses).

Temperature and albedo with and without greenhouse (vapor and CO2) effect



Case1:

Albedo=0.22,

T1=-11.3

T2=15.5

Diff=26.8

Case2:

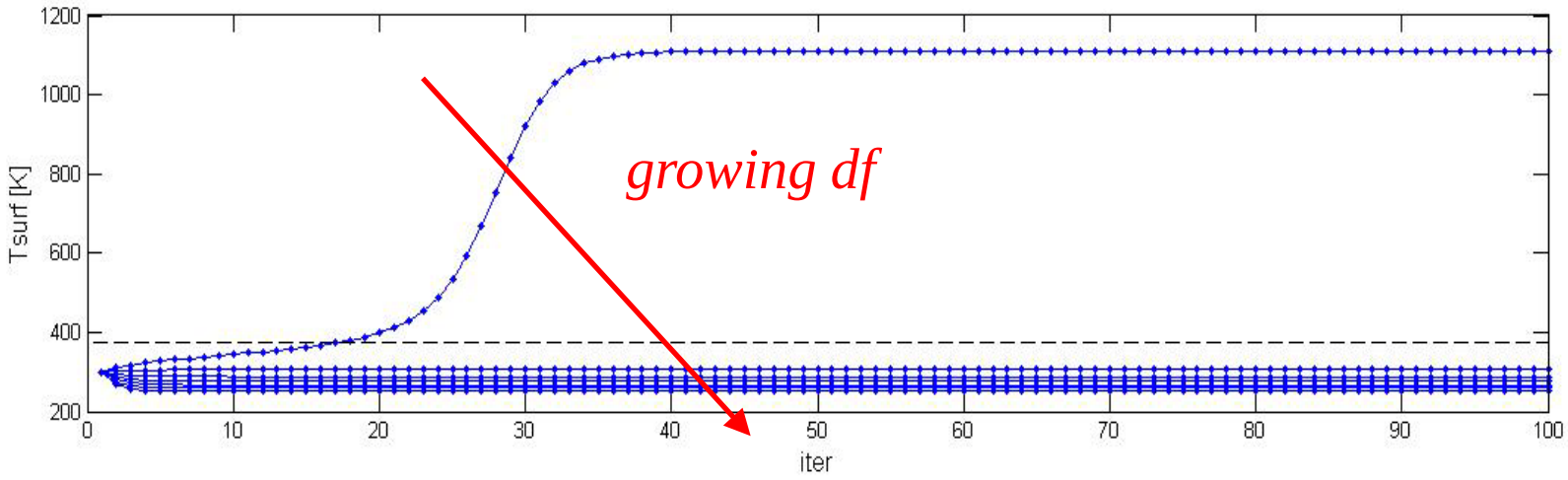
Albedo=0.30,

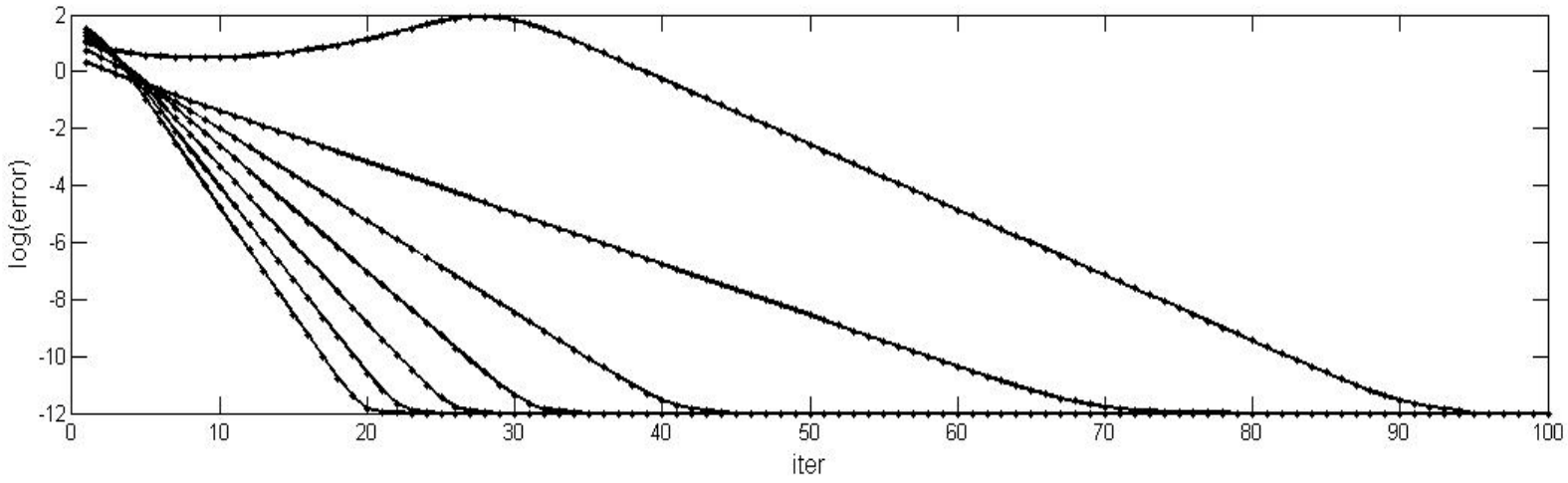
T1=-18.2

T2=7.8

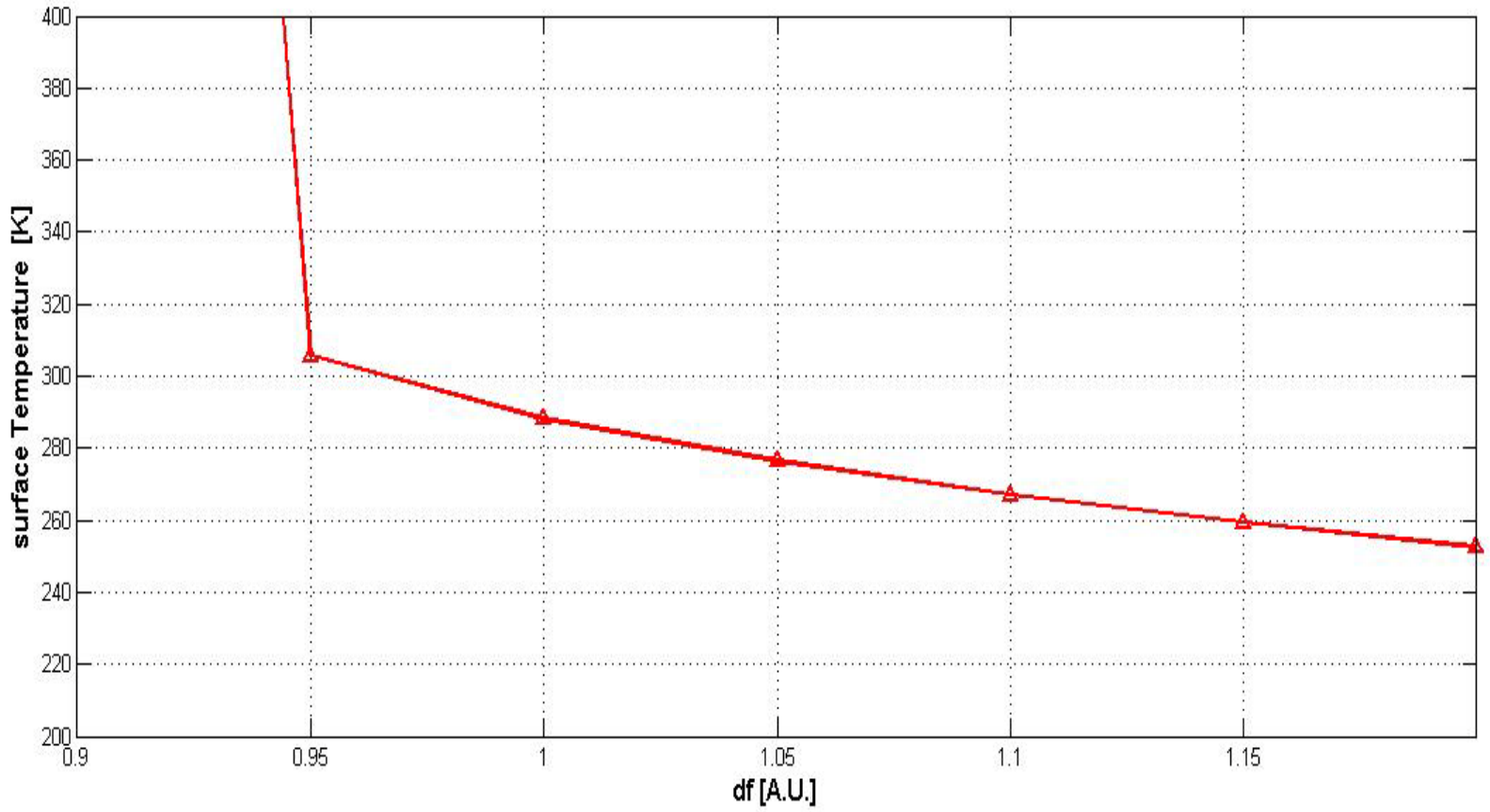
Diff=25.0

MEAN SURFACE TEMPERATURE OF A PLANET AS FUN CTION OF VAPOUR PRESSURE IN THE ATMOSPHERE





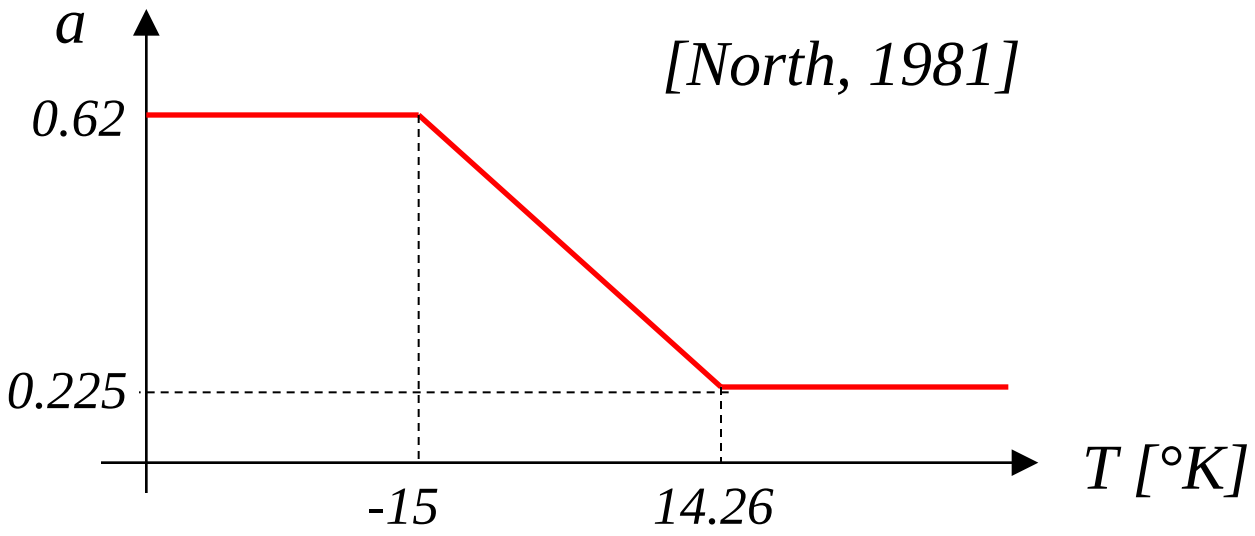
MEAN SURFACE TEMPERATURE OF A PLANET AS FUN CTION OF VAPOUR PRESSURE IN THE ATMOSPHERE



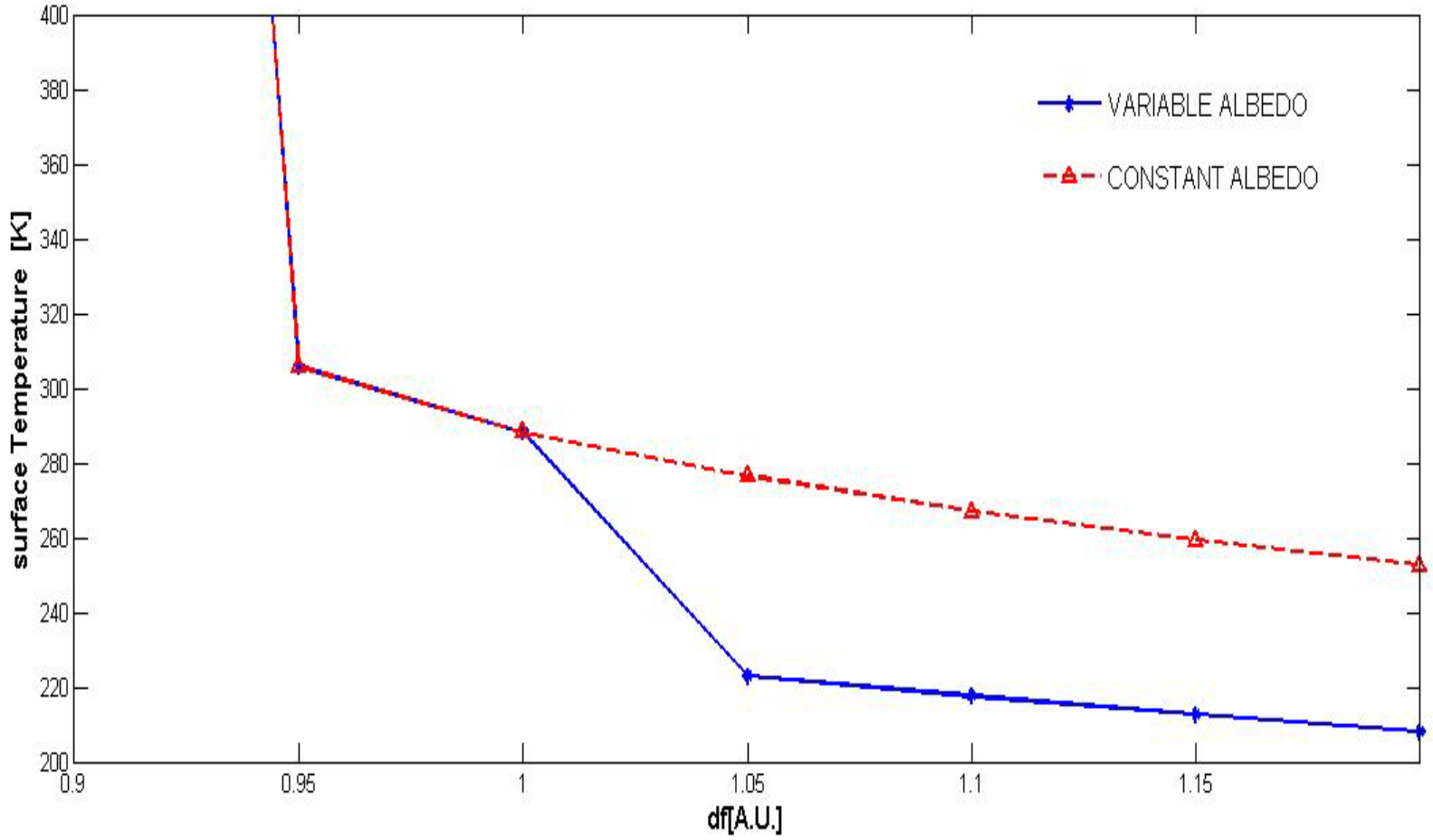
df < 0.95 A.U. & df > 1.1 A.U. → *no liquid water* → *no life*

MEAN SURFACE TEMPERATURE OF A PLANET AS FUN CTION OF VAPOUR PRESSURE IN THE ATMOSPHERE

VARIABLE ALBEDO



MEAN SURFACE TEMPERATURE OF A PLANET AS FUN CTION OF VAPOUR PRESSURE IN THE ATMOSPHERE



MEAN SURFACE TEMPERATURE OF A PLANET AS FUN CTION OF VAPOUR PRESSURE IN THE ATMOSPHERE

$$T_{surf} = (1-a)\frac{E}{4\pi D^2}\frac{1}{4\sigma}\left(1+\frac{3}{4}\tau\right)$$

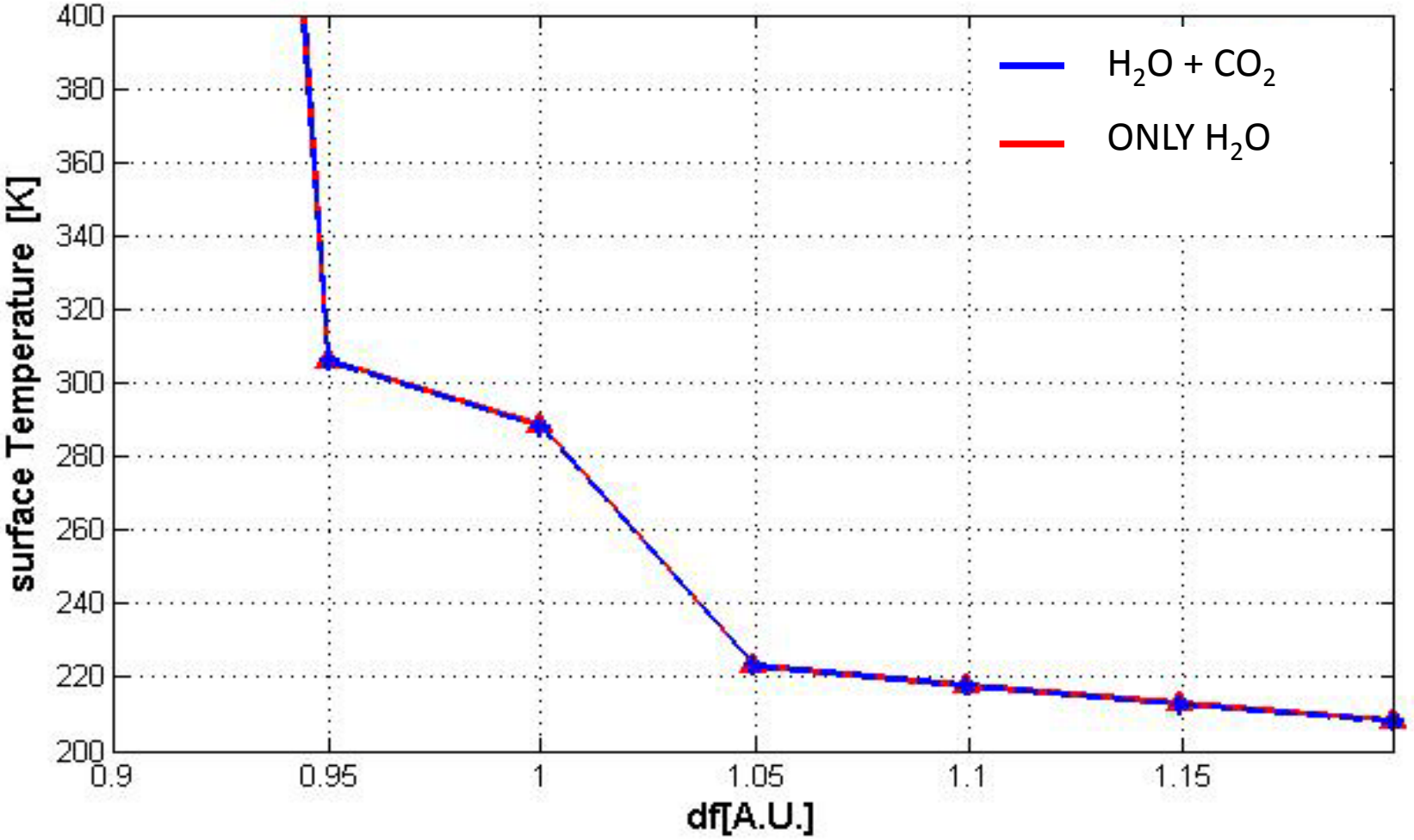
$$\tau = \tau_{H_2O} + \tau_{CO_2}$$

$$\tau_{CO_2} = 1.73 \cdot p_{CO_2}{}^{0.263}$$

WATER VAPOUR + CO_2

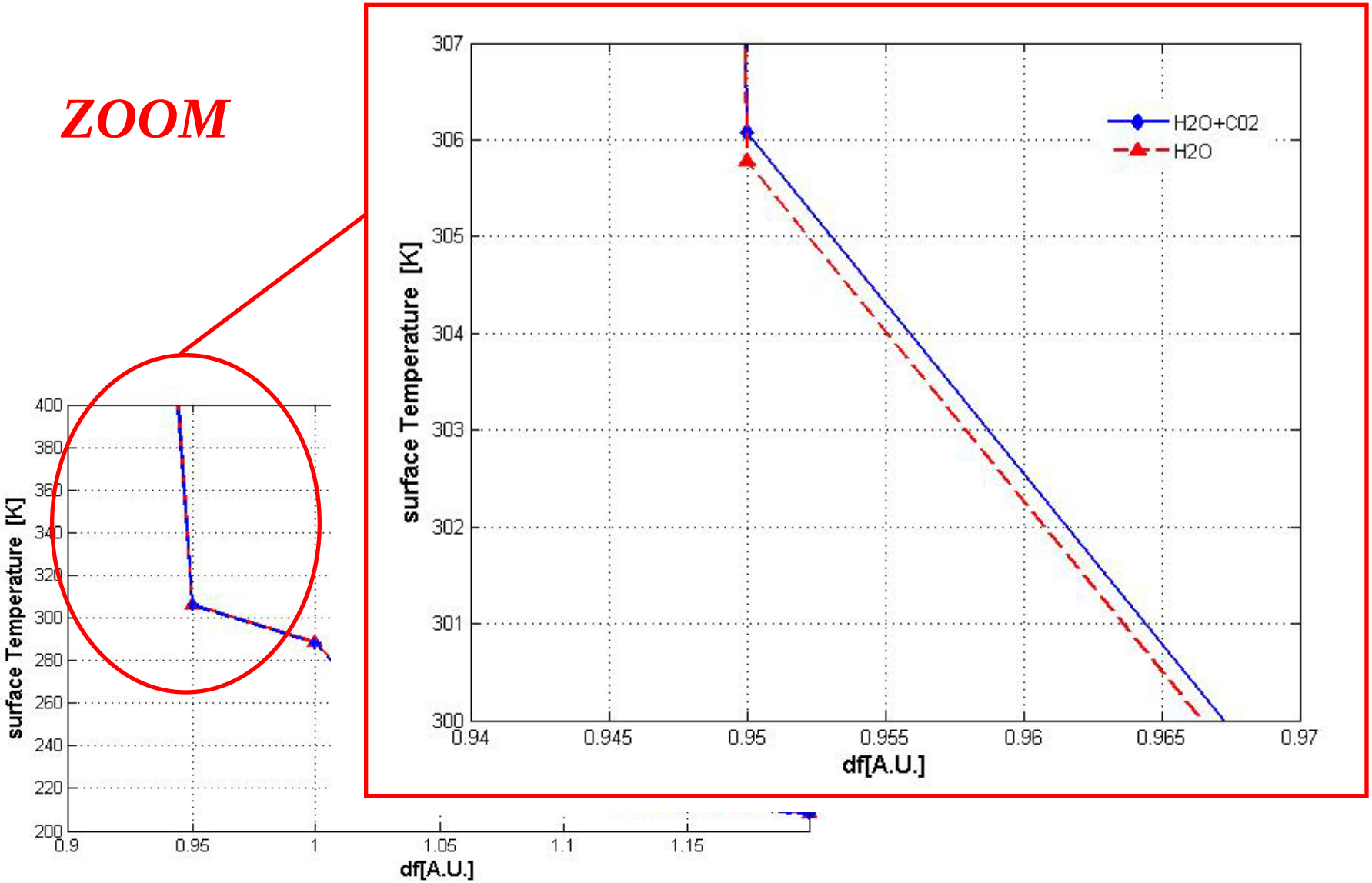
$$p_{CO_2} = p_{0,CO_2}\left(\frac{V}{V_0}\right)^{\frac{10}{3}} \exp\left\{-\frac{(T-T_{eq})}{4.11}\right\}$$

MEAN SURFACE TEMPERATURE OF A PLANET AS FUN CTION OF VAPOUR PRESSURE IN THE ATMOSPHERE



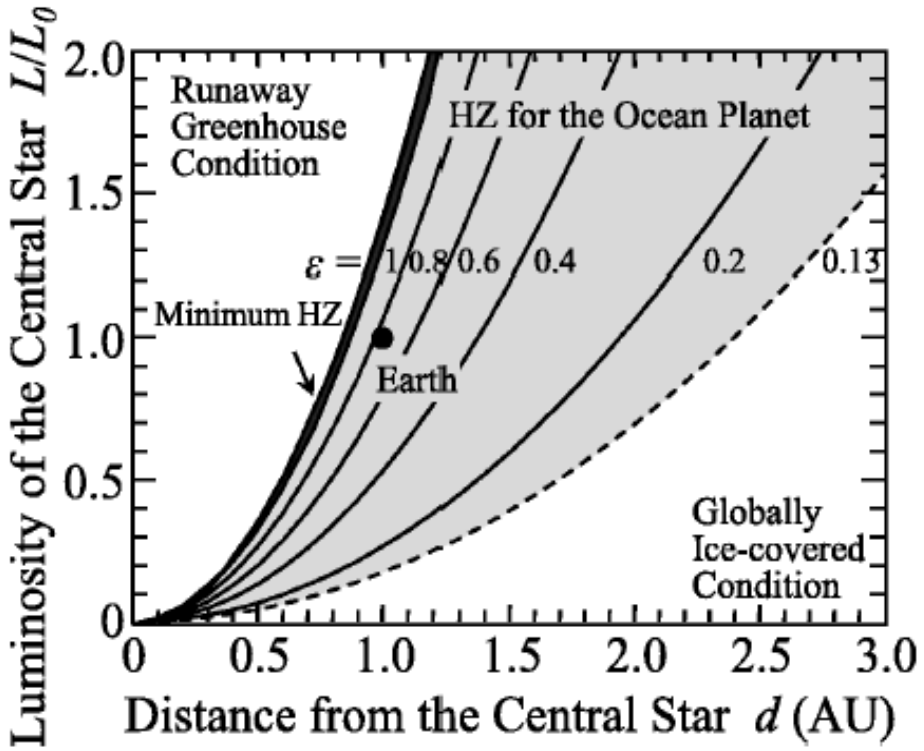
MEAN SURFACE TEMPERATURE OF A PLANET AS FUN CTION OF VAPOUR PRESSURE IN THE ATMOSPHERE

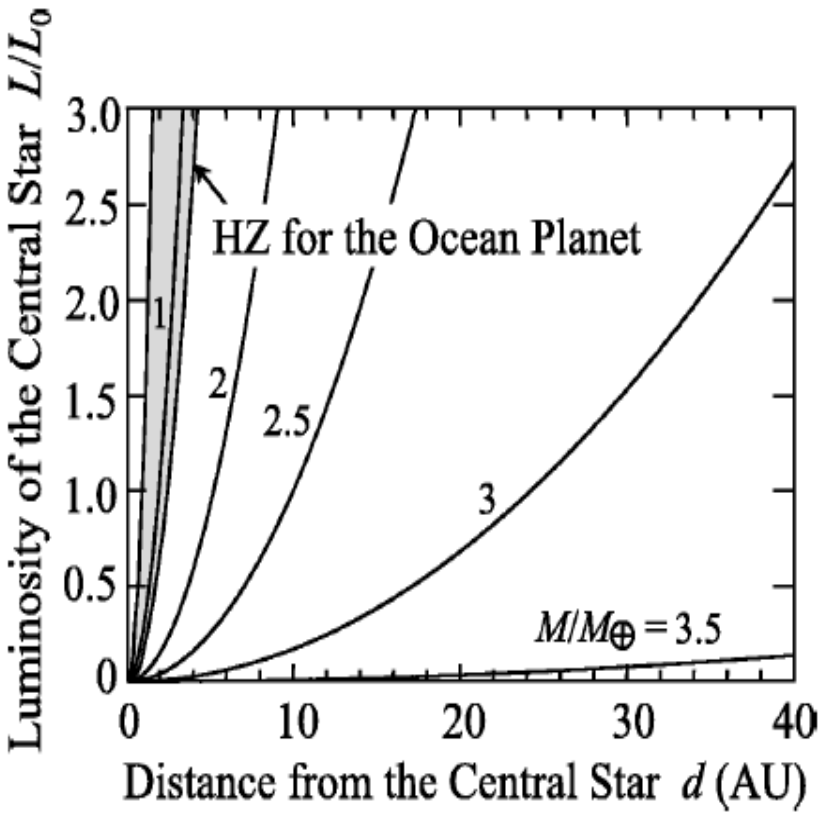
ZOOM



habitable zone (no internal heating through radioactive decay)

habitable zone (internal heating through radioactive decay for different planet sizes, ε=1)

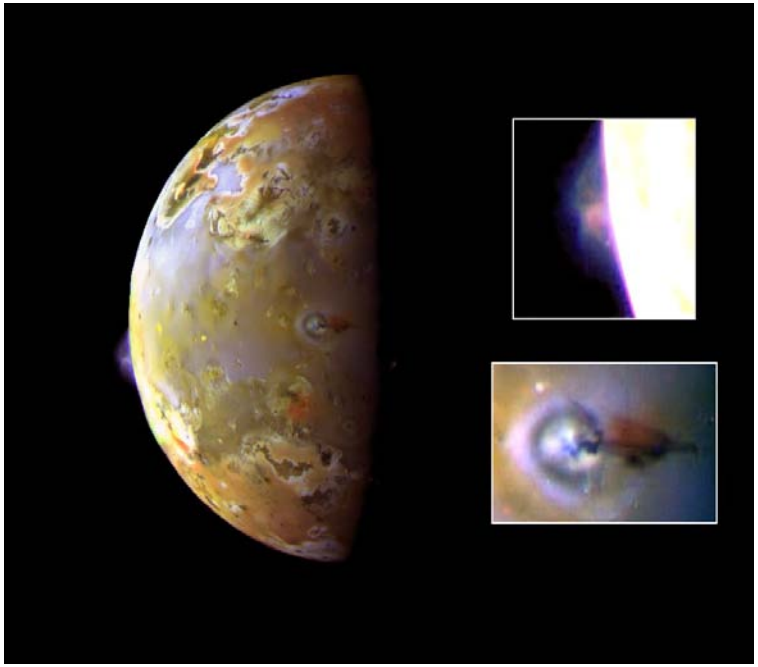




ε: Emissivity
(ε=1 for no other greenhouse-gases
then water-vapor)

E. Tajika 2007

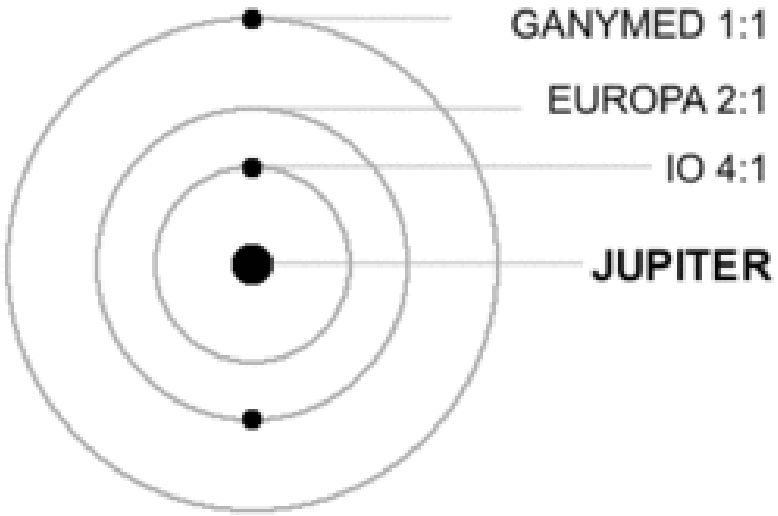
- Does the HZ vary with tidal forces?
  - It should! (e.g. Io)
  - $F_{tid} \sim M/d^3$
  - Huge effects on the int. heat flux of planets near their sun
  - But: These planets should already be tidaly locked! (Kasting et al. 1993)



Picture: NASA

If …

Interactoin between
Small planets or moons



young solar system

- **habitable zone could change dramatically !!**

Outlook

1. Relative humidity – how does this vary with surface temperature and total water content?
2. What is the effect of CO2 atmosphere without presence of water?
3. How can we derive values of empirical parameters from basic physics and not from model calibration?
4. How should albedo vary with different water content?
5. How does this work in a tidally “locked” planet?