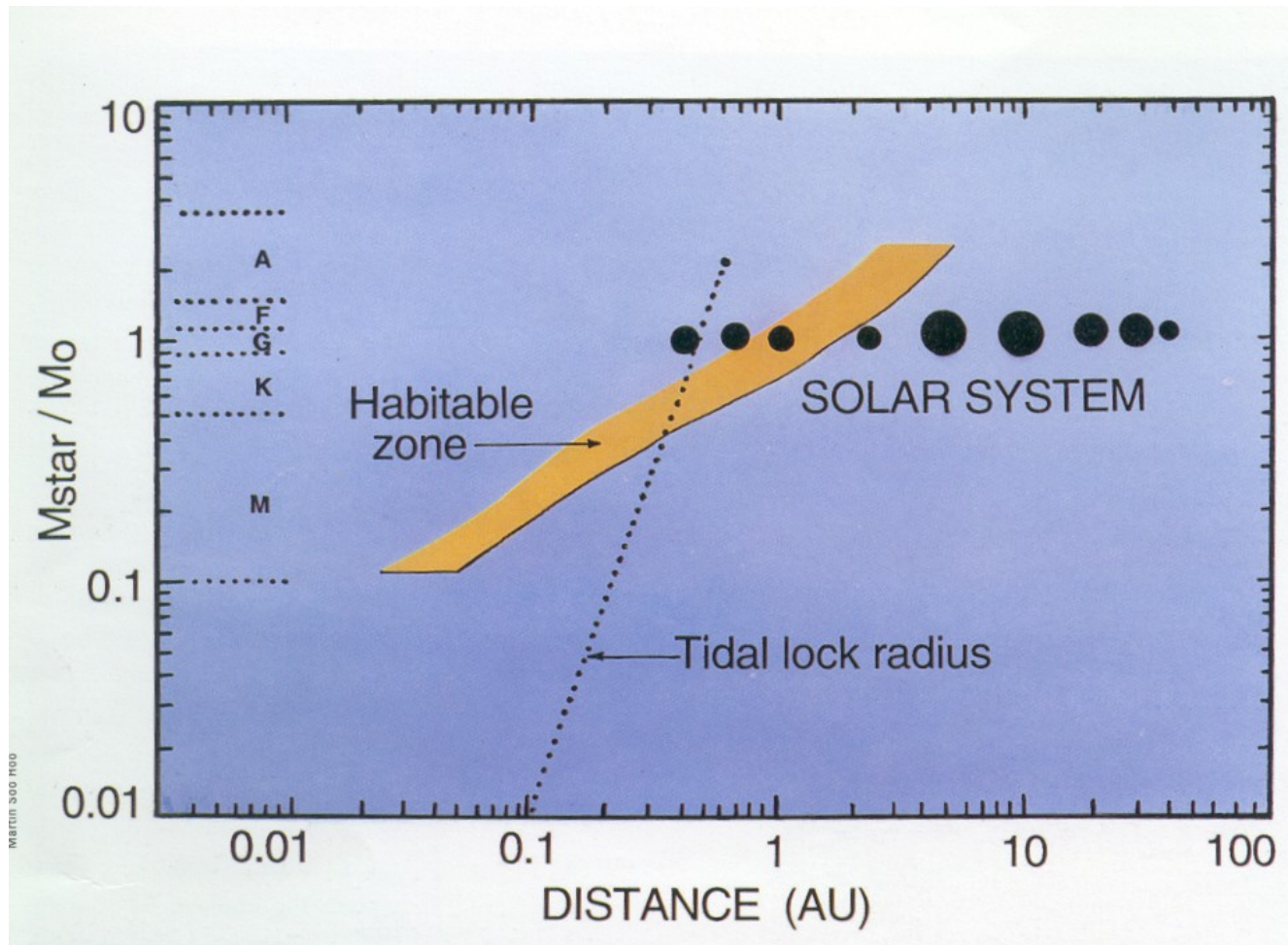# Habitable zone
# of planetary systems

Vera Dobos
Workshop of Young Researchers in Astronomy and Astrophysics

Introduction

- 834 known exoplanets

- Kepler: 2321 planet candidates

- Habitable zones – whether a planet is capable for supporting life

- Different inspected conditions – several habitable zones

- In our work: liquid water habitable zone (LW HZ)
                ultraviolet habitable zone (UV HZ)

Liquid Water Habitable Zone

- A region around a star in which an Earth-like planet could support liquid water on its surface

[1]

- Climate model:
  - Carbonate-silicate cycle
  - Atmospheric composition
  - Star's radiation
- Fit $\longrightarrow$ calculation method
  - Star's temp. & luminosity

Calculation of the LW HZ
Inner boundary: $r_{inner} = \sqrt{\dfrac{L}{S_{inner}}}$
Outer boundary: $r_{outer} = \sqrt{\dfrac{L}{S_{outer}}}$

[1]

Stellar flux at the HZ boundaries – *Kasting*
Inner: $S_{inner} = 1.41 + 2.638 \cdot 10^{-4} \cdot (T - 5700) + 4.19 \cdot 10^{-8} \cdot (T - 5700)^2$
Outer: $S_{outer} = 0.36 + 5.7381 \cdot 10^{-5} \cdot (T - 5700) + 6.1905 \cdot 10^{-9} \cdot (T - 5700)^2$

[2]

Stellar flux at the HZ boundaries – *Jones*
Inner: $S_{inner} = 1.296 - 2.139 \cdot 10^{-4} \, T + 4.19 \cdot 10^{-8} \, T^2$
Outer: $S_{outer} = 0.2341 - 1.319 \cdot 10^{-5} \, T + 6.19 \cdot 10^{-9} \, T^2$

[3]

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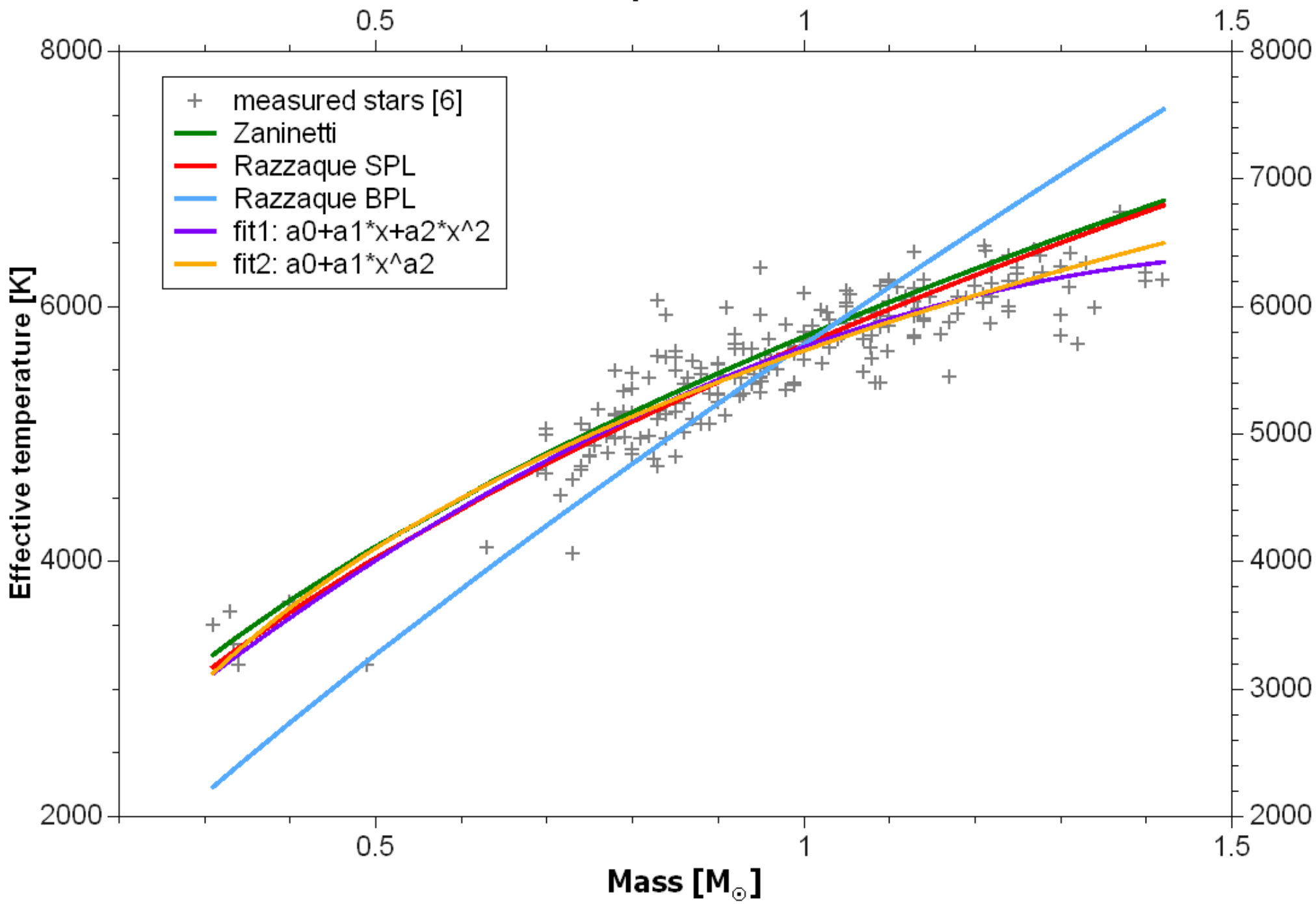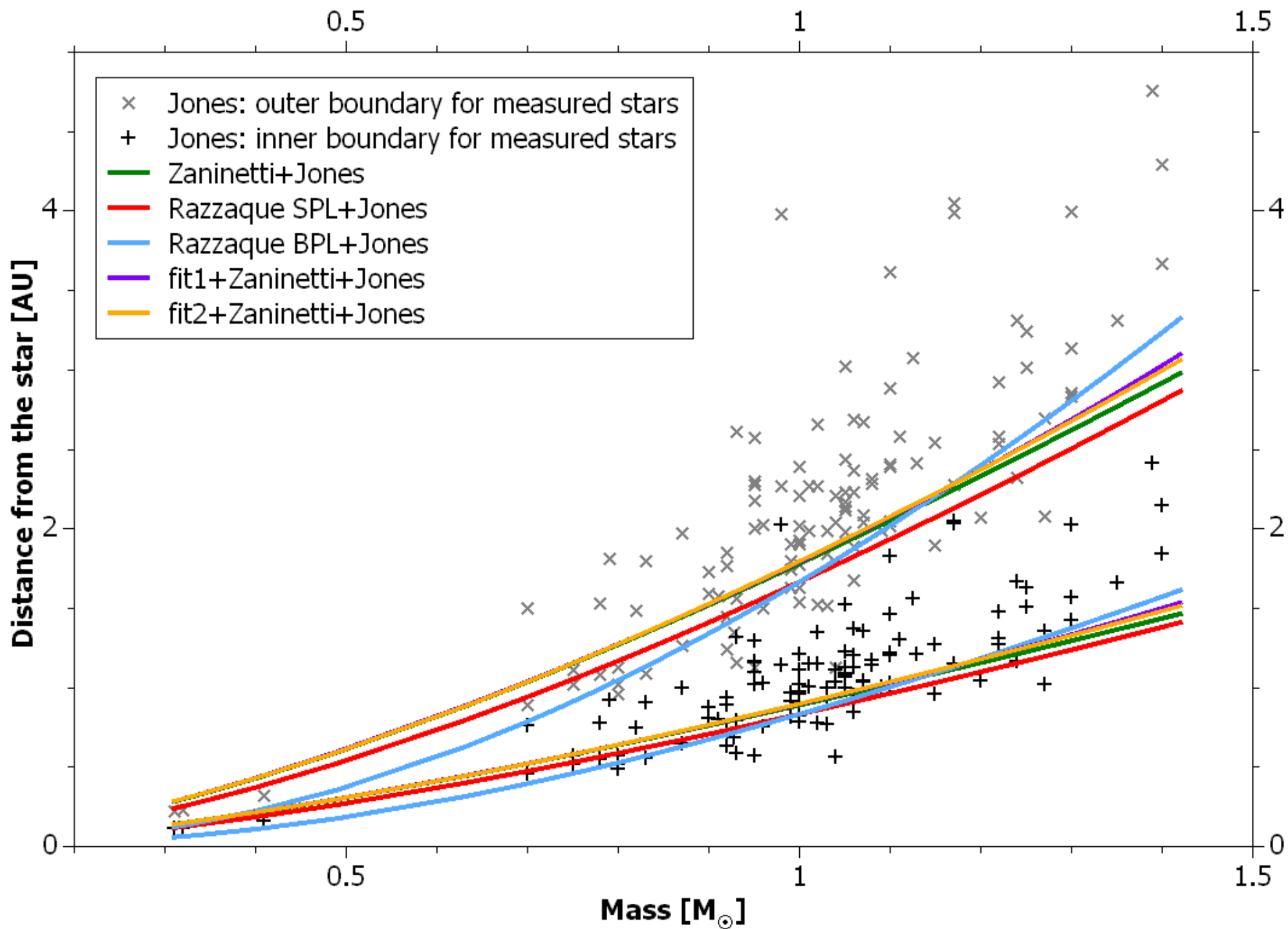| **Stellar flux at the HZ boundaries – *Jones*** |
|:---:|
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[3]

Calculation Method	Effective Temperature	
Zaninetti	$T = 5762.7 \cdot M^{0.4841}$	if $0.3\,M_\odot < M < 18.5\,M_\odot$
Razzaque SPL	$T = 5700 \cdot M^{0.5}$	if $M \leq 10\,M_\odot$
Razzaque BPL	$T = 5700 \cdot M^{0.8}$	if $0.1\,M_\odot < M < 2\,M_\odot$

Calculation Method	Luminosity	
Zaninetti	$L = 1.1535 \cdot M^{3.43}$	
Razzaque SPL	$L = M^{3.6}$	
Razzaque BPL	$L = M^{4.8}$	if $M \leq 2\,M_\odot$

[4], [5]

Effective temperature of stars

- measured stars [6]
- Zaninetti
- Razzaque SPL
- Razzaque BPL
- fit1: $a0+a1*x+a2*x^2$
- fit2: $a0+a1*x^{a2}$

Effective temperature [K]

Mass [$M_\odot$]

LW HZ boundaries

LW HZ boundaries

Legend:
- × Jones: outer boundary for measured stars
- + Jones: inner boundary for measured stars
- Zaninetti+Jones
- Zaninetti+Kasting
- fit1+Zaninetti+Jones
- fit1+Zaninetti+Kasting

X-axis: Mass [M$_\odot$]

Y-axis: Distance from the star [AU]
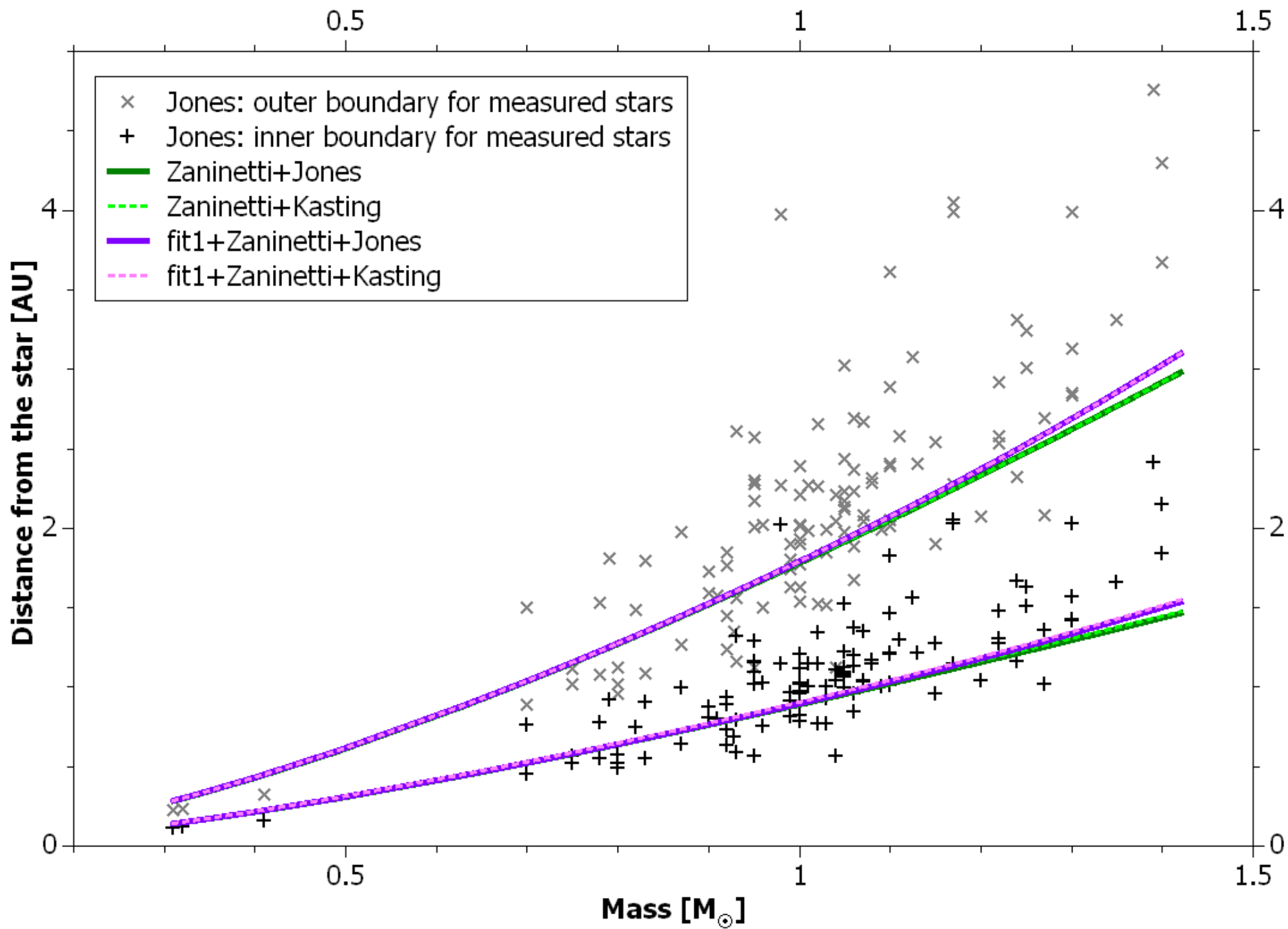
- Best calculation methods:

T: fit1, L: Zaninetti (boundaries: Jones)

- Better T estimation for higher masses
- Best: Residual Sum of Squares
- Usable: 0.3 – 1.4 $M_\odot$

T, L: Zaninetti (boundaries: Jones)

- Best theoretical model
- Very good: Residual Sum of Squares
- Usable: 0.3 – 18.5 $M_\odot$

Ultraviolet Habitable Zone

- Defined by Buccino et al. (2006) [7]

- Inner boundary:

  - induces DNA damage

  - inhibits photosynthesis

  - causes lesion in a wide variety of proteins and lipids [8]

- Outer boundary:

  - energy source for chemical synthesis of complex molecules
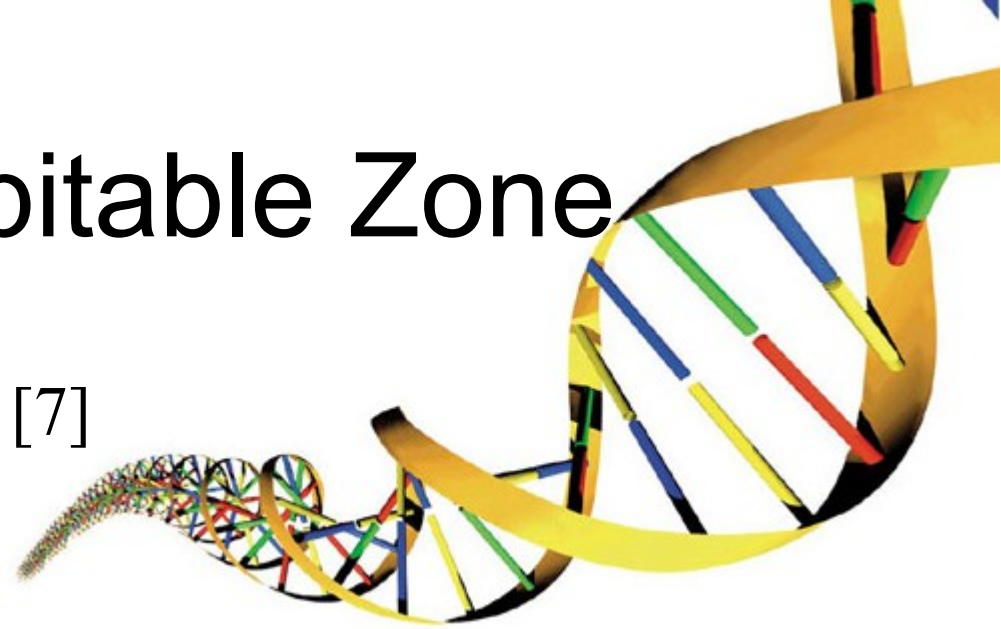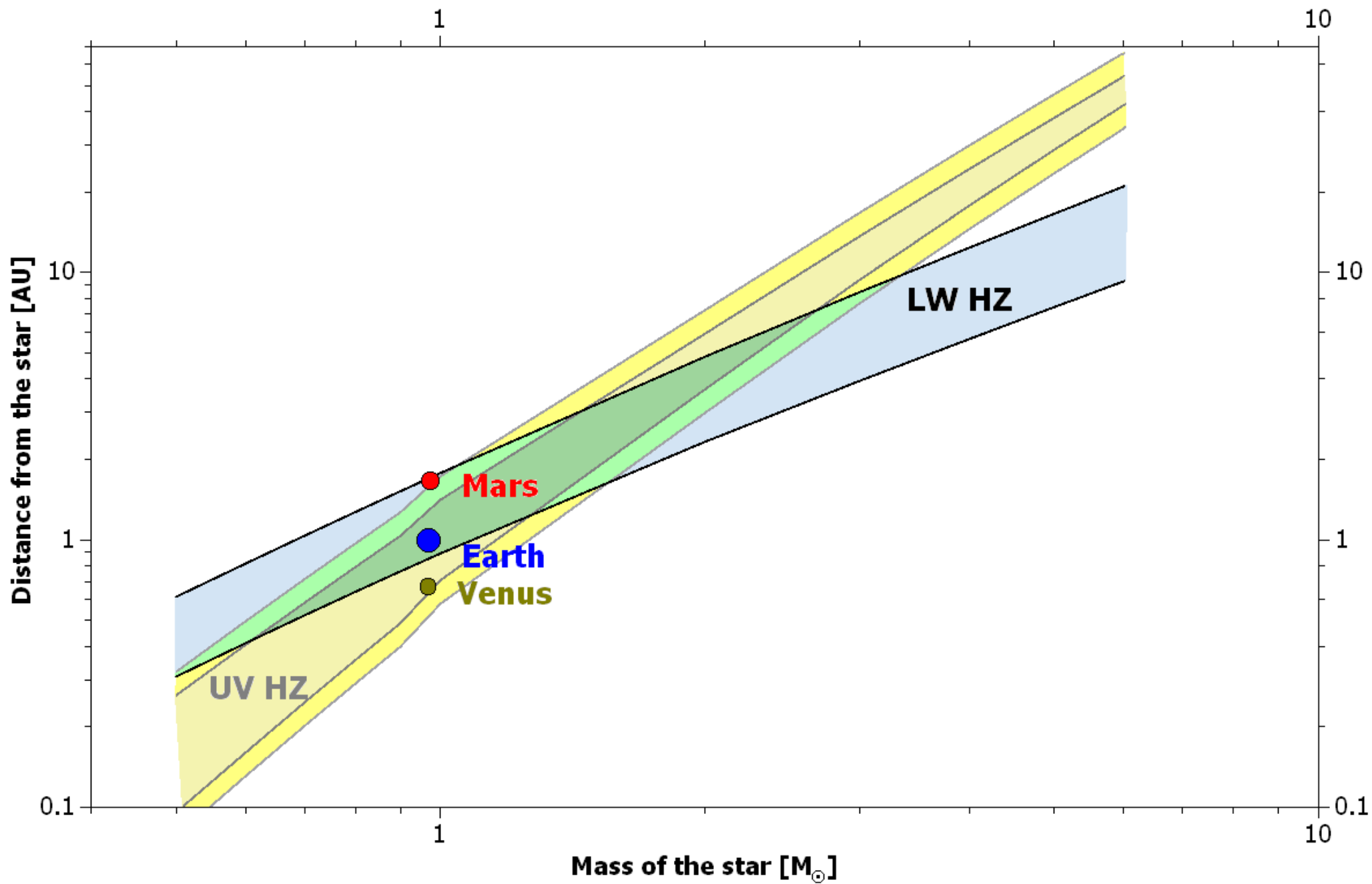
- Improved formulae

Inner

$$\frac{d_{inner}^2}{d_\oplus^2} \geq \frac{\int\limits_{200nm}^{400nm} B(\lambda) \cdot R_*^2 \cdot E_*(\lambda)\, d\lambda}{x \cdot \int\limits_{200nm}^{400nm} B(\lambda) \cdot R_\odot^2 \cdot E_\odot(\lambda)\, d\lambda}$$

Outer

$$\frac{d_{outer}^2}{d_\oplus^2} \leq \frac{\int\limits_{200nm}^{400nm} R_*^2 \cdot E_*(\lambda)\, d\lambda}{y \cdot \int\limits_{200nm}^{400nm} R_\odot^2 \cdot E_\odot(\lambda)\, d\lambda}$$

- B(λ): biological action spectrum [9]
- *x, y:* multiplicators of the terrestrial UV radiation

  x: UV level that still can be tolerated by DNA, proteins and photosynthetic process

  y: UV level which is absolutely necessary for chemical reactions

Thank you for your attention!

[1] Kasting et al. 1993 Icarus 101, 108

[2] Catling&Kasting *'Atmospheric Evolution'* Cambridge Univ. Press
   – *in prep.*

[3] Jones et al. 2006 ApJ 649, 1010

[4] Zaninetti et al. 2008 Serbian Astronomical Journal 177, 73

[5] Razzaque et al. 2009 ApJ 697, 483

[6] Schneider *'The Extrasolar Planets Encyclopaedia'* exoplanet.eu

[7] Buccino et al. 2006 Icarus 183, 491

[8] Cockell 1998 J. Theor. Biol. 193, 717

[9] Modos et al. 1999 J. Photochem. Photobiol. B: Biol. 49, 171