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# Characterisation of the interior structures and atmospheres of multiplanetary systems

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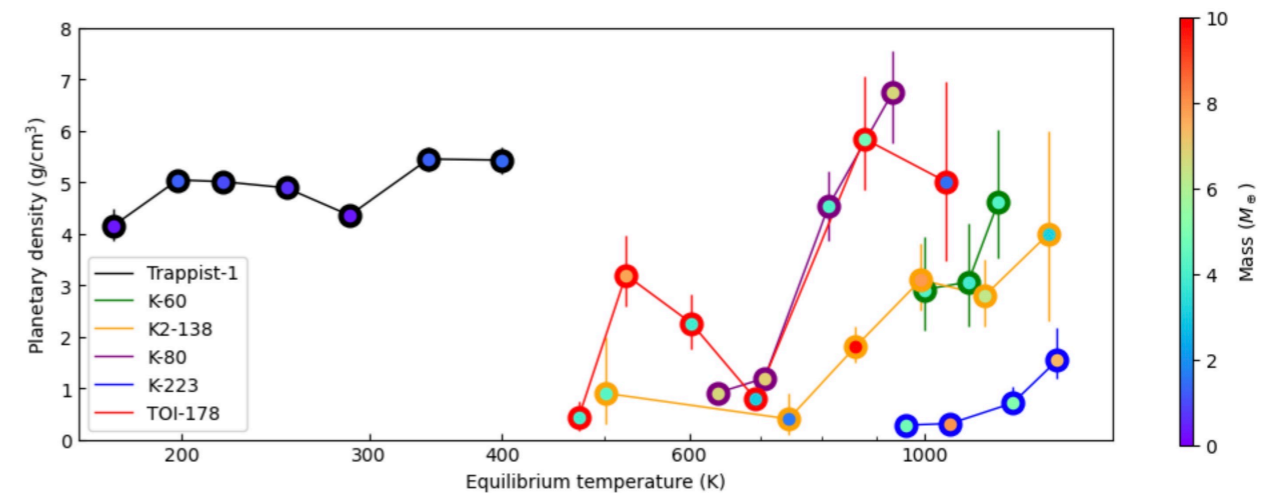
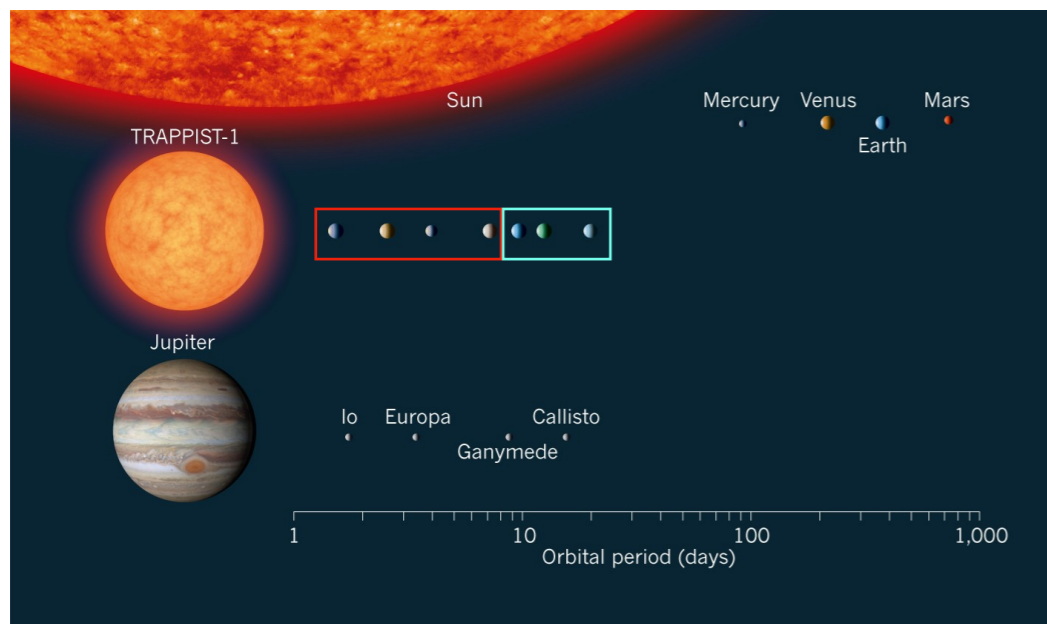
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PLATO conference 2021



# Introduction

- TRAPPIST-1 (Acuña+ 21, Agol+ 20), TOI-178 (Leleu+ 21):



Leleu+ 21

- Multiplanetary systems are environments suitable to explore the compositional diversity of low-mass planets, their formation and evolution

# Interior structure model

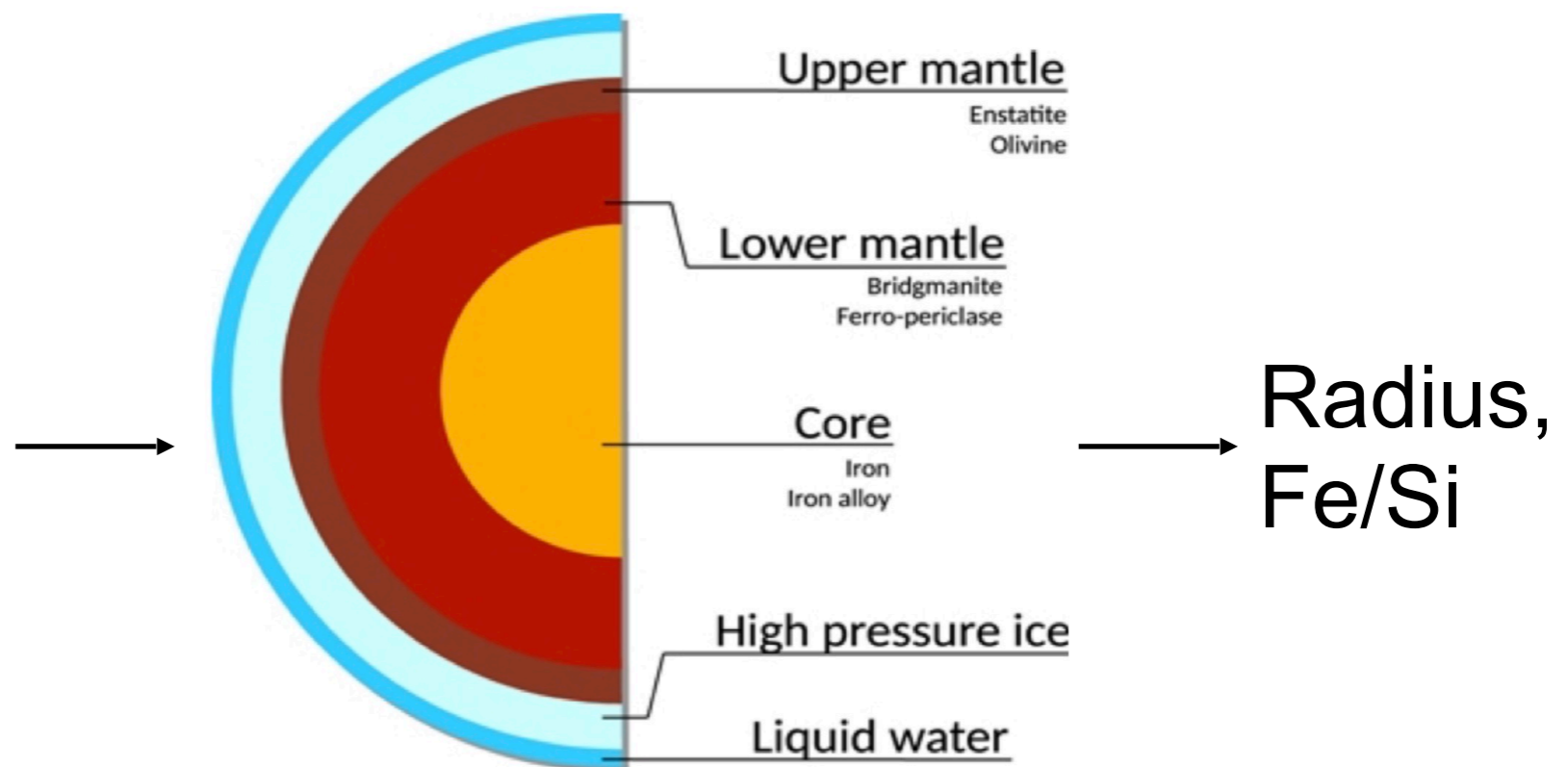
- Bruggen+ 16, 17:

Mass

Core Mass  
Fraction (CMF)

Water Mass  
Fraction (WMF)

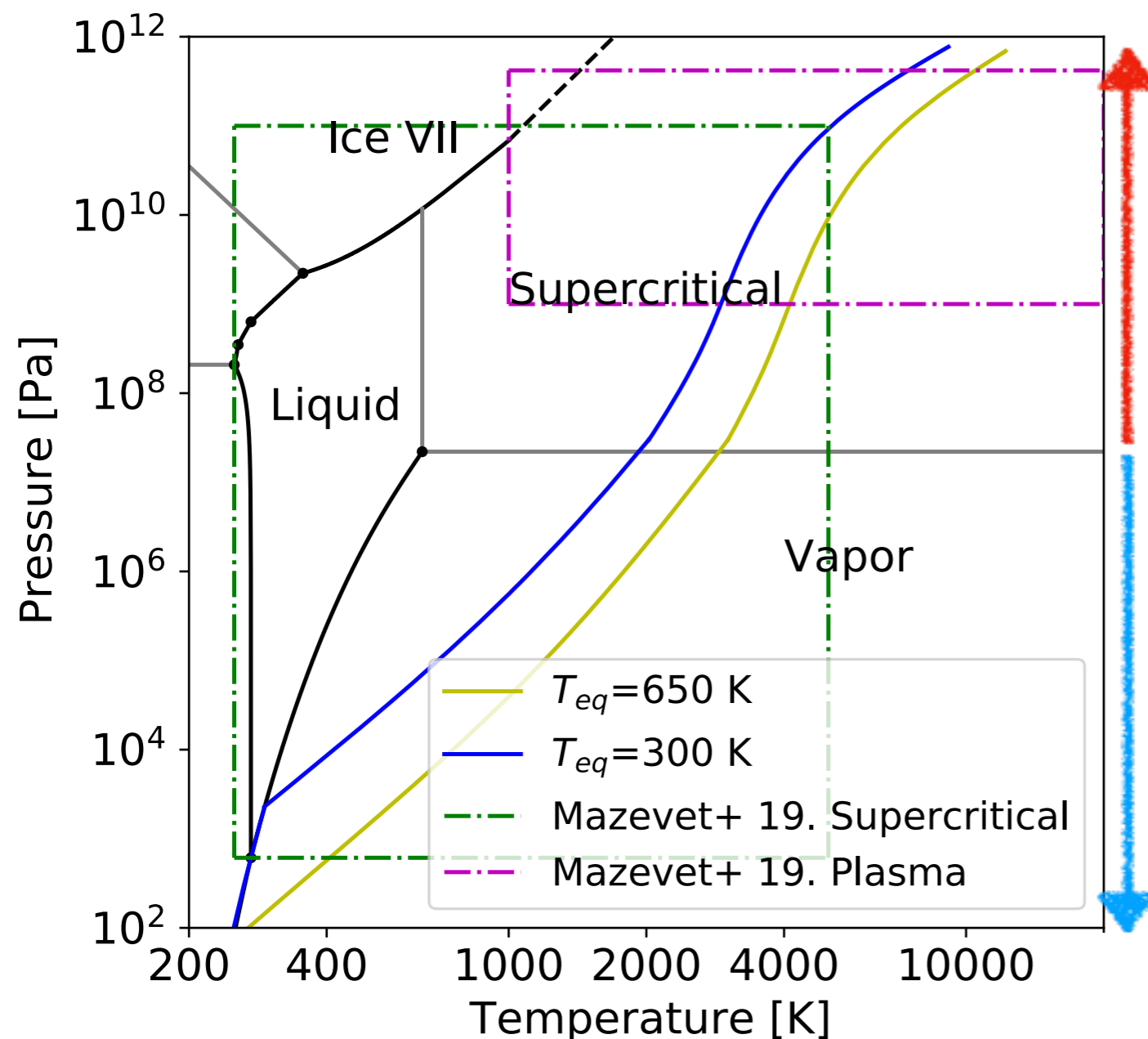
Surface  
pressure and  
temperature



Pressure  $P(r)$   
Gravity  $g(r)$   
Temperature  $T(r)$   
Density  $\rho(r)$

# Interior-atmosphere coupling

- Water phase diagram:



- Supercritical: Mousis+ 20. EOS from Mazevet+ 19
- Atmosphere model: Pluriel+19, Marcq+17
- Coupling algorithm: Acuña+ 21

# Multiplanetary systems

- Low-mass planets ( $M < 20 M_{\oplus}$ )
- Systems with 5 or more planets

TRAPPIST-1

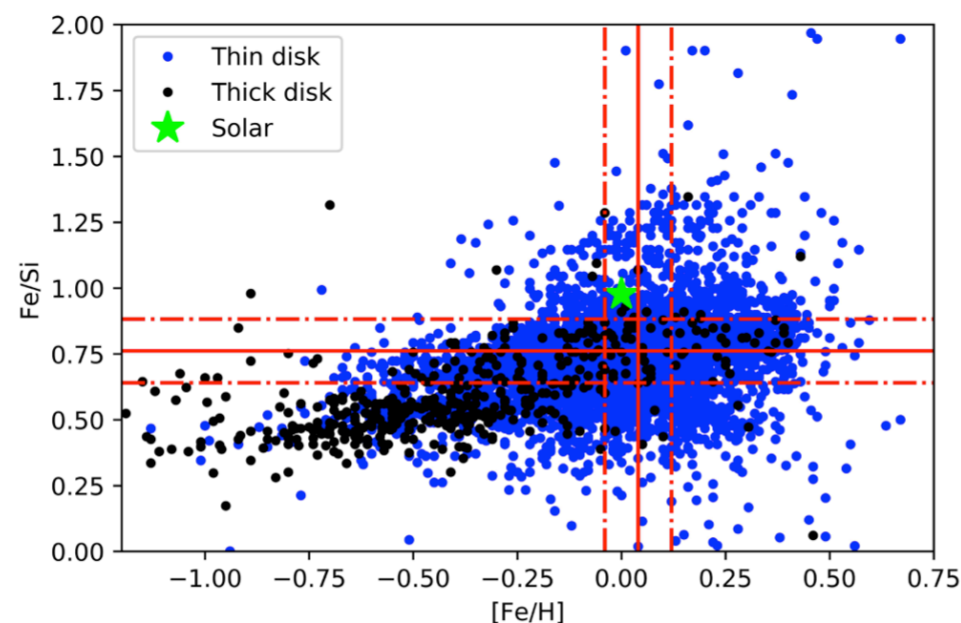
K2-138

TOI-178

Kepler-11

Kepler-102

Kepler-80



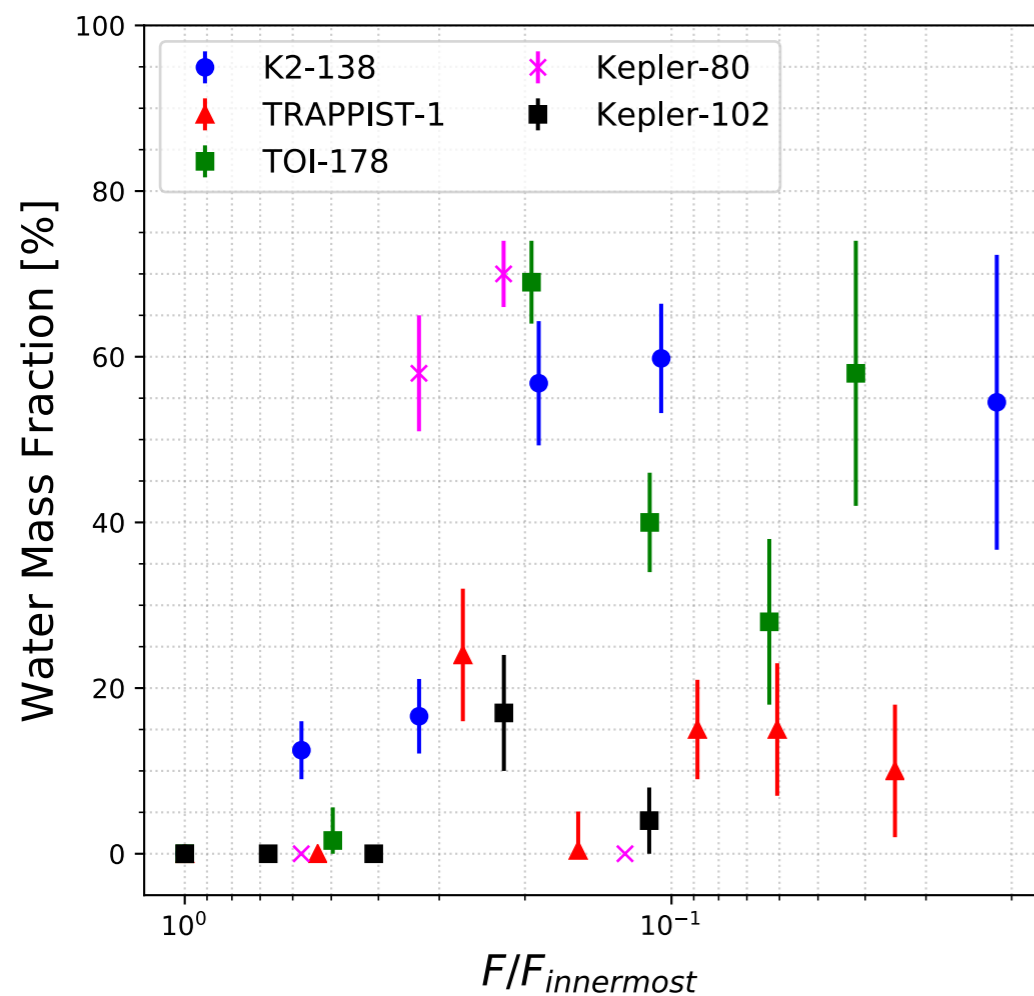
Masses, radii and stellar abundances



MCMC Bayesian algorithm  
(Dorn+ 15, Acuña+ 21)

# Results

# WMF in multiplanetary systems



Gradient + plateau trend

System	Planet	CMF	WMF	Significance	$\Delta M_{H_2}$ [ $M_{\oplus}$ ]
TOI-178	b	$0.21 \pm 0.30$	0	$< 1 \sigma$	0.83
	c	$0.30 \pm 0.02$	$0.02^{+0.04}_{-0.02}$	$< 1 \sigma$	$< 0.01$
	d	$0.10 \pm 0.01$	$0.69 \pm 0.05$	$1.3 \sigma$	0.16
	e	$0.18 \pm 0.02$	$0.40 \pm 0.06$	$< 1 \sigma$	$< 0.01$
	f	$0.22 \pm 0.03$	$0.28 \pm 0.10$	$< 1 \sigma$	$< 0.01$
	g	$0.10 \pm 0.01$	$0.58 \pm 0.16$	$3.0 \sigma$	$< 0.01$
	Kepler-11	b	$0.20 \pm 0.04$	$0.27 \pm 0.10$	$< 1 \sigma$
c		$0.18 \pm 0.01$	$0.33 \pm 0.04$	$1.7 \sigma$	$< 0.01$
d		$0.10 \pm 0.02$	$0.65 \pm 0.05$	$2.4 \sigma$	$< 0.01$
e		$0.12 \pm 0.01$	$0.55 \pm 0.04$	$4.4 \sigma$	$< 0.01$
f		$0.14 \pm 0.06$	$0.47 \pm 0.10$	$1.9 \sigma$	0.56
Kepler-102		b	$0.91^{+0.09}_{-0.16}$	0	$< 1 \sigma$
	c	$0.95^{+0.05}_{-0.30}$	0	$< 1 \sigma$	0.10
	d	$0.80 \pm 0.14$	0	$< 1 \sigma$	$< 0.01$
	e	$0.22 \pm 0.02$	$0.17 \pm 0.07$	$< 1 \sigma$	0.01
	f	$0.27 \pm 0.09$	$0.04 \pm 0.04$	$< 1 \sigma$	0.02
	Kepler-80	d	$0.97^{+0.03}_{-0.05}$	0	$< 1 \sigma$
e		$0.43 \pm 0.18$	0	$< 1 \sigma$	$< 0.01$
b		$0.13 \pm 0.02$	$0.58 \pm 0.07$	$< 1 \sigma$	$< 0.01$
c		$0.09 \pm 0.01$	$0.70 \pm 0.04$	$< 1 \sigma$	$< 0.01$
g		$0.31 \pm 0.02$	$< 1.5 \times 10^{-3}$	$< 1 \sigma$	140

Trend deviations case by case



# Conclusion

- Our **interior structure model** can be applied to low-mass planets at a **wide range of irradiations**.
- We obtain a clear **increasing water content with distance from host star + a plateau** for several multiplanetary systems.
- These trend could be shaped by **atmospheric escape, migration type I and pebble accretion in the vicinity of the ice line**.
- We analyse case-by-case those planets that do not fit the trend. We are able to explain these cases with either **Jeans atmospheric escape, H/He envelopes or high-CMF forming processes**, such as mantle evaporation, collisions or formation in the vicinity of the rocklines.

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