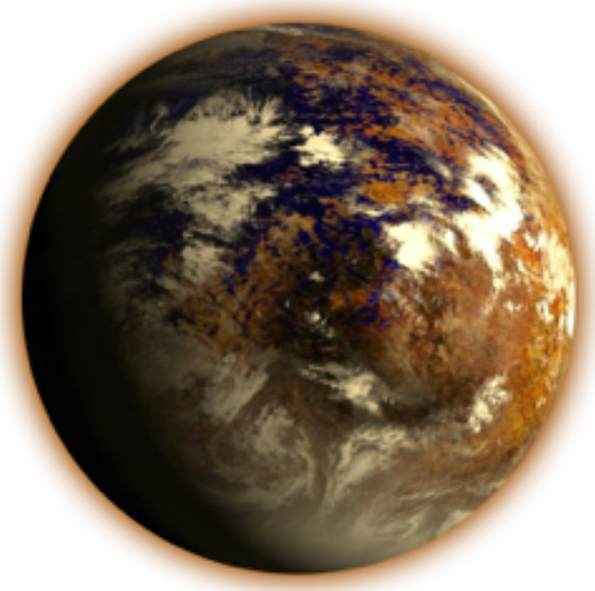


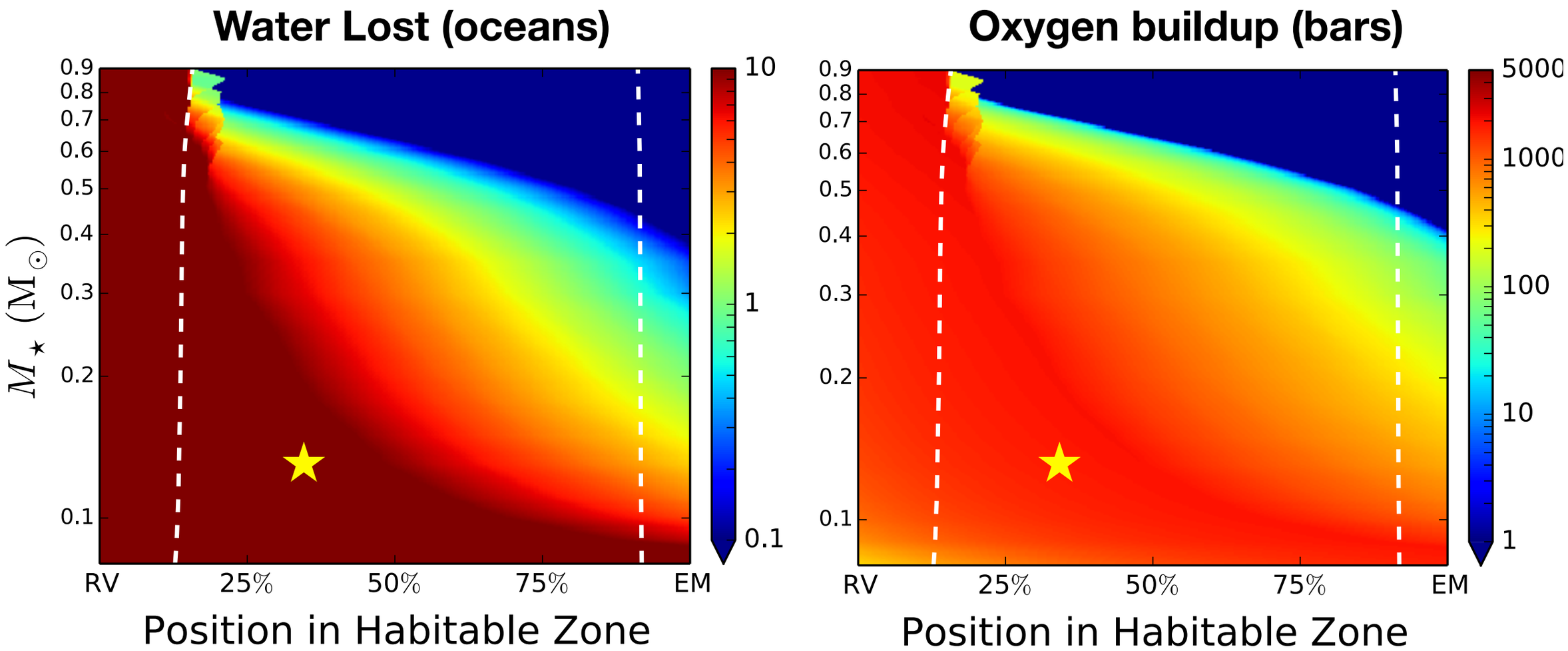
How Much Water is There on Proxima Cen b?

ABSCICON — APRIL 28 2017

Rodrigo Luger

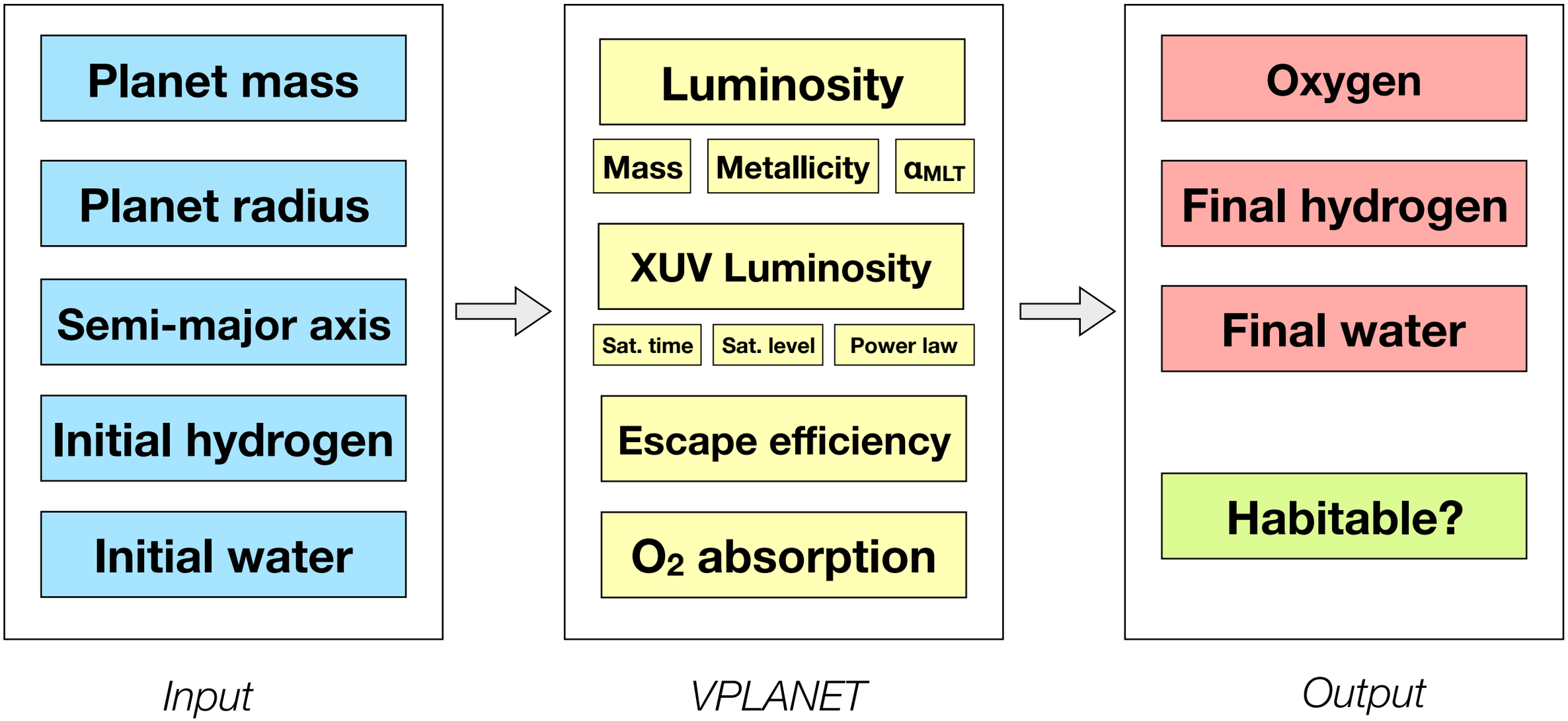
with Rory Barnes, Russel Deitrick, Peter Driscoll, Thomas Quinn, David Fleming, Benjamin Guyer, Diego McDonald, and the VPL Team

Water Loss

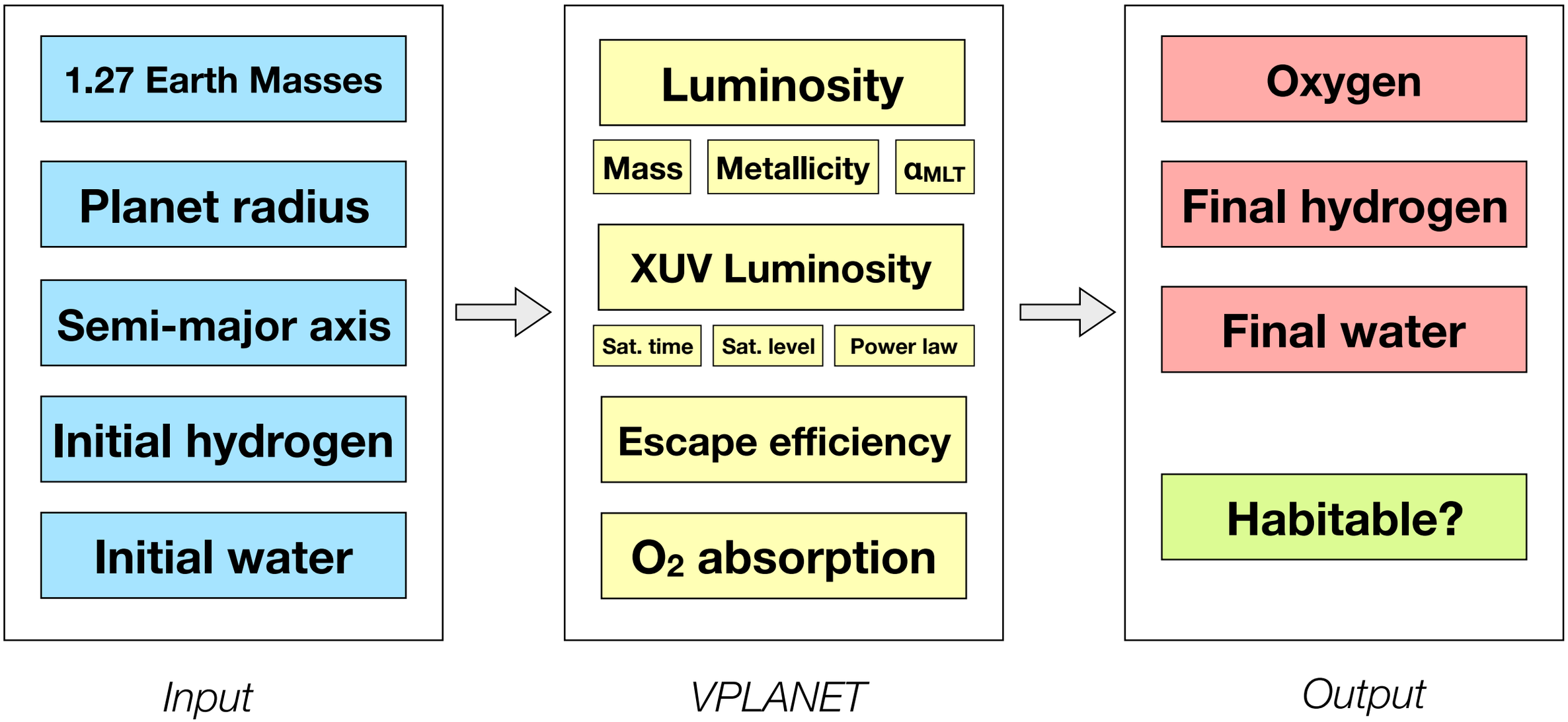


Luger and Barnes (2015)

The Problem

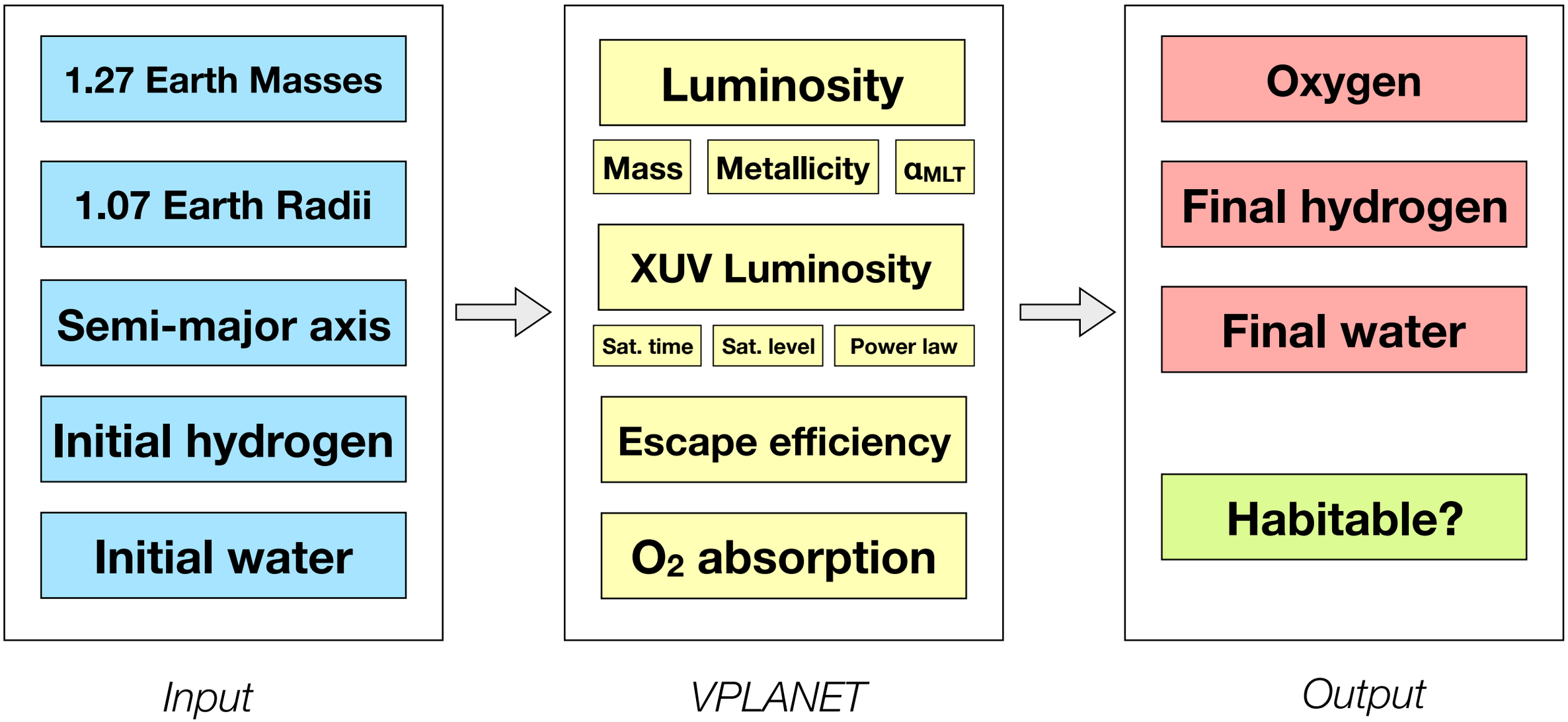

Planet mass
Planet radius
Semi-major axis
Initial hydrogen
Initial water
Input
Luminosity
Mass
Metallicity
α_{MLT}
XUV Luminosity
Sat. time
Sat. level
Power law
Escape efficiency
O_2 absorption
VPLANET
Oxygen
Final hydrogen
Final water
Habitable?
Output

The Problem



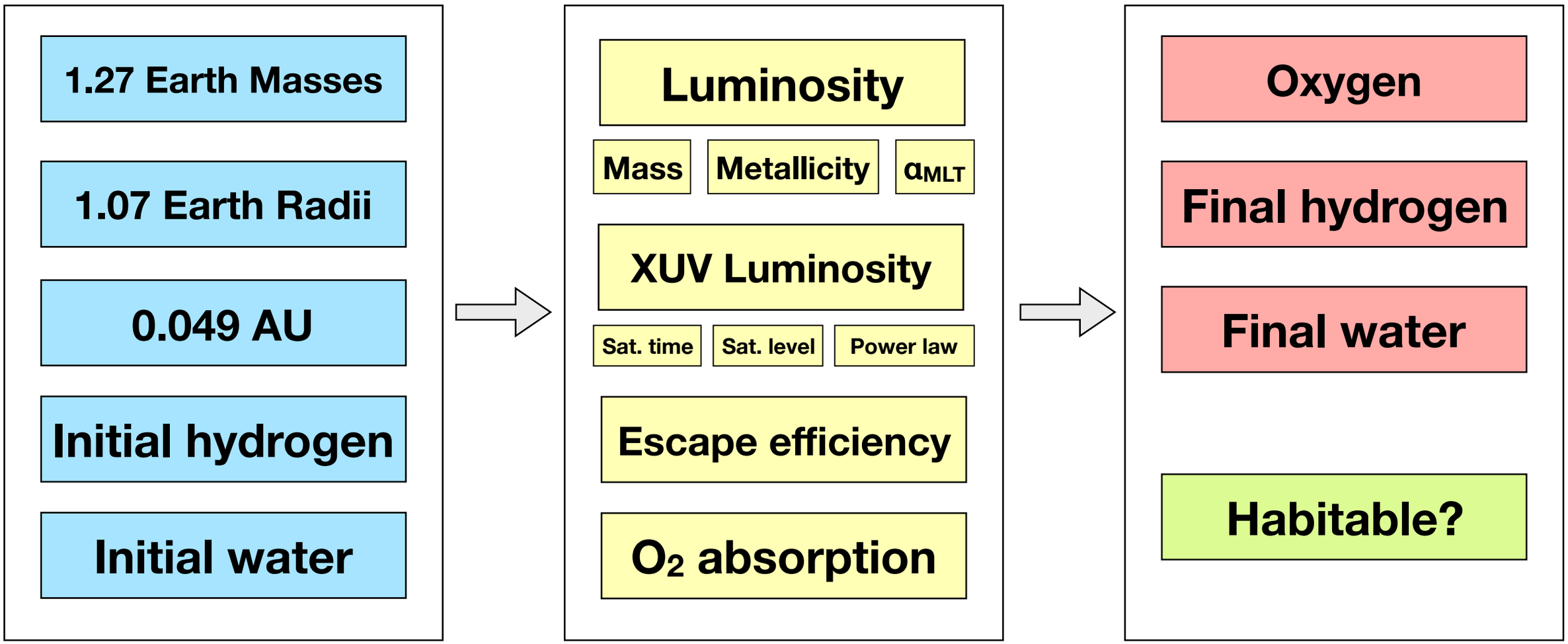
Input *VPLANET* *Output*

The Problem



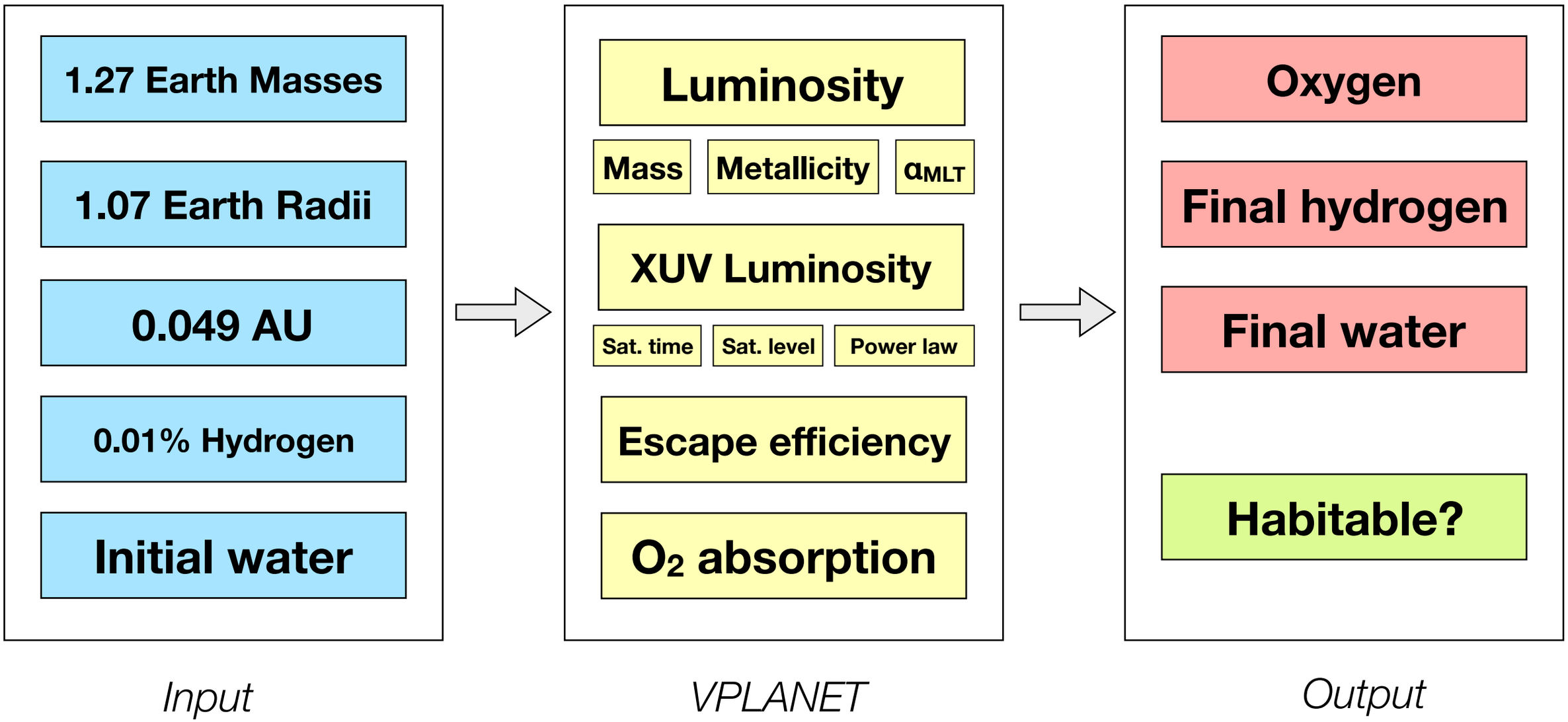
Input *VPLANET* *Output*

The Problem



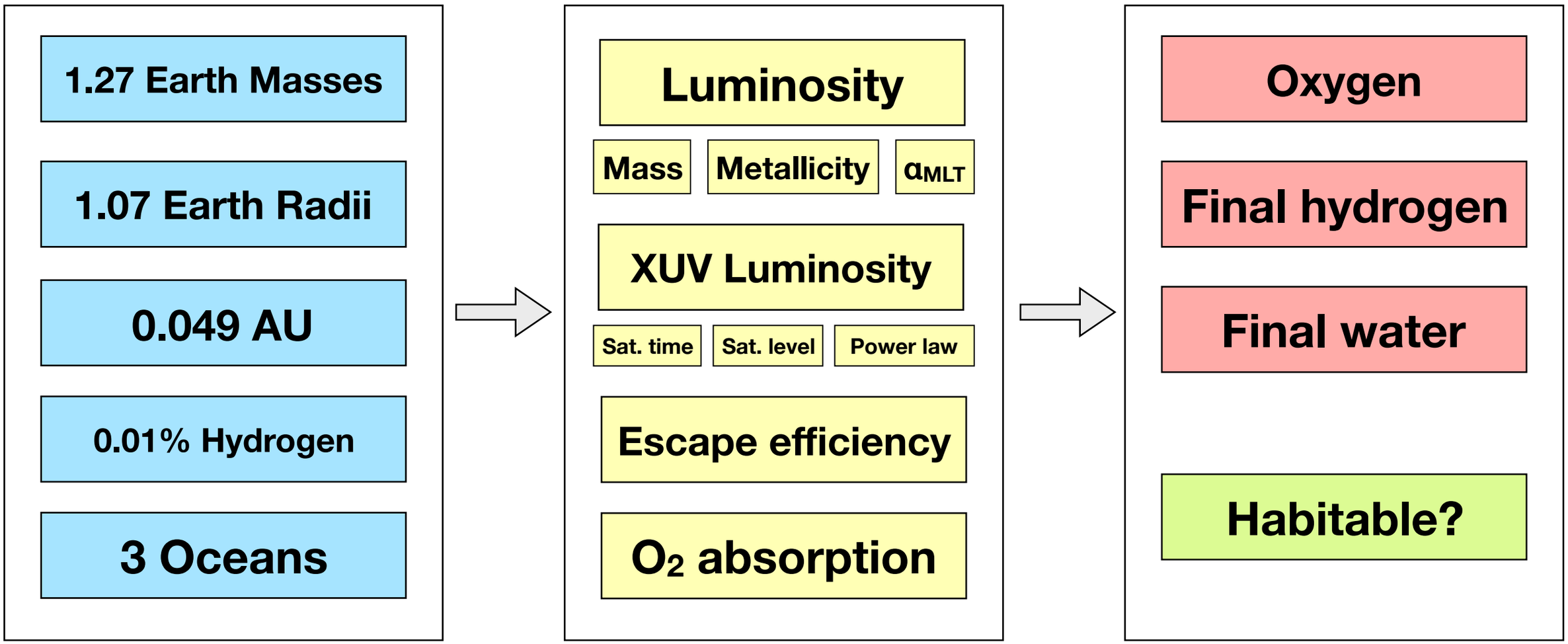
Input *VPLANET* *Output*

The Problem



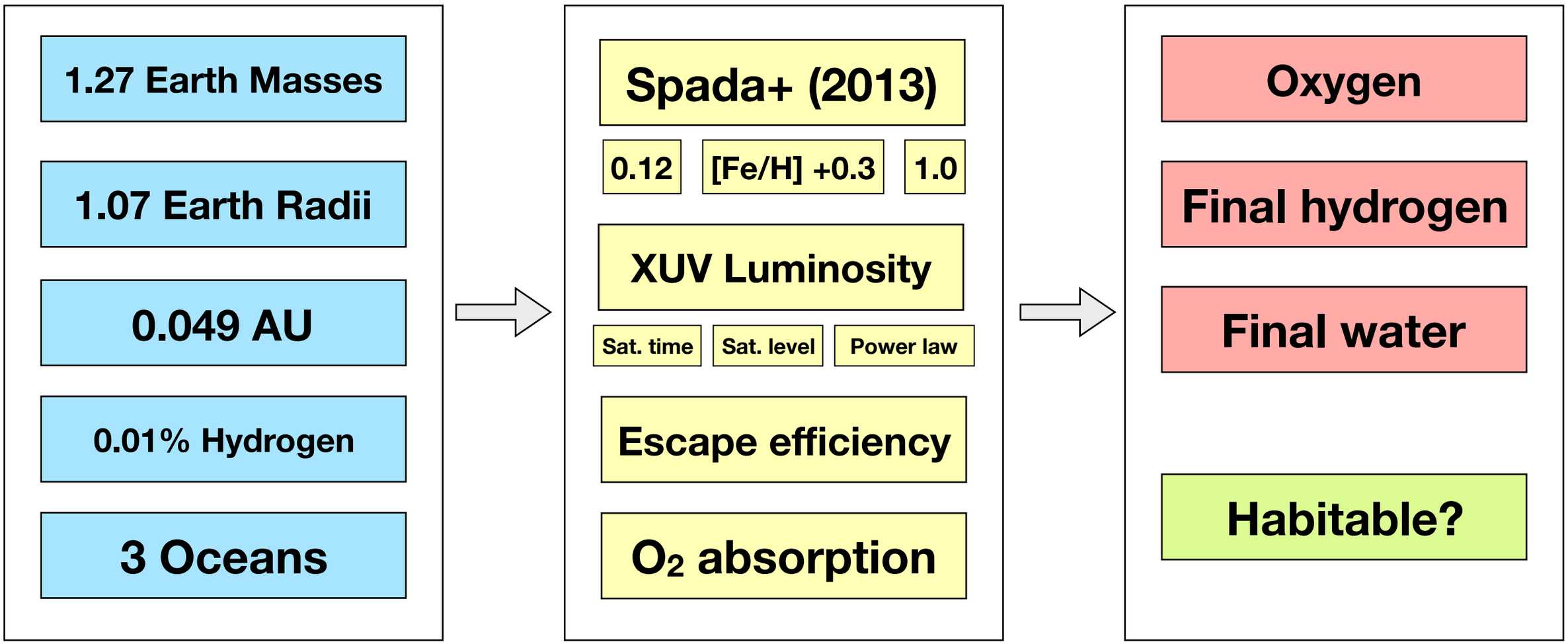
Input *VPLANET* *Output*

The Problem



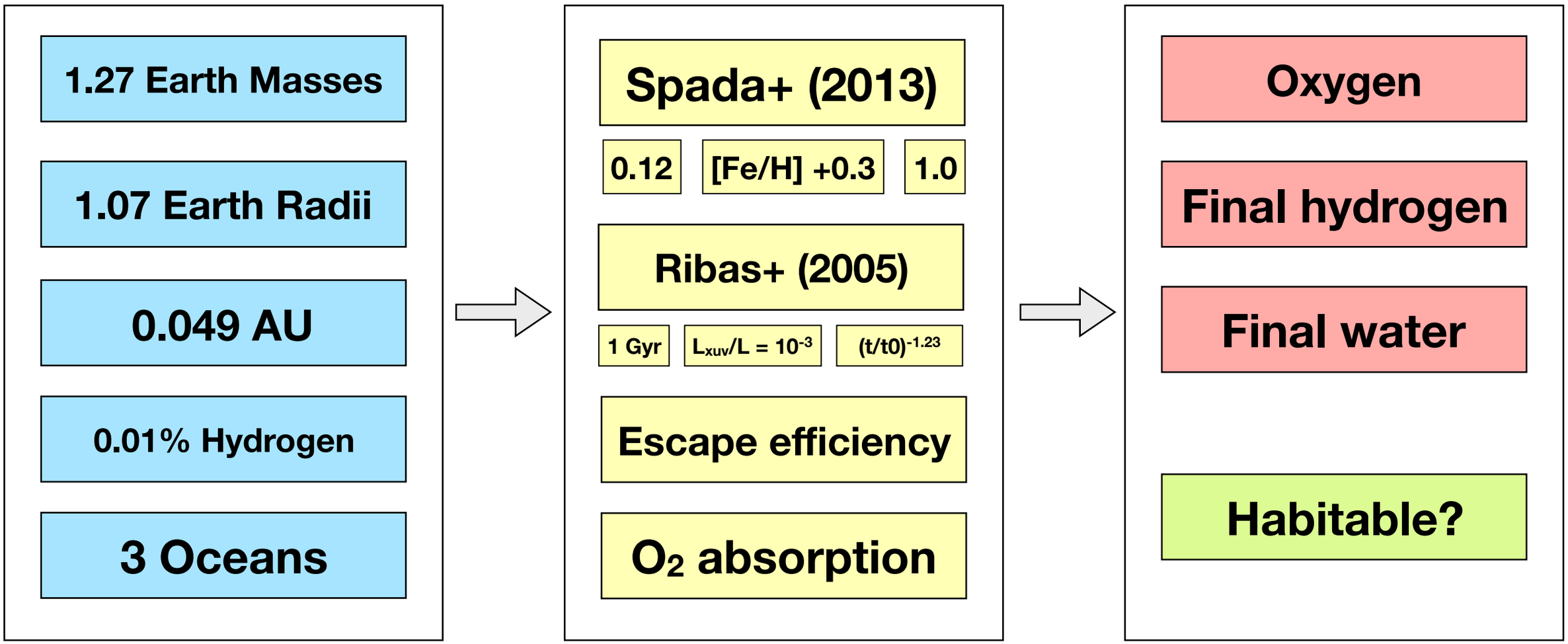
Input *VPLANET* *Output*

The Problem



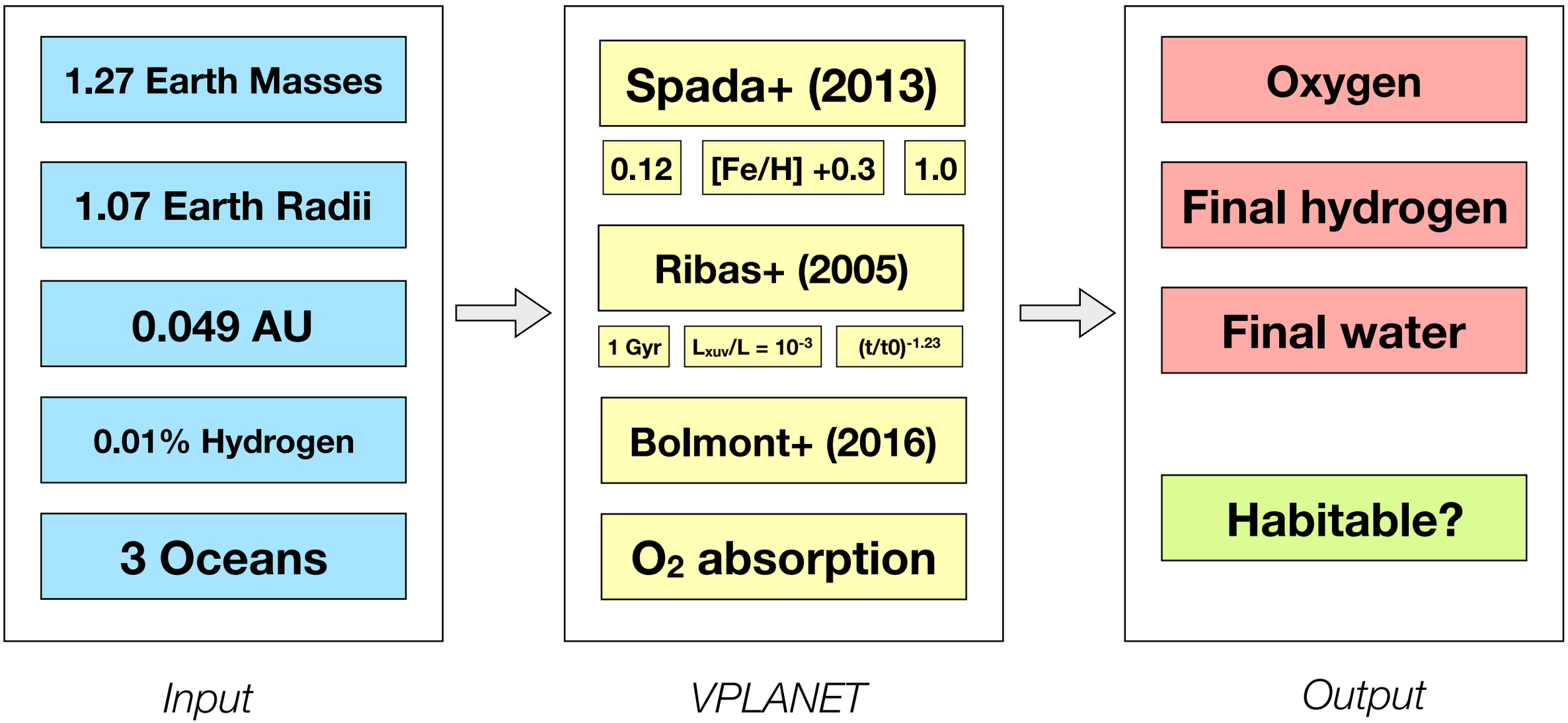
Input *VPLANET* *Output*

The Problem



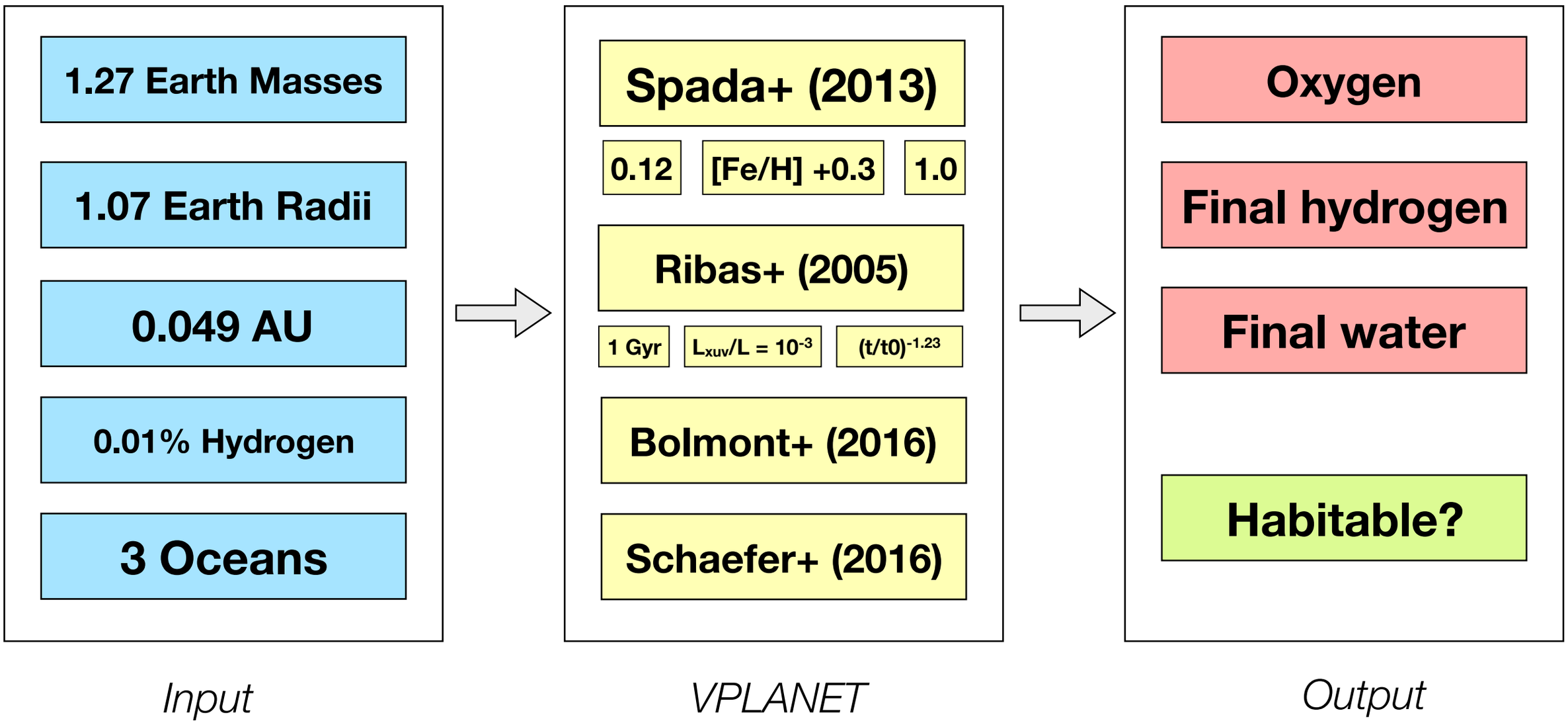
Input *VPLANET* *Output*

The Problem



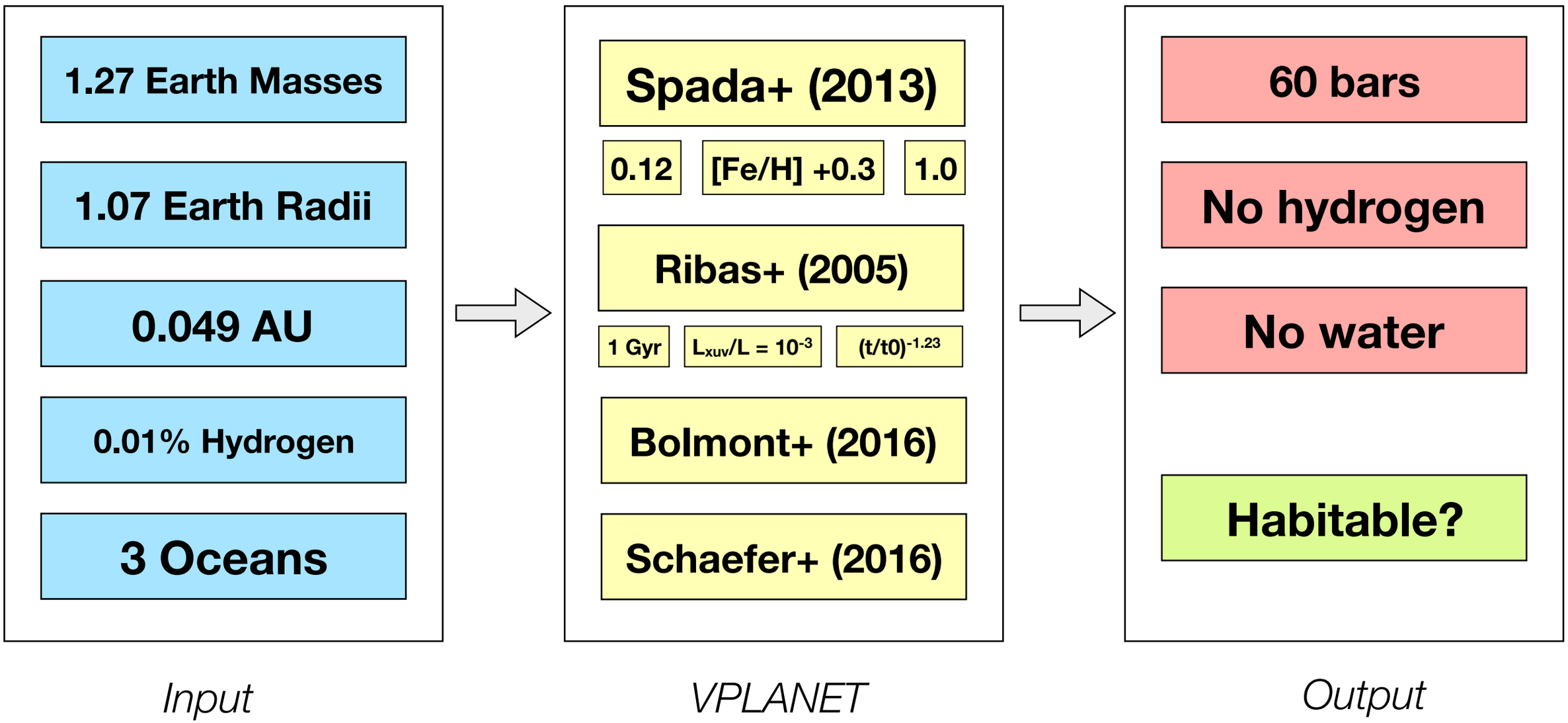
Input *VPLANET* *Output*

The Problem



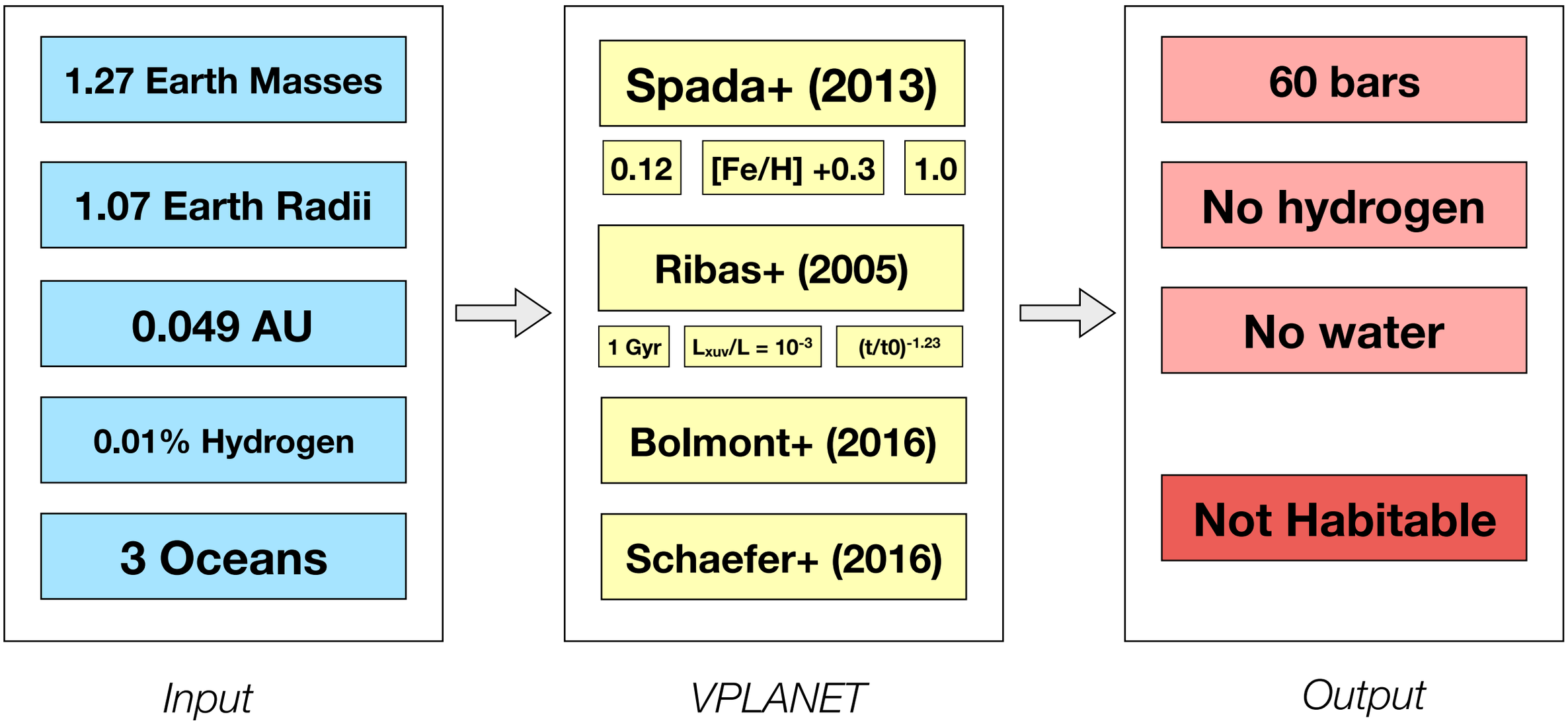
Input *VPLANET* *Output*

The Problem



Input *VPLANET* *Output*

The Problem



Input *VPLANET* *Output*

Conclusions

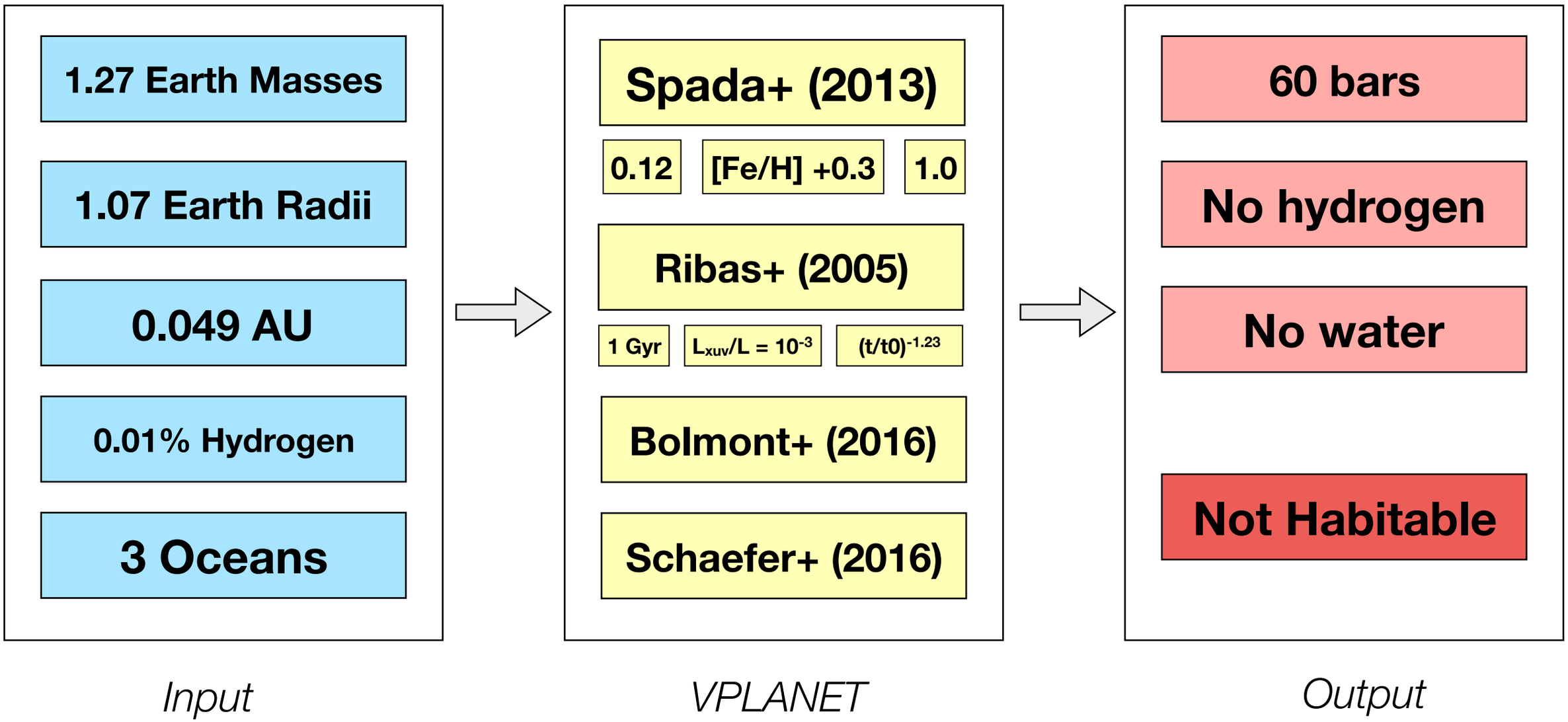
Proxima Cen b is not habitable

Conclusions

Proxima Cen b is not habitable

(Just kidding.)

Can we really say this with any confidence?



Uncertainties matter

1.27 Earth Masses

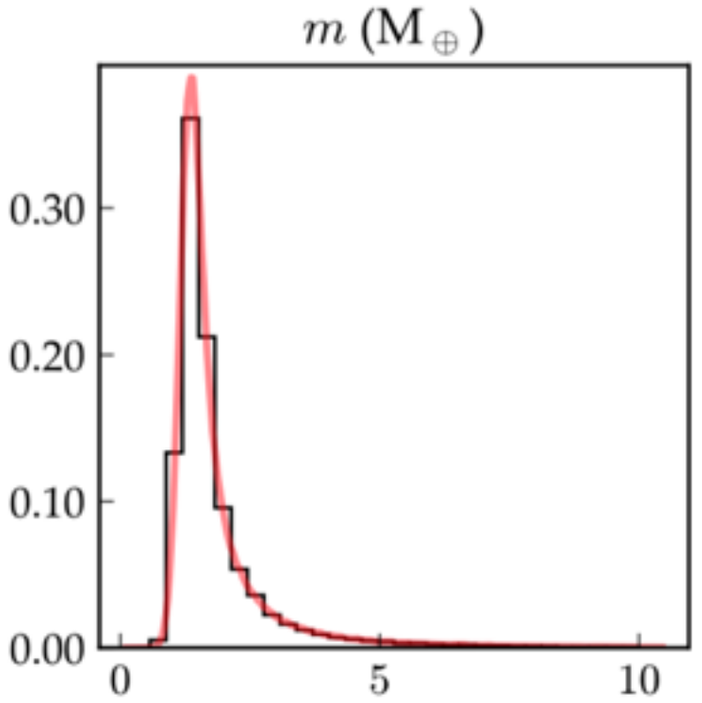
1.07 Earth Radii

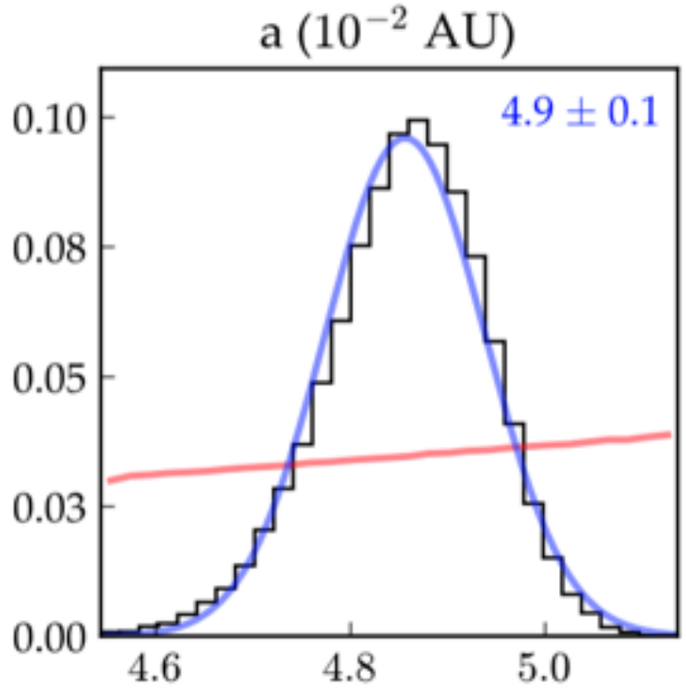
0.049 AU

0.01% Hydrogen

3 Oceans

Input





Data matters

Spada+ (2013)

0.12 | **[Fe/H] +0.3** | **1.0**

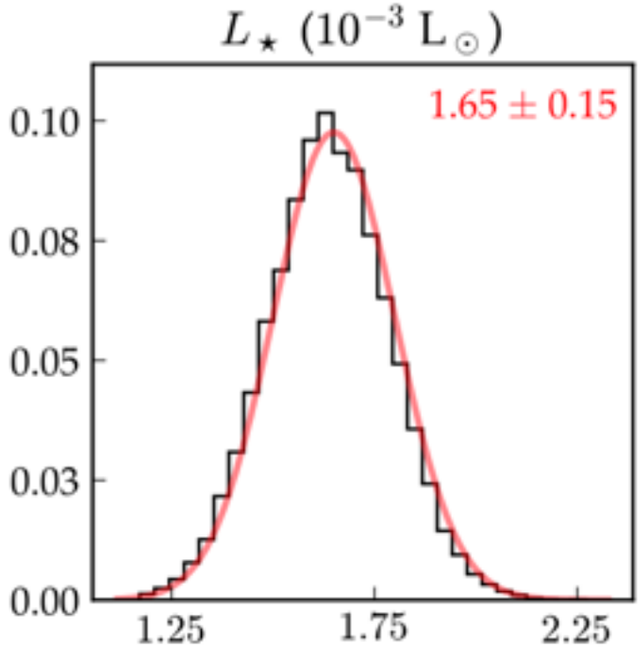
Ribas+ (2005)

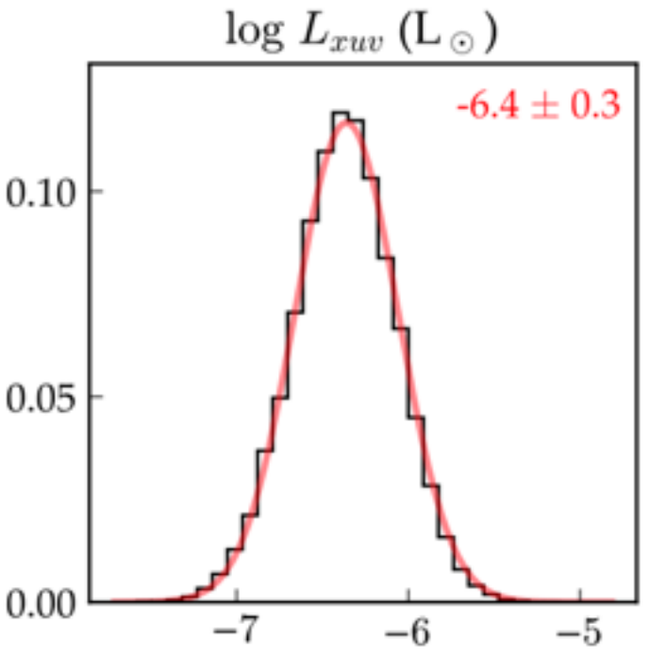
1 Gyr | **$L_{xuv}/L = 10^{-3}$** | **$(t/t0)^{-1.23}$**

Bolmont+ (2016)

Schaefer+ (2016)

VPLANET





Priors matter

1.27 Earth Masses

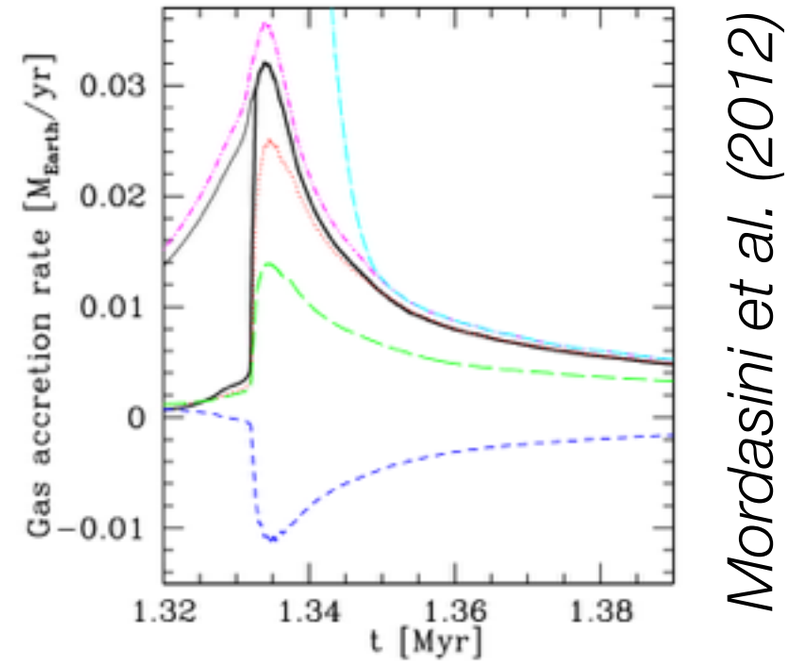
1.07 Earth Radii

0.049 AU

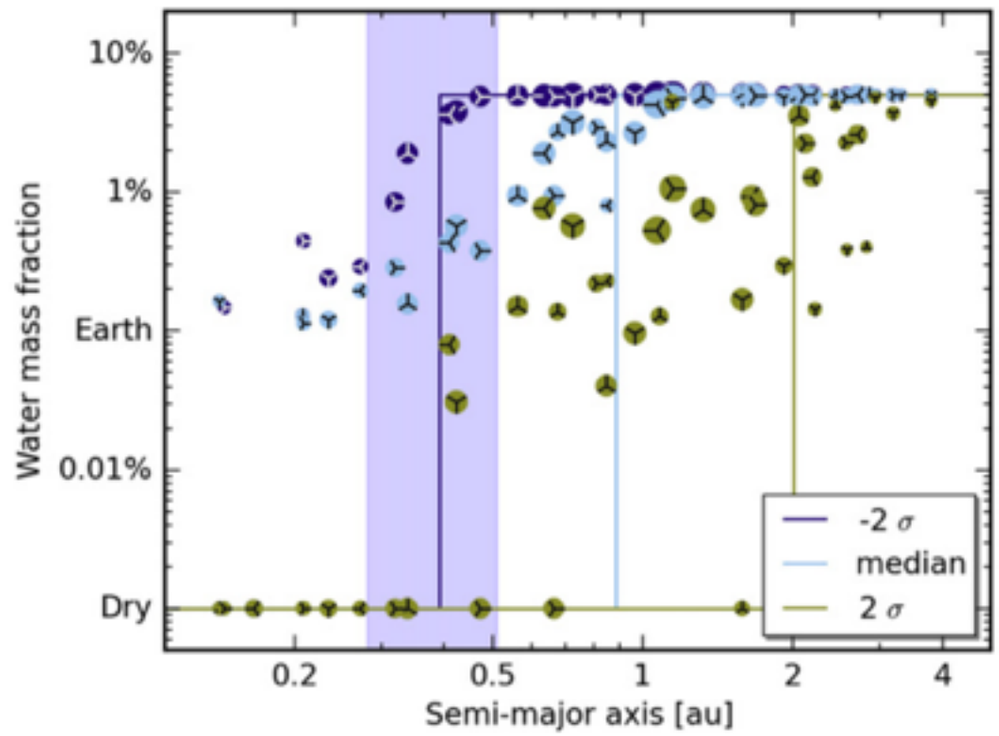
0.01% Hydrogen

3 Oceans

Input

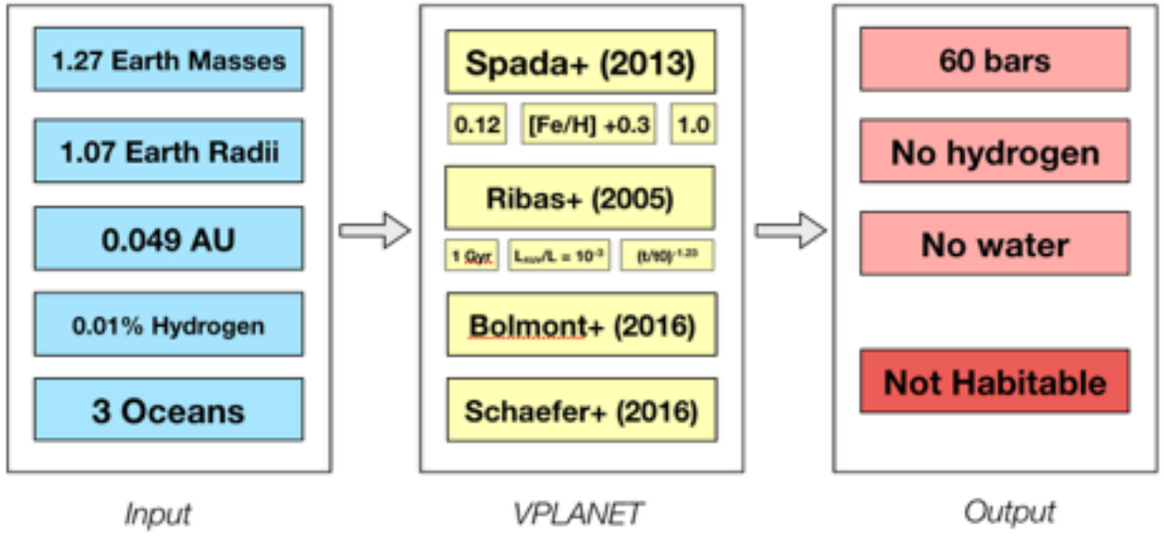


Mordasini et al. (2012)

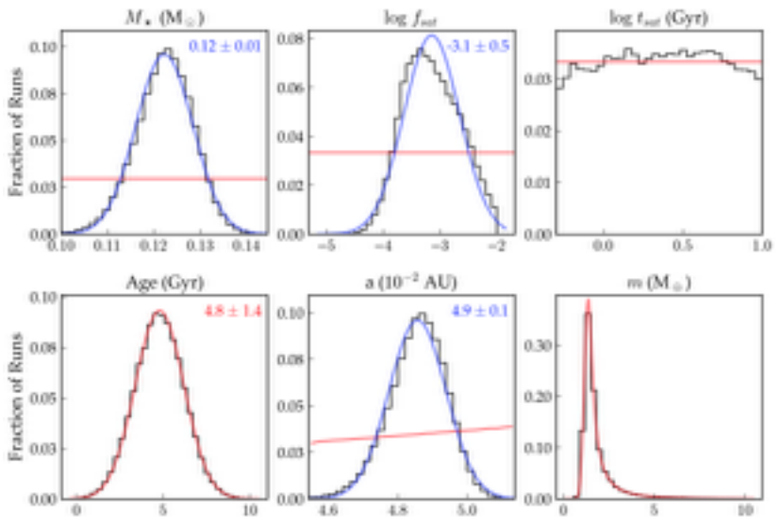


Mulders et al. (2015)

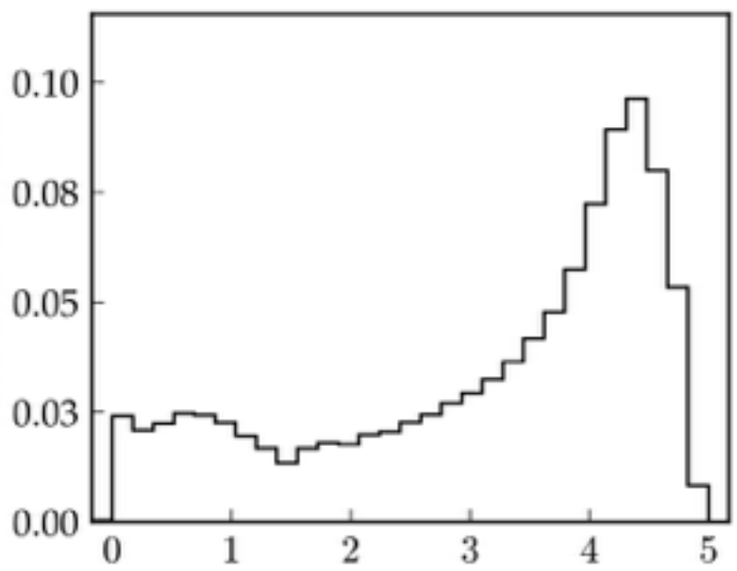
Maximum Likelihood



The Bayesian Approach



Priors, data, uncertainties



Water content (oceans)

Framing the problem

Priors & data

$$\mathbf{x} = \{M_\star, t_\star, f_{\rm sat}, t_{\rm sat}, \beta_{\rm xuv}, a, M_p, M^0_{\rm H}, M^0_{\rm H_2O}\}$$

Model outputs

$$\mathbf{y}(\mathbf{x}) = \{L_\star, L_{\rm xuv}, M_{\rm H}, M_{\rm H_2O}, M_{\rm O_2}\}$$

Framing the problem

Priors & data

$$\mathbf{x} = \{M_\star, t_\star, f_{\rm sat}, t_{\rm sat}, \beta_{\rm xuv}, a, M_p, M^0_{\rm H}, M^0_{\rm H_2O}\}$$

Model outputs

$$\mathbf{y}(\mathbf{x}) = \{L_\star, L_{\rm xuv}, M_{\rm H}, M_{\rm H_2O}, M_{\rm O_2}\}$$

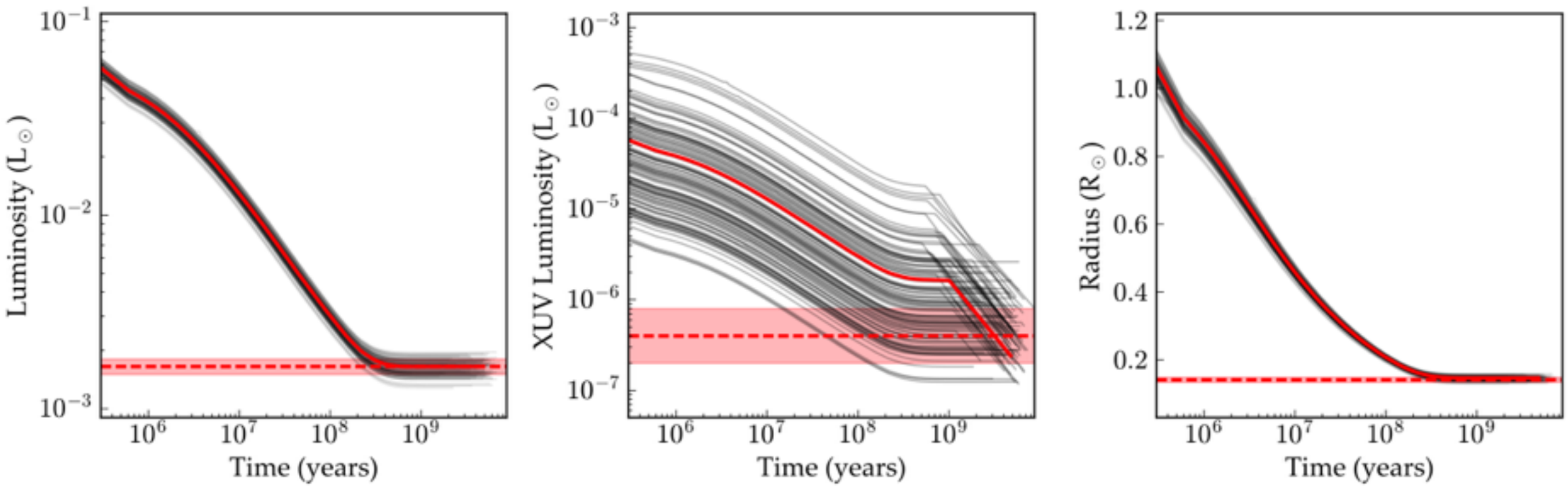
Likelihood Function

$$\ln \mathcal{L}(\mathbf{x}) = -\frac{1}{2}\left[\frac{(L_\star(\mathbf{x}) - L_\star)^2}{\sigma^2_{L_\star}} + \frac{(L_{\rm xuv}(\mathbf{x}) - L_{\rm xuv})^2}{\sigma^2_{L_{\rm xuv}}}\right] + \ln \text{Prior}(\mathbf{x}) + C$$

Markov Chain Monte Carlo (MCMC)

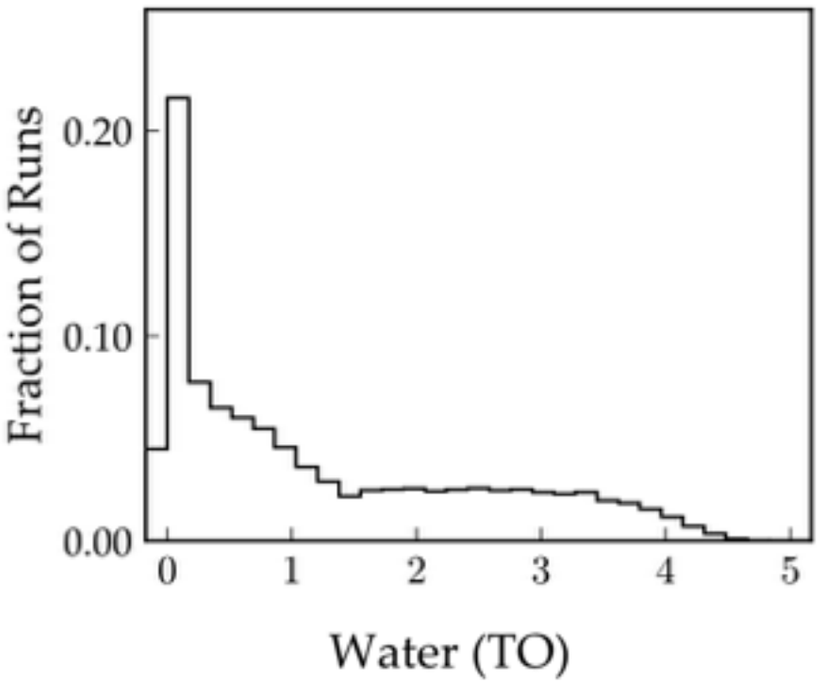
$$\ln\, \mathcal{L}(\mathbf{x}) \rightarrow P(M_{\rm H_2O})$$

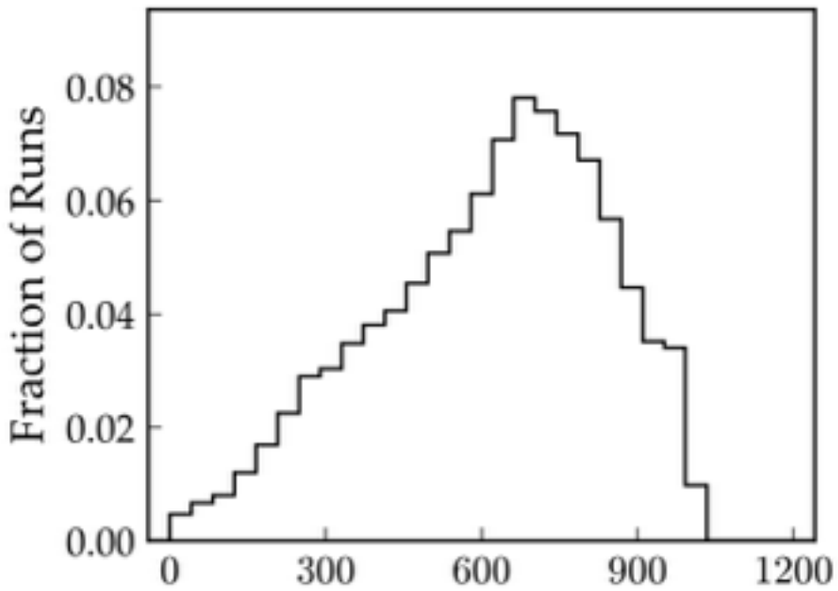
Stellar Evolution

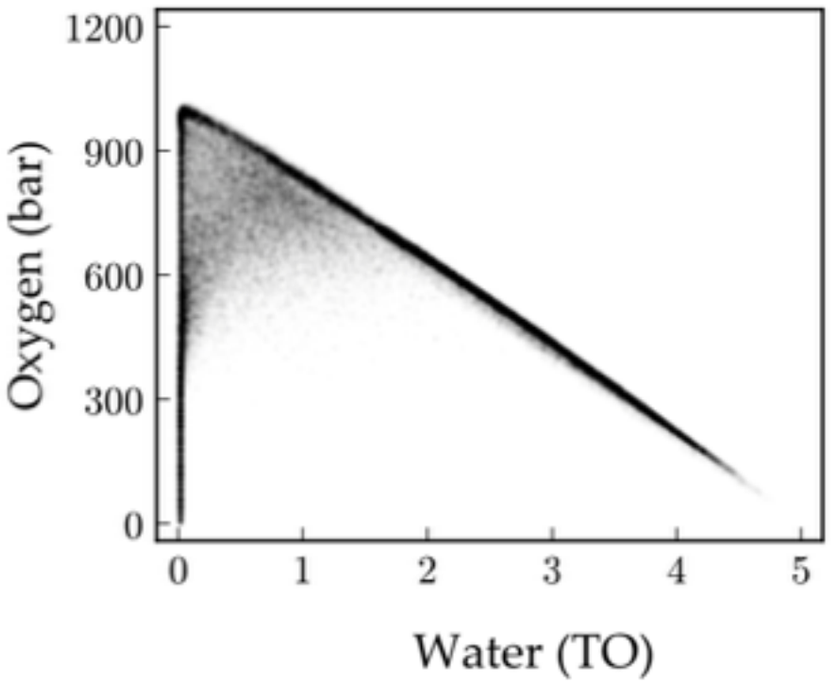


Posterior samples

Water Evolution*





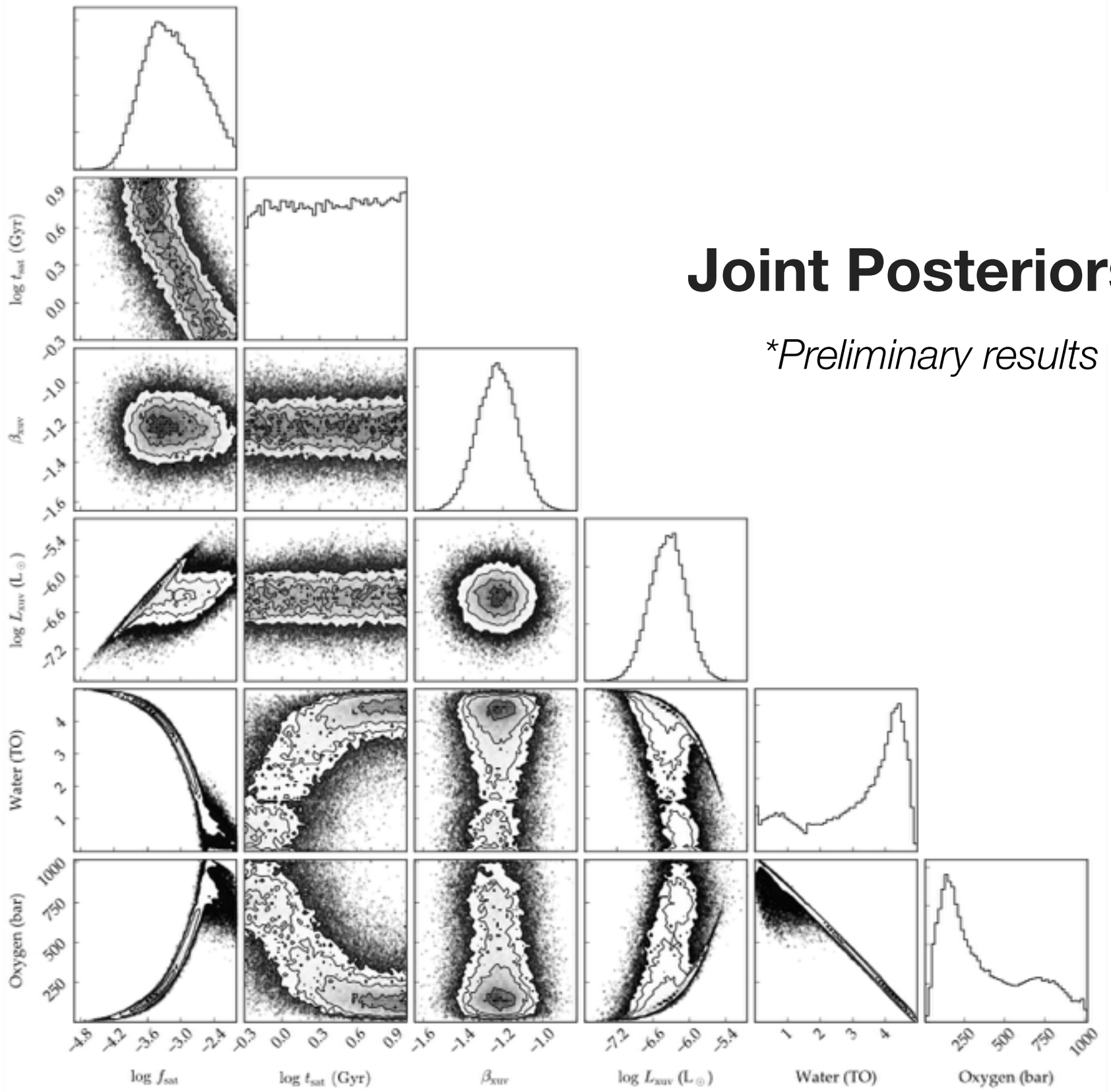


**Not marginalized over population synthesis outputs*
($M^0_{H_2O}$ = 5 Oceans, M^0_H = 0)

***Inefficient O_2 sinks*

Joint Posteriors*

**Preliminary results*



Conclusions *(For real this time)*

We must account for the **uncertainty** on all model inputs.

We must correctly account for all **prior information.***

A flat prior is **not uninformative!*

We need **robust posterior distributions** to assess habitability.

This will be an **incremental**, iterative problem.