

# Early Mercury's magma ocean atmosphere

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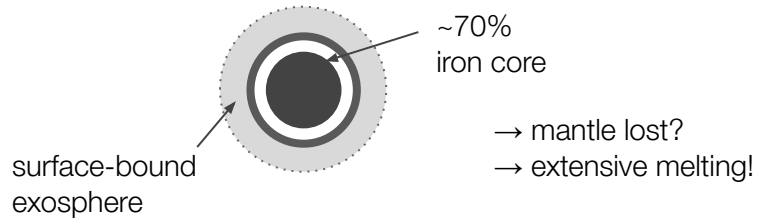
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# The Big Picture

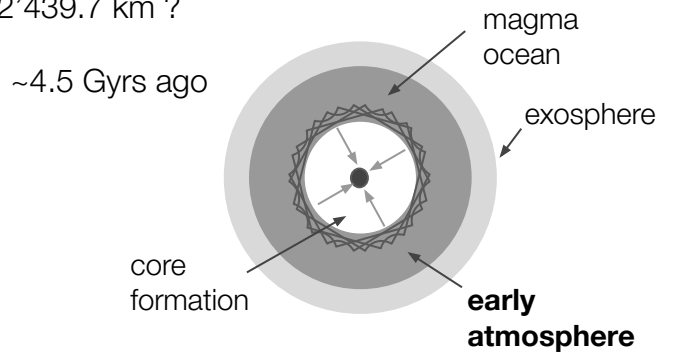
## Today's-Mercury

$T_{surf} \sim 550-700 \text{ K}$   
 $R = 2'439.7 \text{ km}$



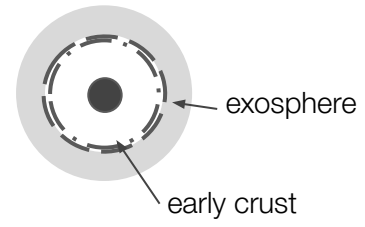
## "Early"-Mercury

$T \sim 2400 \text{ K}$   
 $R \geq 2'439.7 \text{ km} ?$



## "Early"-Mercury + crust

$T \sim 1500 \text{ K}$

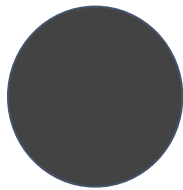


- What is its lifetime?
- What is its speciation?
- How much material is lost from it?

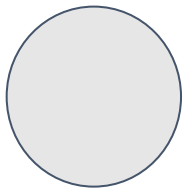
# Cases

Small

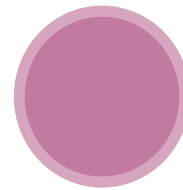
R = 2440 km (present Mercury)



Black-body  
SB



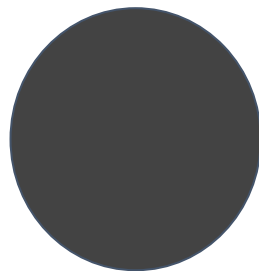
Grey-body  
SG



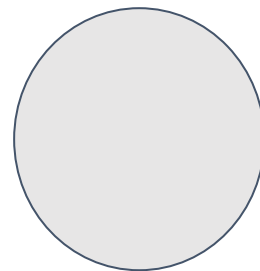
Volatiles  
SV

Large

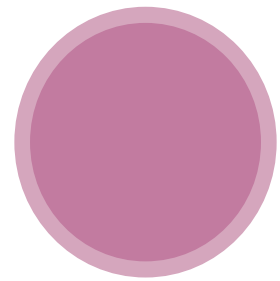
R = 3290 km



Black-body  
LB



Grey-body  
LG



Volatiles  
LV

Magma Ocean Composition:

CB/ EH4  
Chondrite

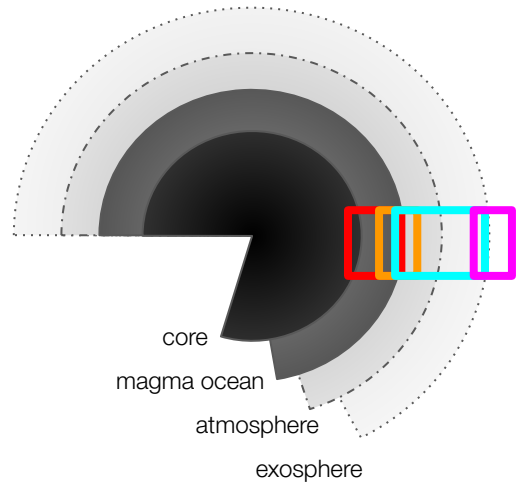
NSP source

NSP lava

primitive

mature

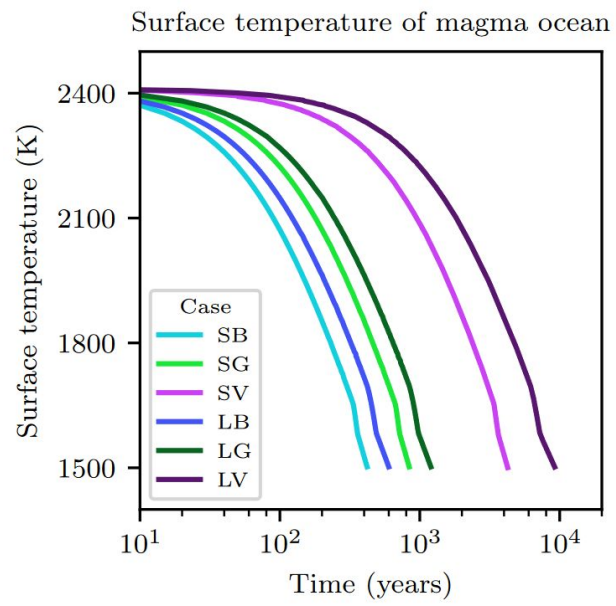




<p>Magma ocean cooling, atmospheric structure, ±volatile degassing</p> <p><b>SPIDER</b> e.g., Bower+ 2019</p>	<p>Degassing of metal oxides</p> <p><b>VapoRock (MELTS)</b> after the approach of Lamoreaux+ 1987</p>	<p>Atmospheric Chemistry</p> <p><b>VULCAN</b> Tsai+ 2017</p>	<p>Atmospheric loss</p> <p><b>Exospheric Monte Carlo model (E-MC)</b> Wurz &amp; Lammer 2003, Vorburger+ 2015</p> <p><b>DISHOOM</b> Oza+ 2019</p>
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# SPIDER - Magma ocean cooling time

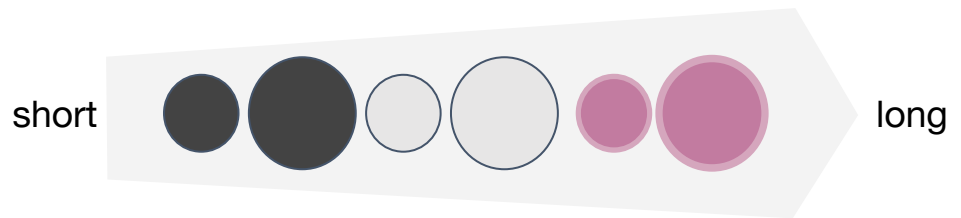
**400 - 10'000 years**



Emissivity difference of non-volatile black and greybody cases only marginally affect cooling time.

Presence of volatiles greatly extend magma ocean lifetimes.

Large Mercury reaches maximum of 10'000 years in magma ocean lifetime!

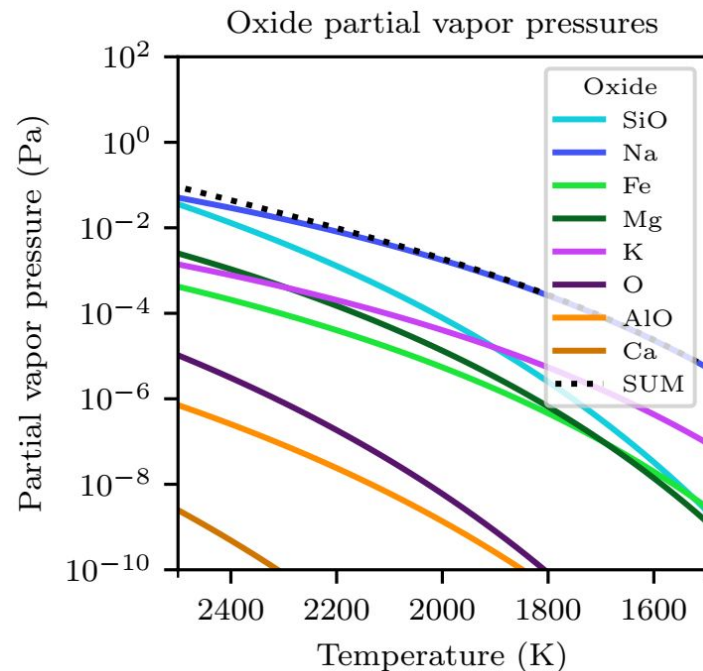


# VapoRock (and MELTS by ENKI)

## results independent on initial composition

- Na:K pressure ratio is about 10:1
- at 2500 K
  - Total pressures reach  $\sim 0.1$  bar
  - SiO reaches a mixing ratio of  $\sim 50\%$
- at 1500 K
  - pressures drop to  $\sim 10^{-4}$  bar
  - Na is the main species (minor K)

## VOLATILE & NON-VOLATILE CASES

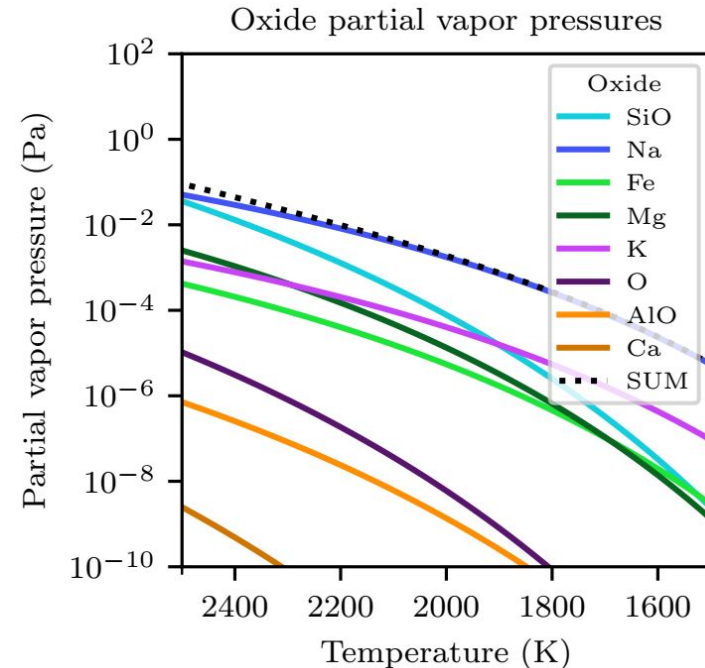


# VapoRock (and MELTS by ENKI)

## results dependent on initial composition

- small changes in trace element composition:
  - large impact on activity
  - large impact on vapor pressure
  
- VULCAN

## VOLATILE & NON-VOLATILE CASES



# VULCAN (+ fastchem)

Takes outputs of SPIDER and VapoRock

Input:

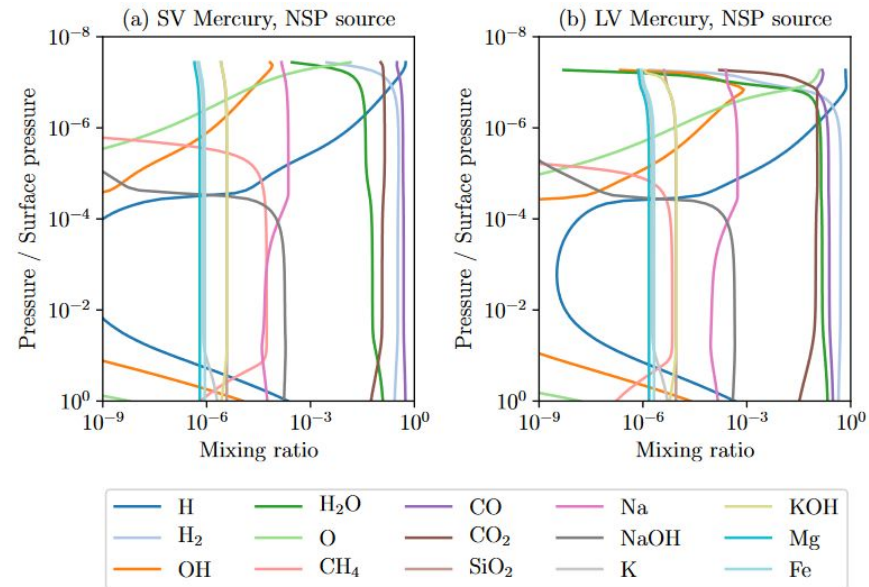
- photochemical network
- gravitational acceleration (3.6 or 4 m/s<sup>2</sup>)
- distance to the Sun.

Computes:

- speciation of atmosphere

→ Atmospheric Model

## VOLATILE CASE



# Atmospheric structure of small Mercury

VOLATILE CASE

5 bar @ 2000 K

NON-VOLATILE CASES

0.1 bar @ 2500 K

10<sup>-5</sup> bar @ 1500 K

Exobase

H, O, CO\*, C, Na, K

Homopause

H<sub>2</sub>, H<sub>2</sub>O, CO, CO<sub>2</sub>, KOH, Na, K

**bloated due to hotter upper atmosphere**

Na, K, SiO\*\*, Mg\*\*, Fe\*\*

Na, K, SiO\*\*, Mg\*\*, Fe\*\*

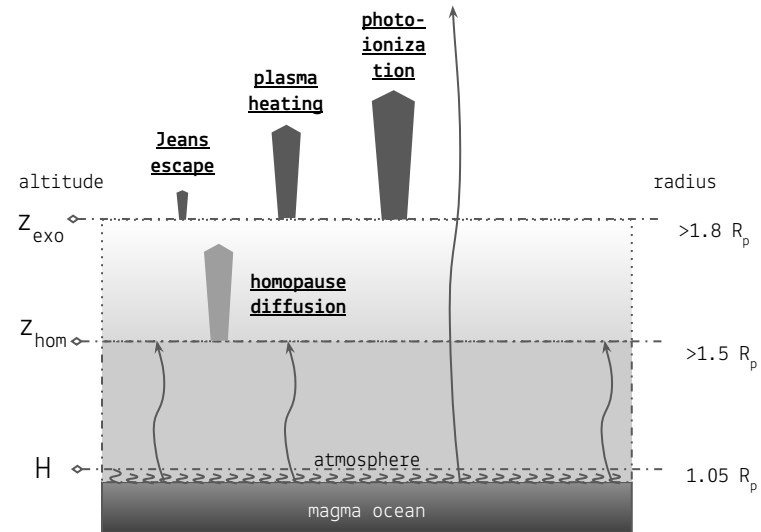
\*likely to dissociate into C & O

\*\*likely to condensate before reaching exobase

# Atmospheric Loss (E-MC and DISHOOM model)

Mass loss rates at the exobase

- Photoionization → 100%
- Jeans escape
- Plasma heating
- **limited by diffusion**



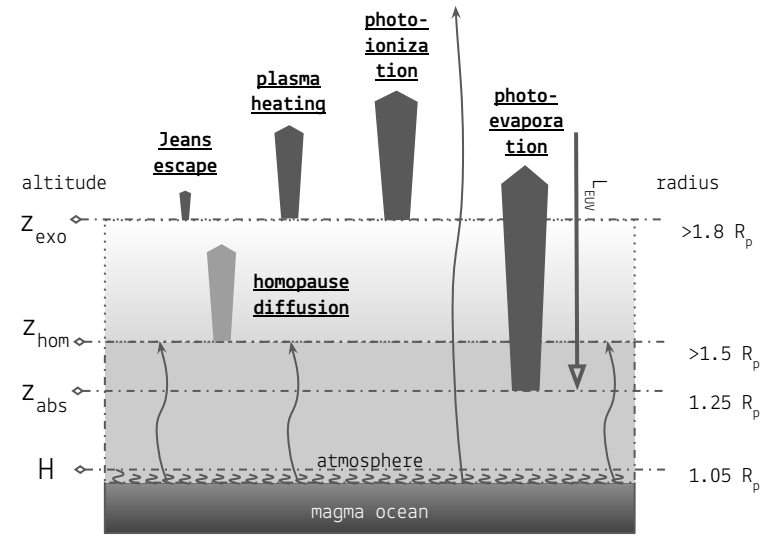
# Atmospheric Model & Exospheric Loss (E-MC and DISHOOM model)

Mass loss rates at the exobase

- Photoionization → 100%
- Jeans escape
- Plasma heating
- **limited by diffusion**

Mass loss rates in the 'upper' atmosphere

- Photoevaporation
- **not diffusion limited**



# Integrated loss vs. mantle reservoir

**In non volatile case:**

$\leq 10^{15}$  kg Na by **diffusion limited processes**

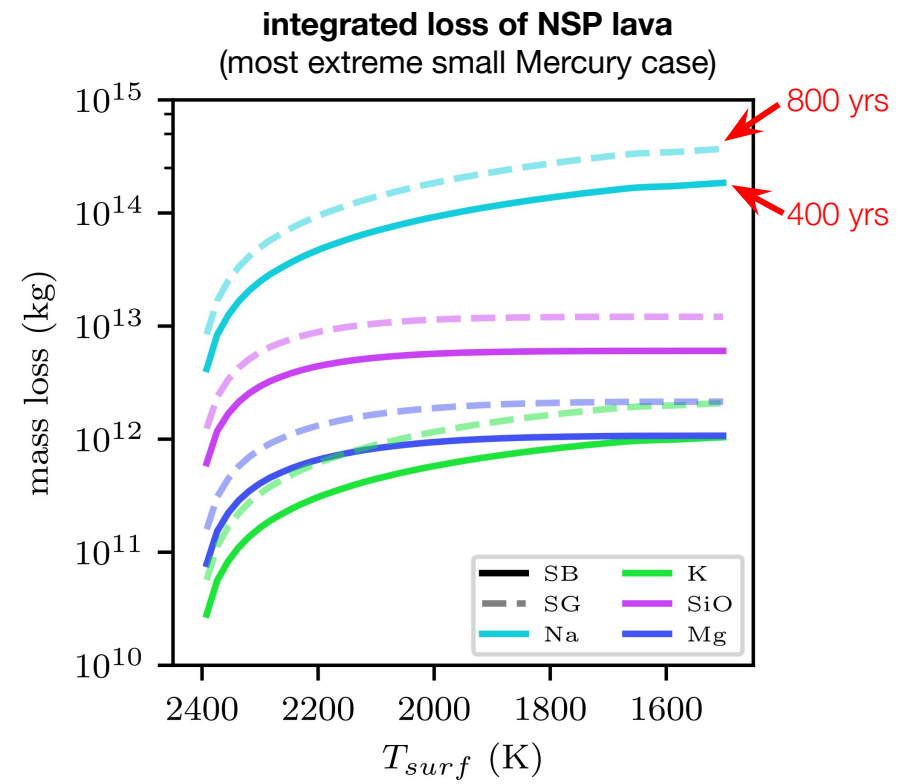
$\leq 10^{20}$  kg by **photoevaporation**  
(not only Na!)

**Mantle makes up ~30% of  $M_{\text{Mercury}}$**

$$M_{\text{mantle}} = \sim 1 \times 10^{23} \text{ kg}$$

$$X_{\text{Na}} = [0.1 \dots 5.2] \text{ wt\%}$$

$$M_{\text{Na}} = [1.4 \dots 50] \times 10^{20} \text{ kg}$$



## Trying to alter Mercury's Na-reservoir

- **bulk loss of Na** over the explored magma ocean lifetimes **is negligible.**
- accumulation of Na assuming a collapse of the atmosphere when  $T_{\text{surf}} = 1500 \text{ K}$  leads to a few microns thick layer of Na metal (unlikely)
- **crustal reservoir enrichment** of Na by incorporation of condensed material into a reservoir of a depth exceeding the minimum excavation depth by impactors of 10 m to 5 km **is negligible**

Atmospheric loss processes are unlikely to have significantly changed early Mercury's composition in its magma ocean phase!

# Take home messages

magma ocean:

- **cooling times of 400 - 10'000 yrs**

atmosphere **speciation** and **structure**:

- depend on species **activities and fO<sub>2</sub>**
- atmospheric **pressure is highly sensitive to volatiles degassing**
- **Na:K = 10:1** in vapor pressures for a range of realistic Mercury compositions

atmospheric loss:

- large XUV of early sun leads to **complete ionization and high loss rates** but it ...
  - ...is generally **homopause diffusion limited** and/or
  - ...remains a **small fraction of the total** reservoir

Thank you for your attention!

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