Rocky exo-planet diversity from protoplanet solidification

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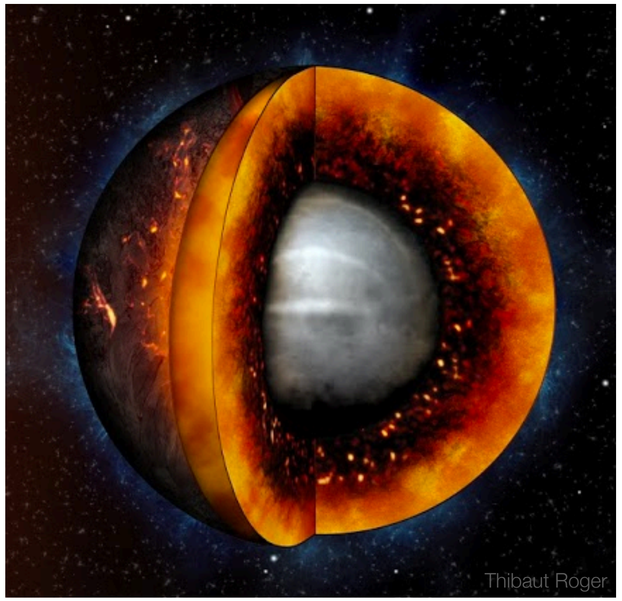
Dan Bower (U Bern)
Patrick Sanan (ETH Zurich)
Ryan Boukrouche (Oxford)
Mark Hammond (Oxford)
Shami Tsai (Oxford)
Raymond Pierrehumbert (Oxford)



UNIVERSITY OF OXFORD
SIMONS FOUNDATION

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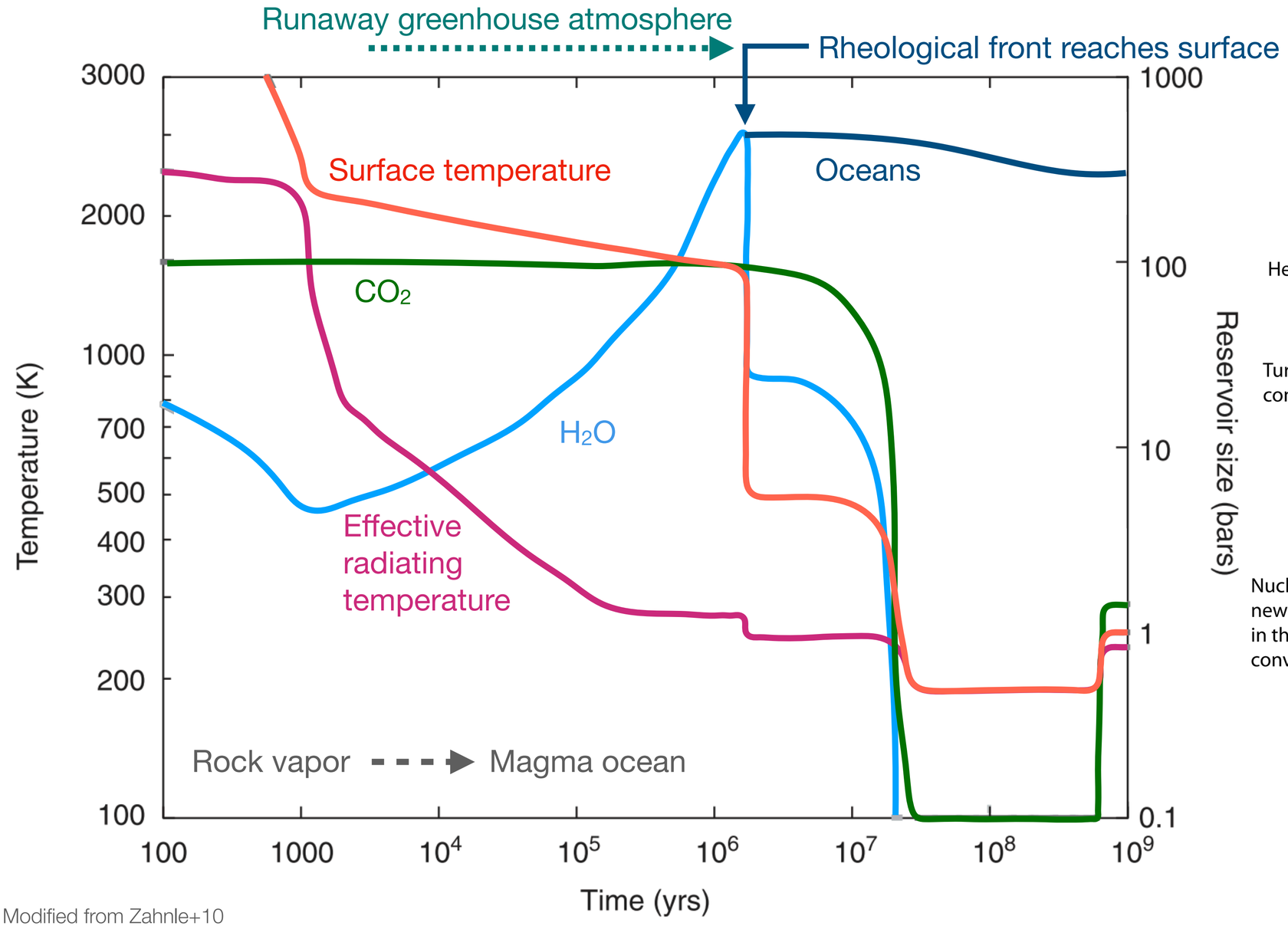
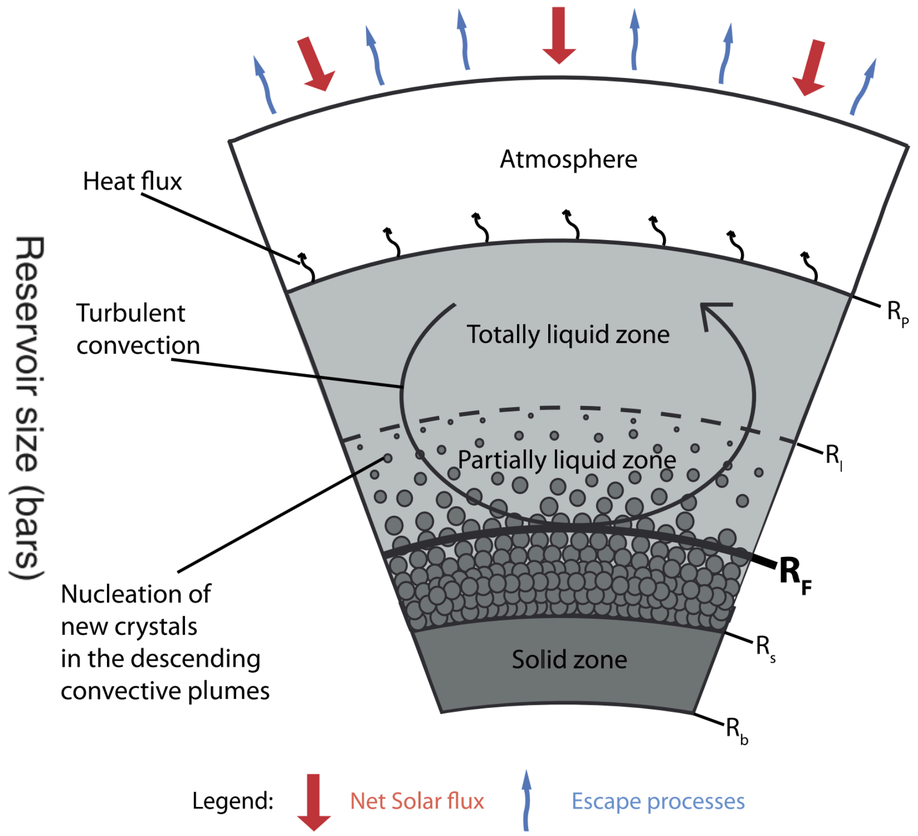
Robin Canup, SwRI

Haden Earth: from magma- to water-oceans

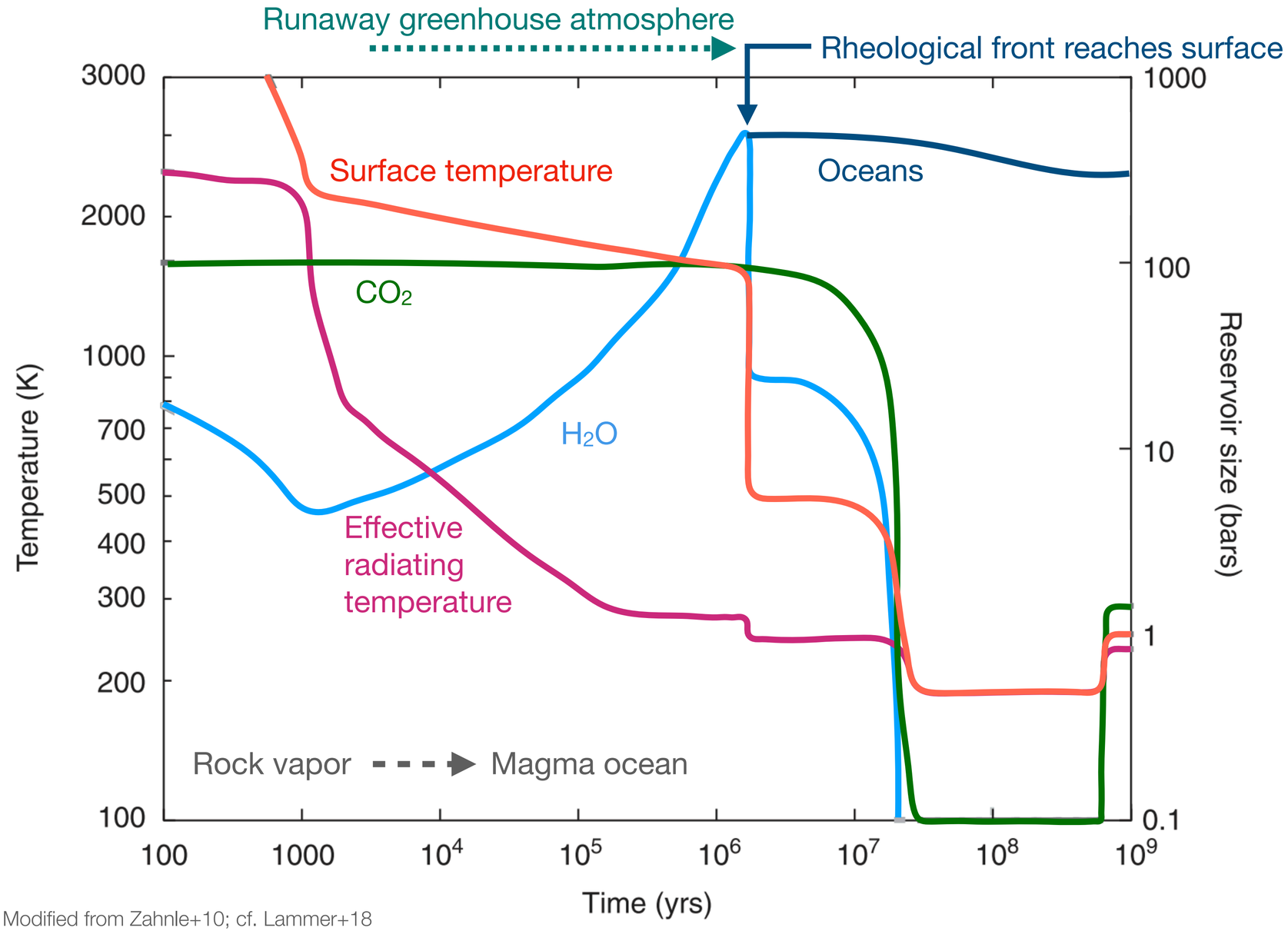


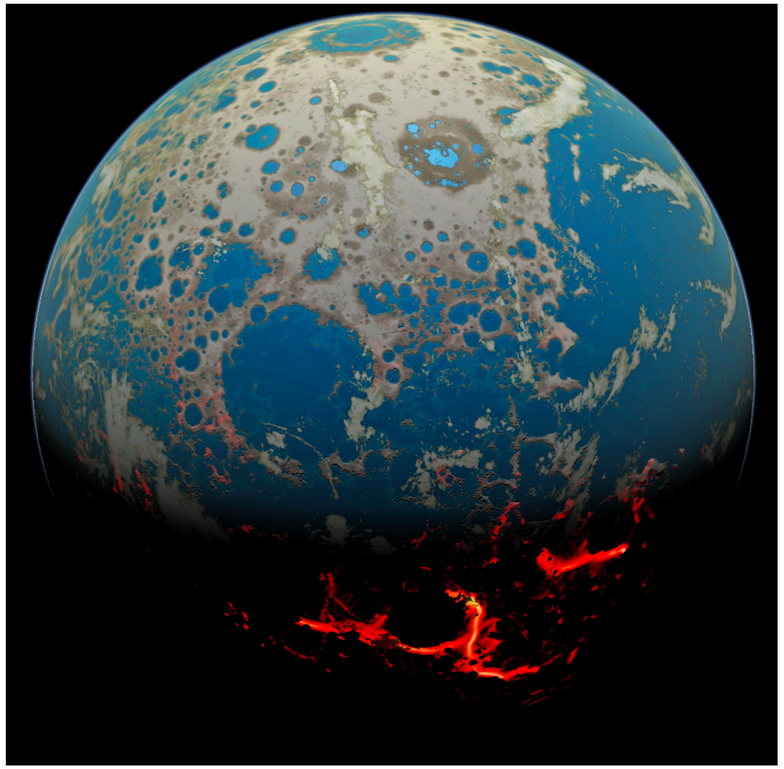


Modified from Zahnle+10

Solomatov 15; Massol+16

Haden Earth: from magma- to water-oceans

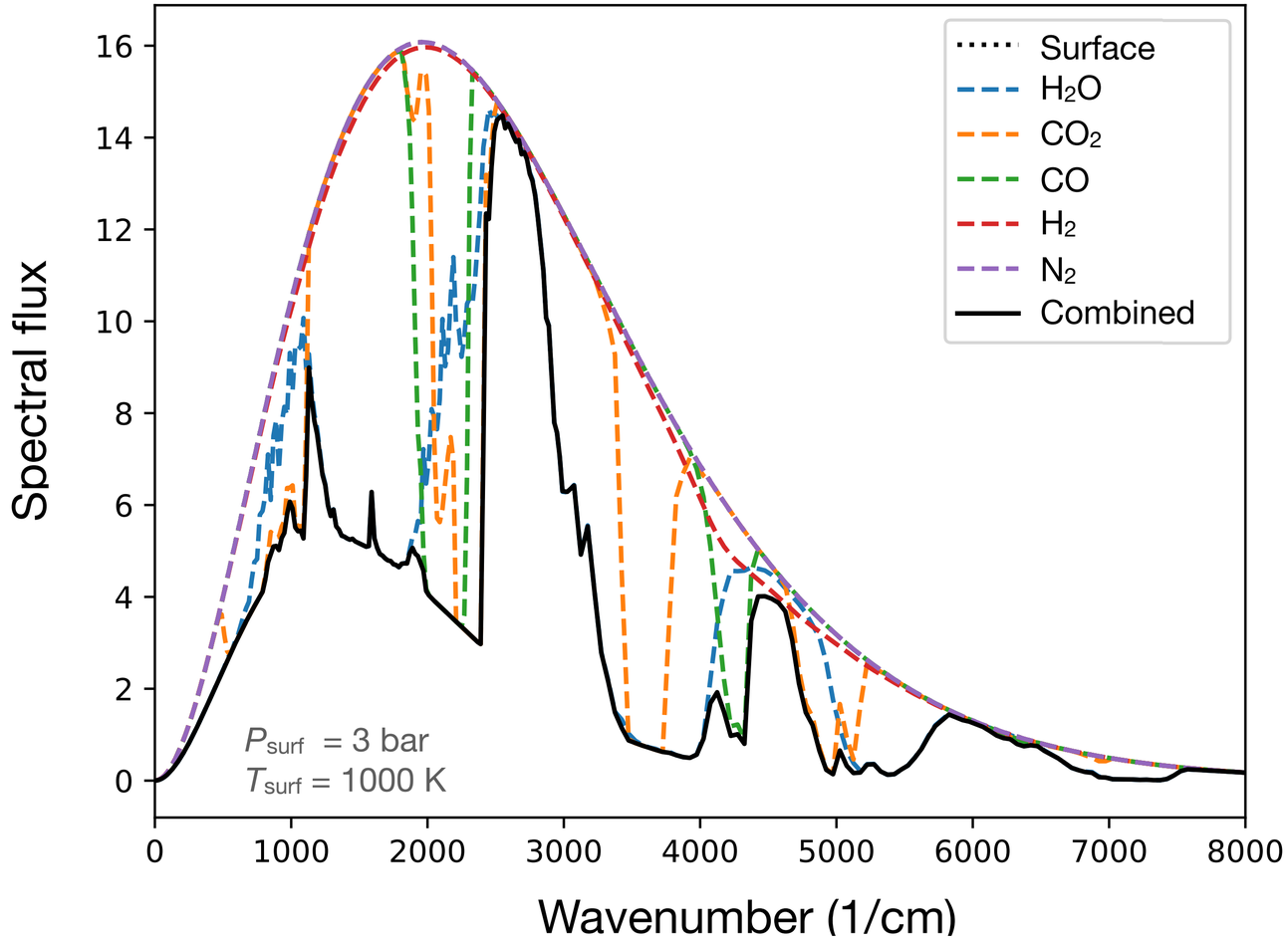


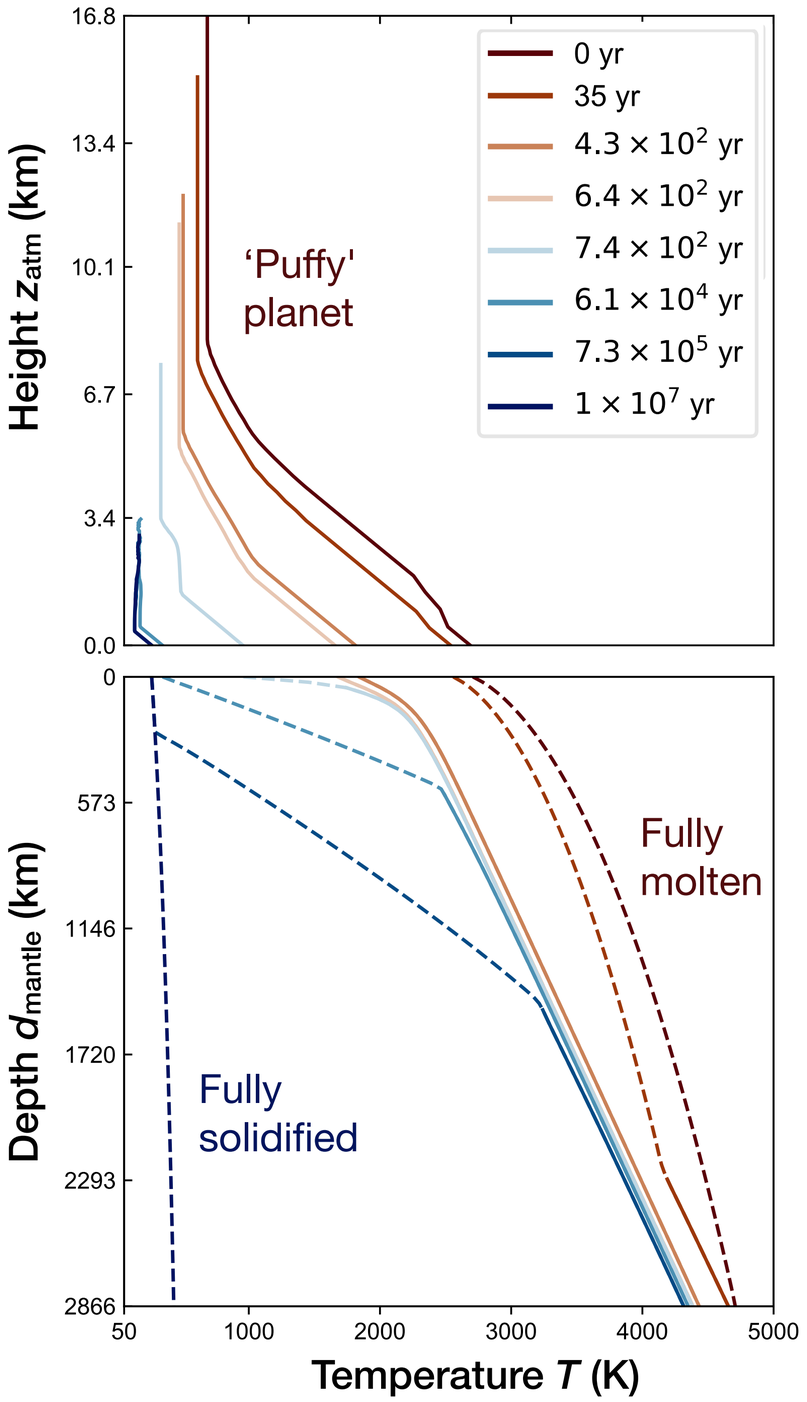


Modified from Zahnle+10; cf. Lammer+18

SwRi/S. Marchi

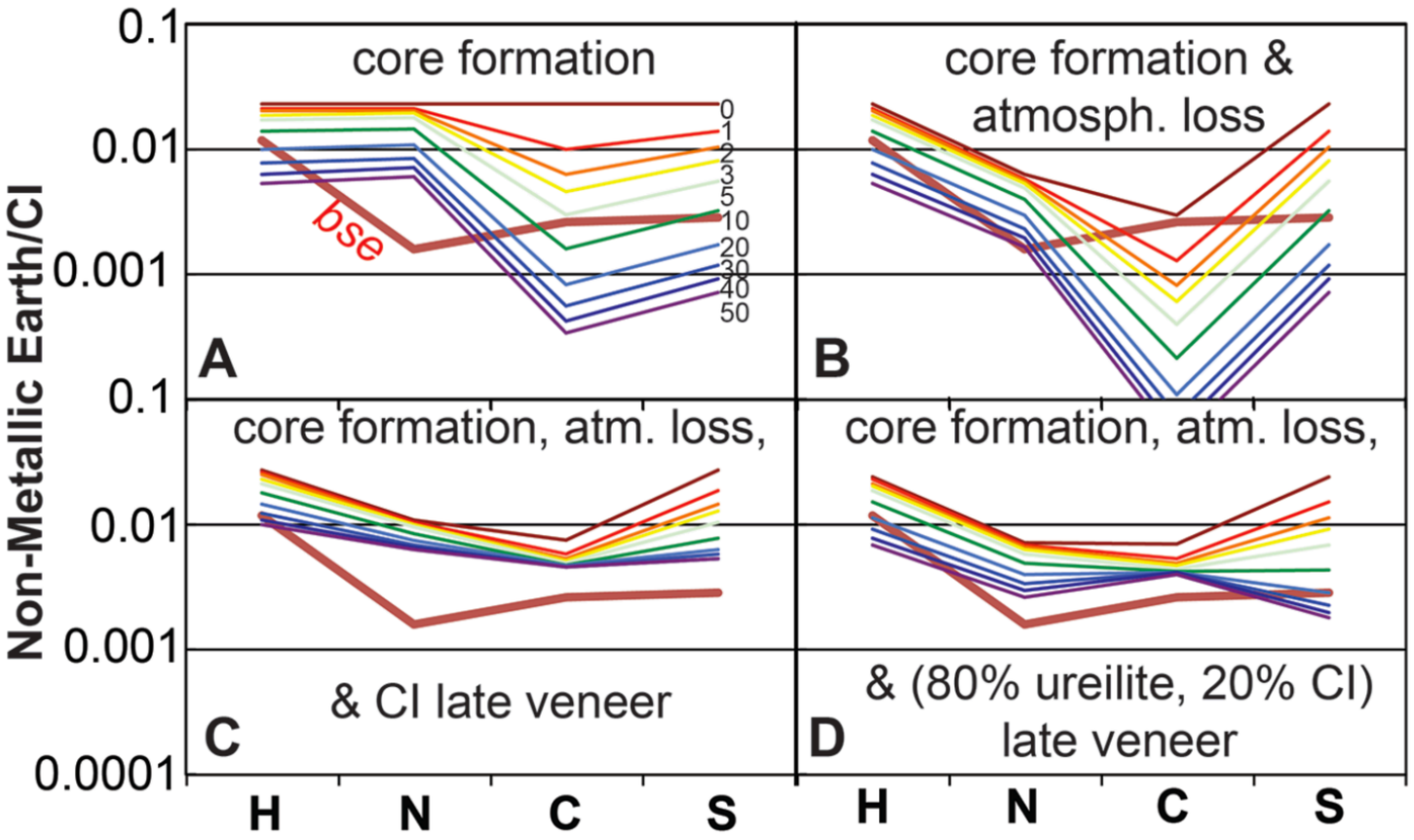
Cooling timescale & planet structure function of atmospheric speciation

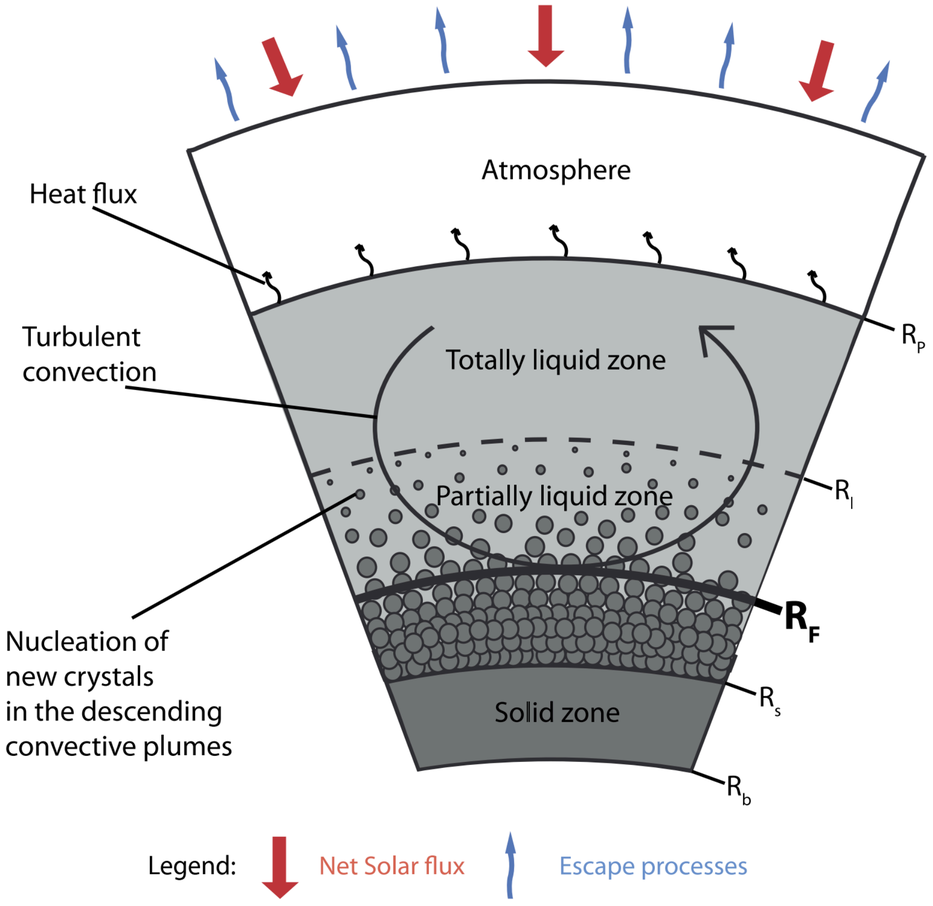




Lichtenberg, Hammond, Bower, Tsai, Sanan, Boukrouche, Pierrehumbert, in prep.

Volatile fractionation from core formation + atmospheric loss

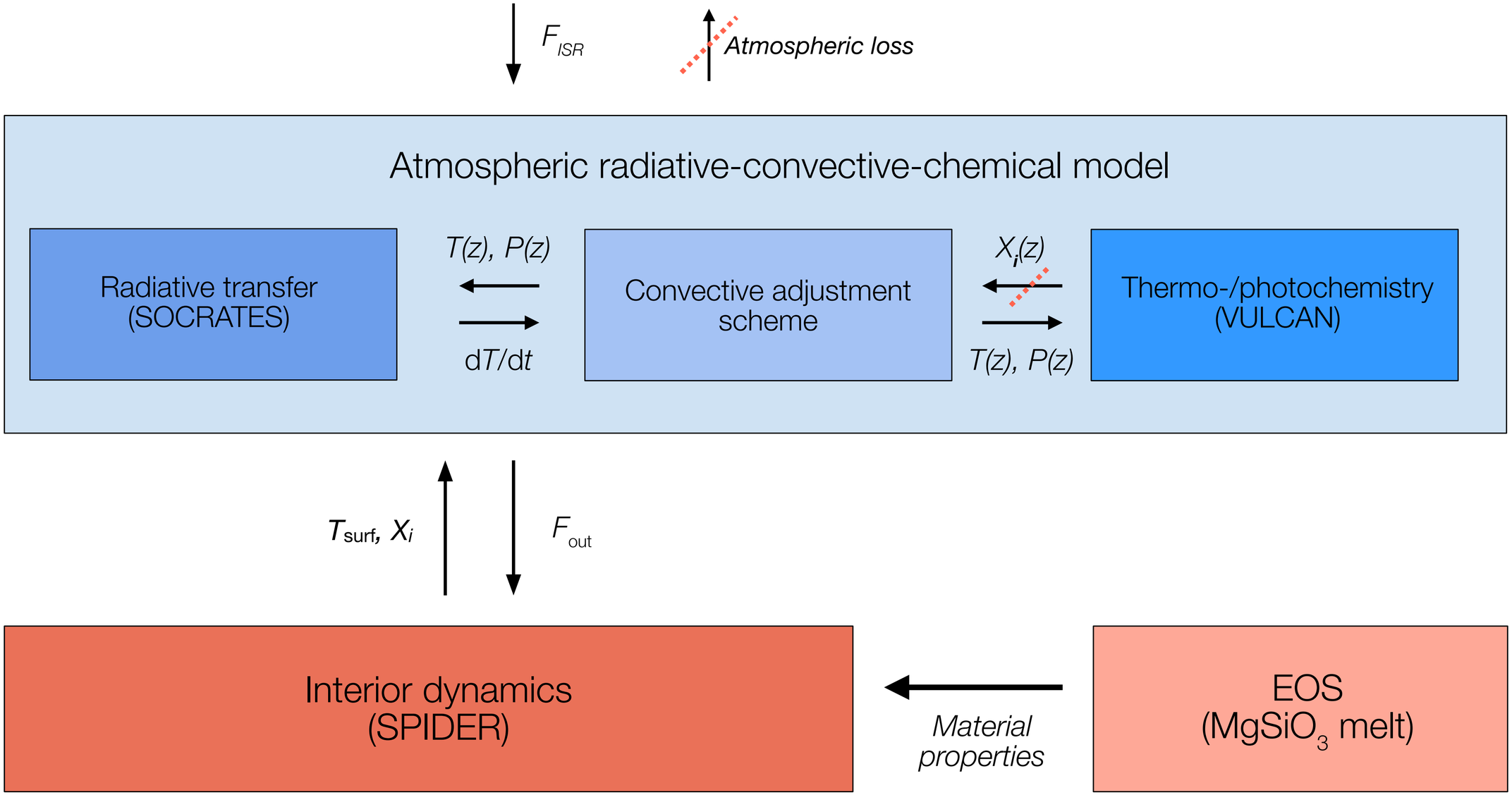




Hirschmann 16

Solomatov 15; Massol+16

Integrated magma ocean—atmosphere framework



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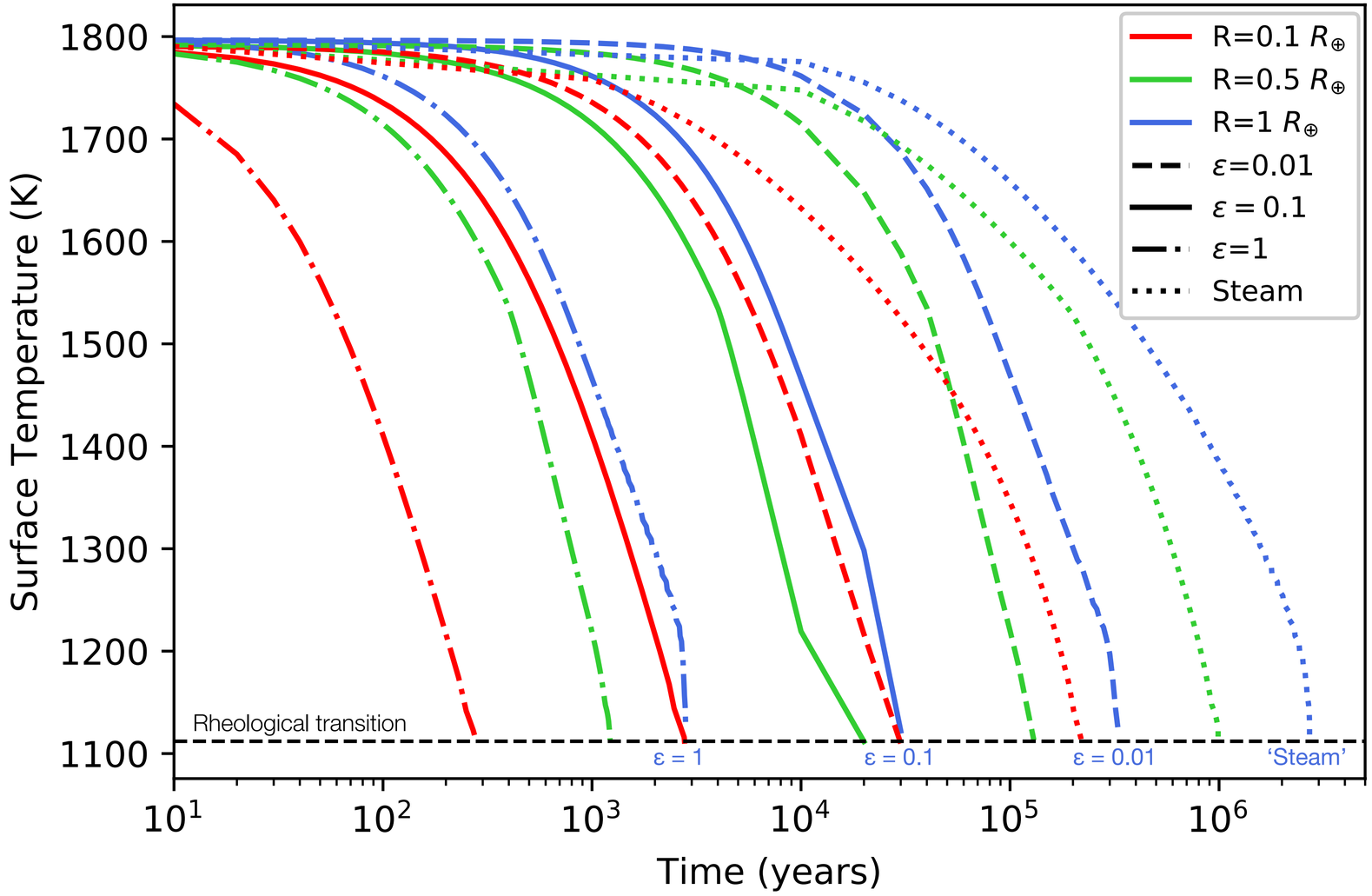
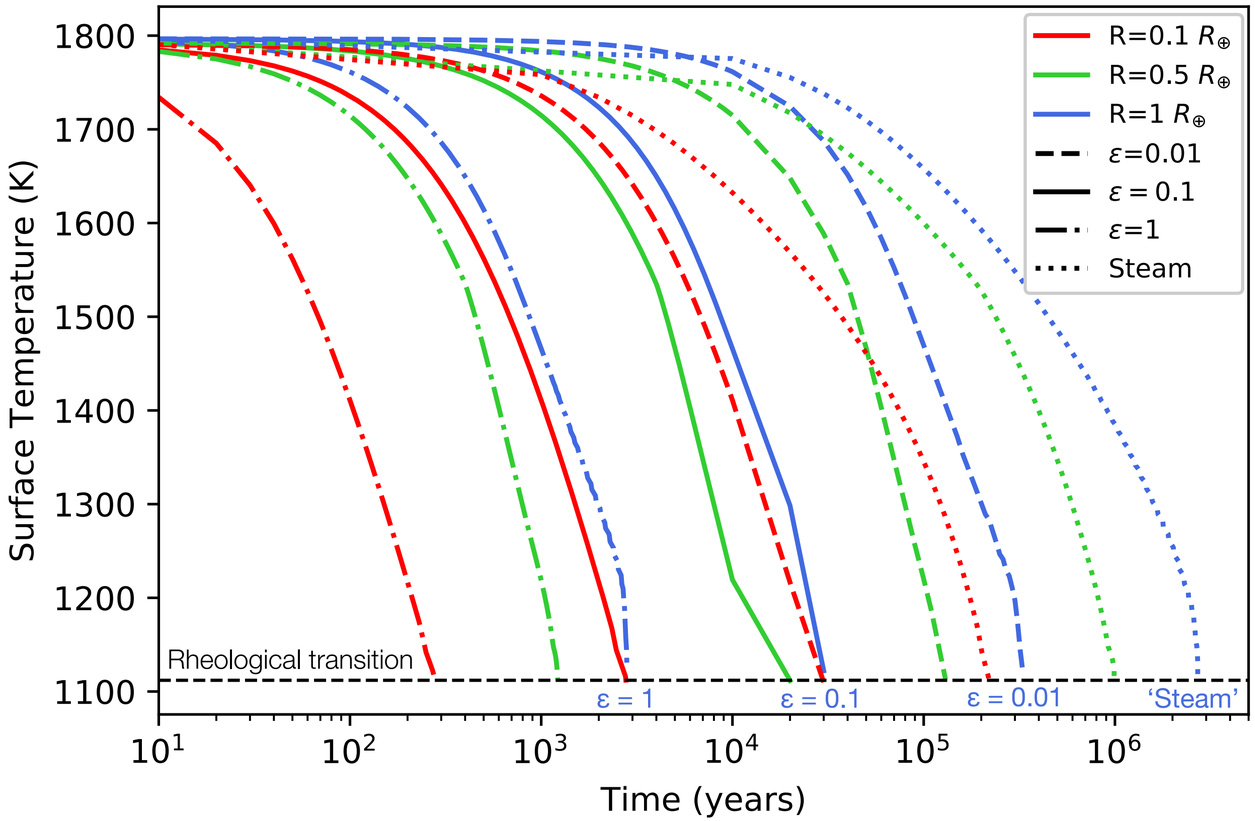
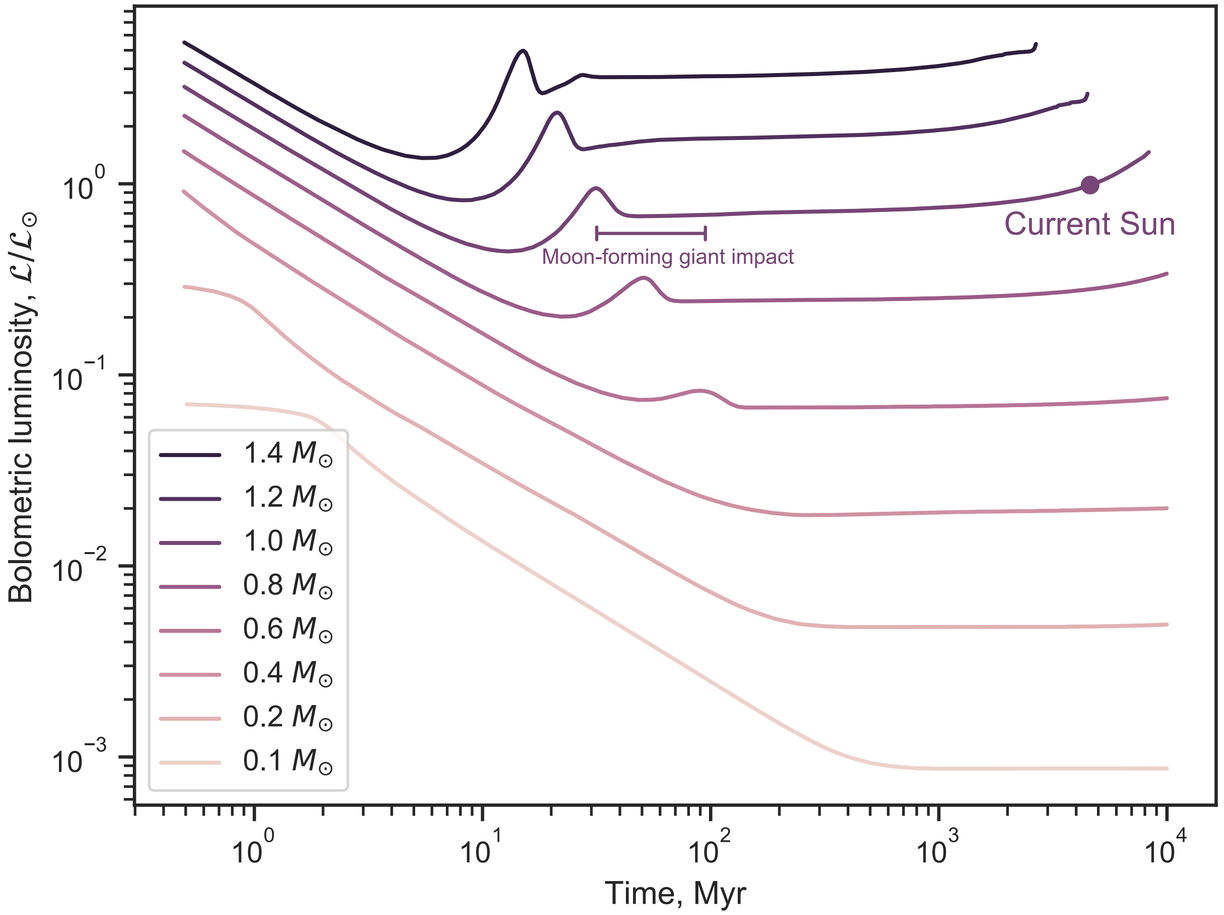
Impact of planet size and (fixed) atmosphere



Bonati, Lichtenberg+ 19

Stellar influence

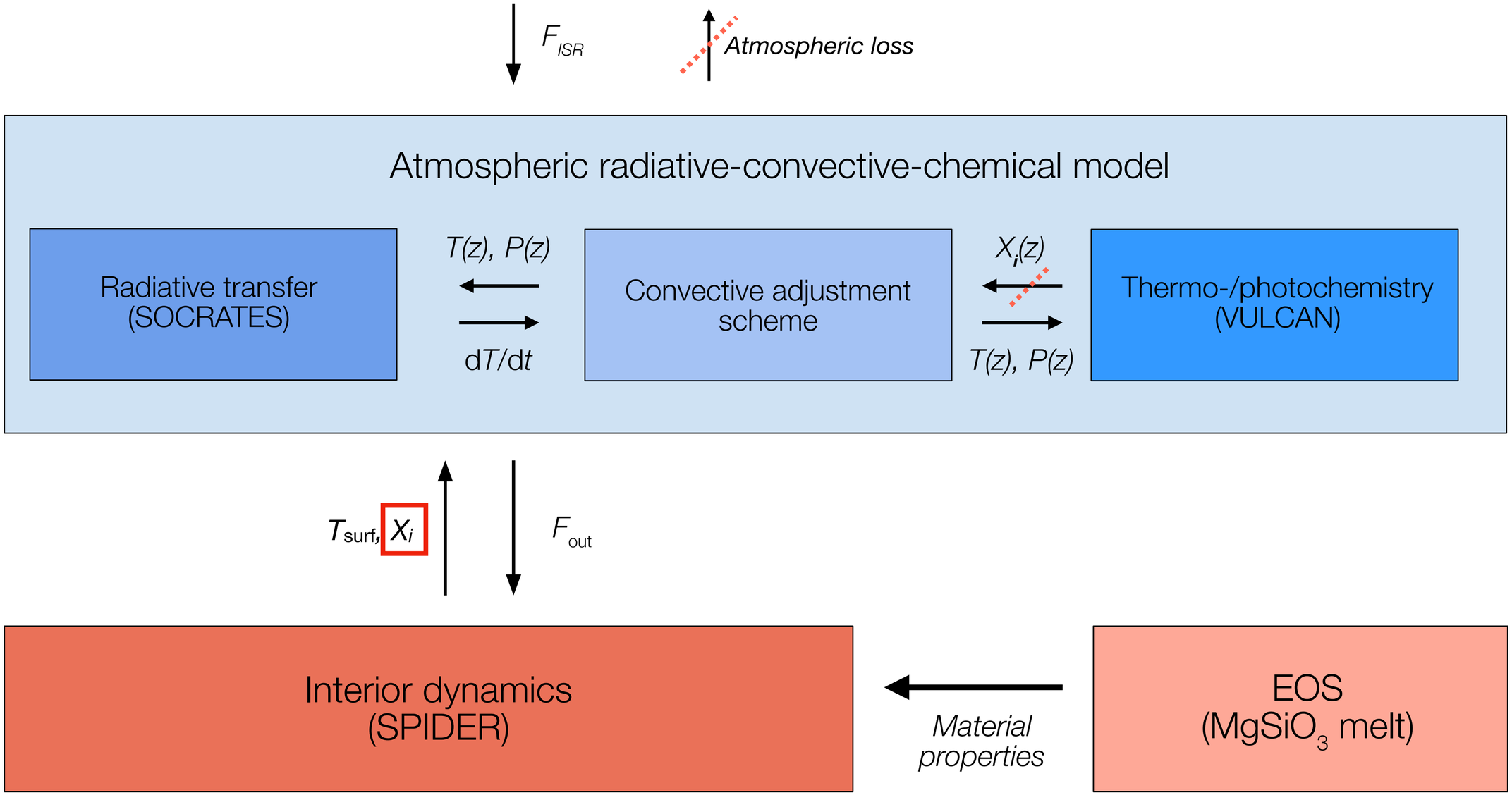




Bonati, Lichtenberg+ 19

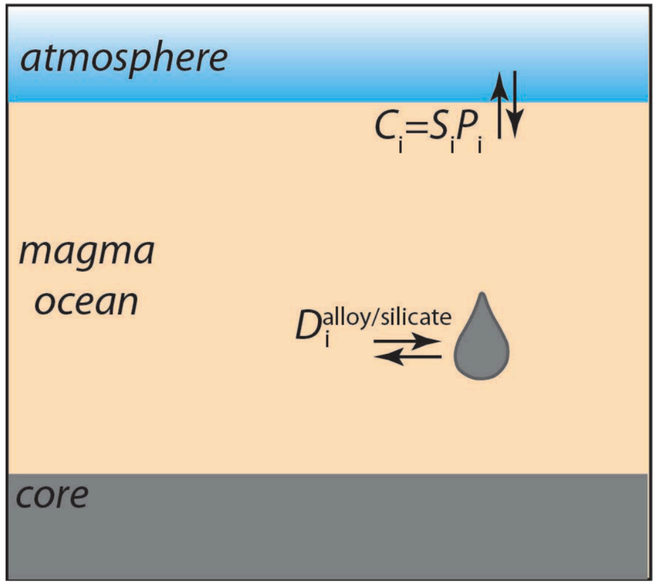
Data from Baraffe+ 03

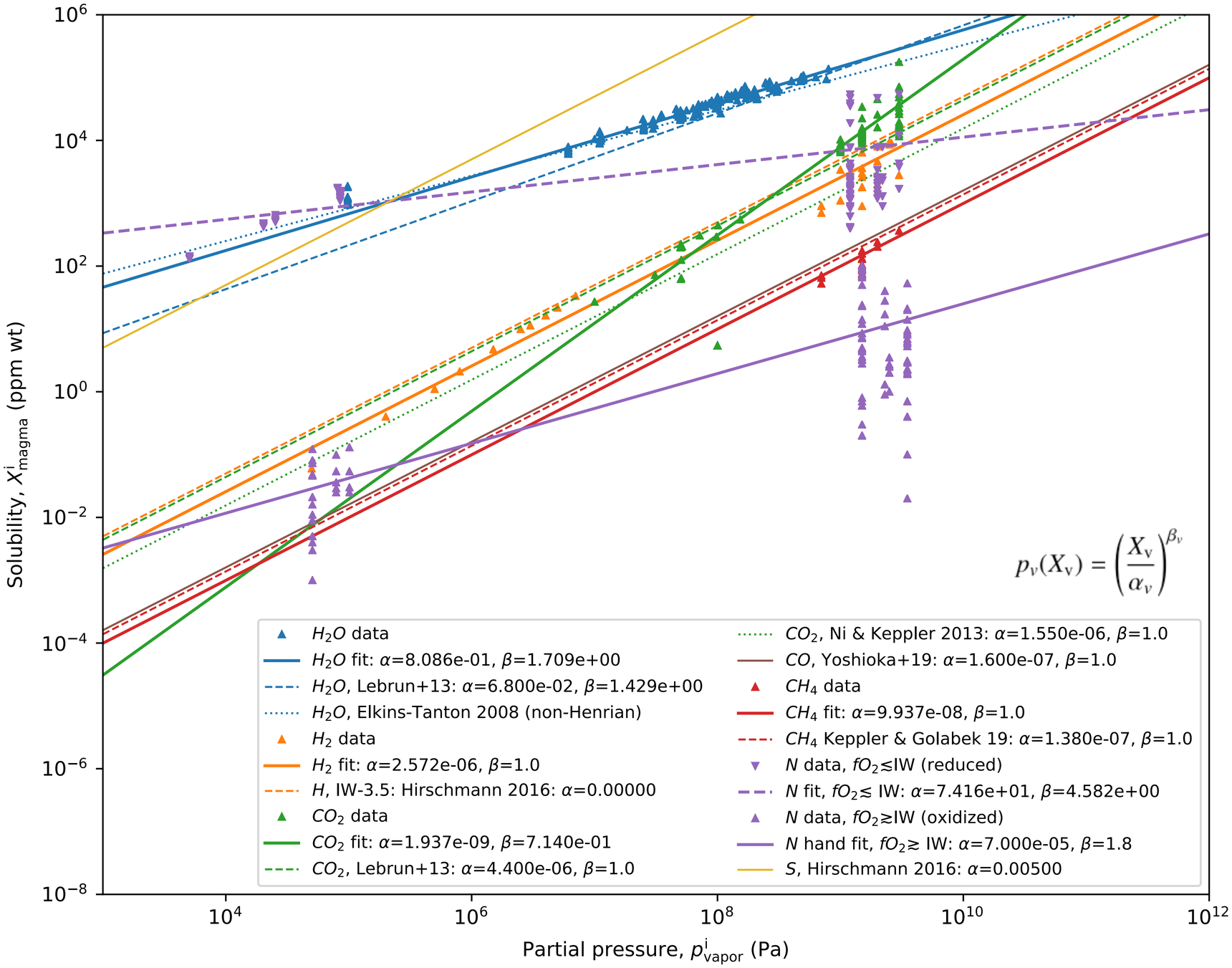
Integrated magma ocean—atmosphere framework



Lichtenberg, Hammond, Bower, Tsai, Sanan, Boukrouche, Pierrehumbert, in prep.

Outgassing/ ingassing





Hirschmann 16

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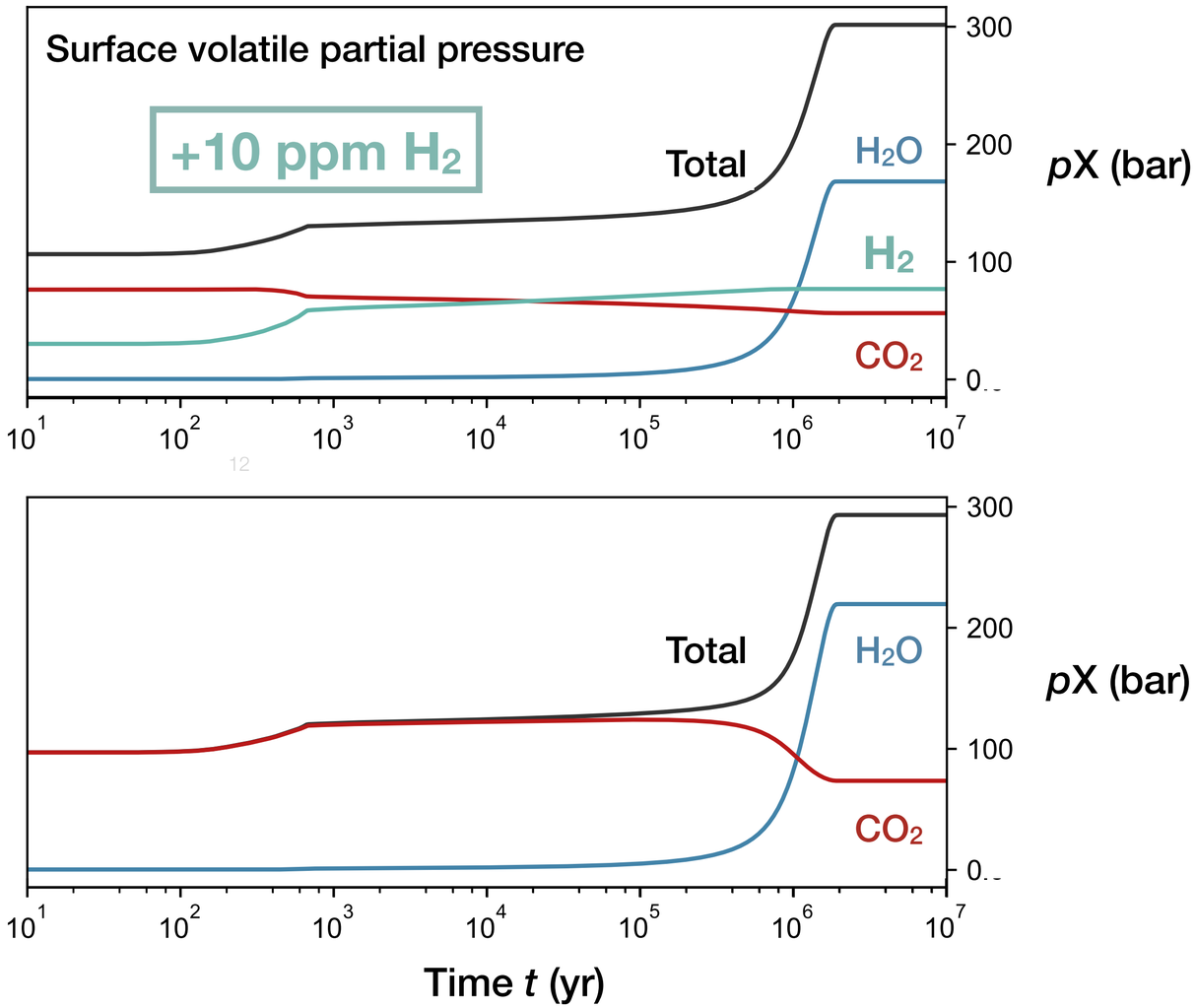
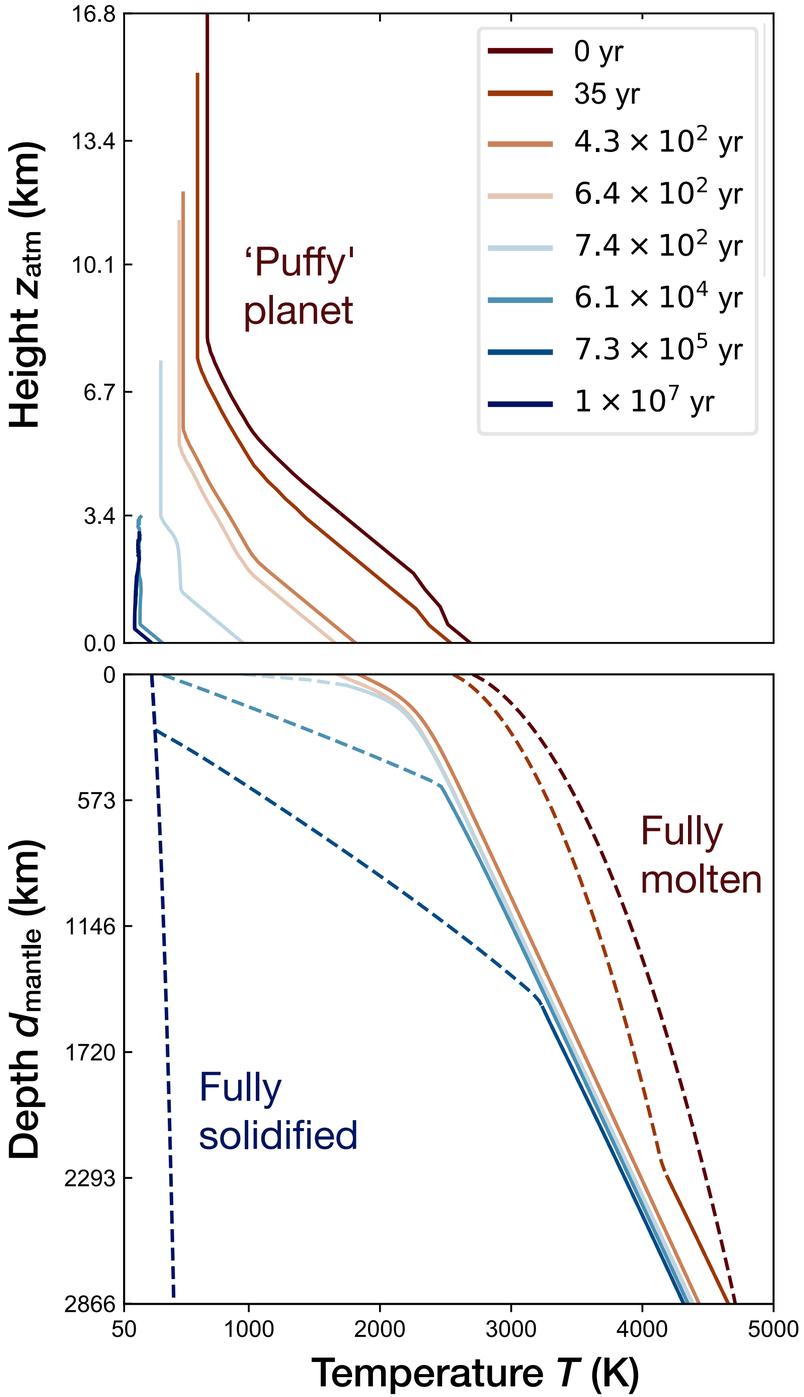
Outgassing/ingassing history





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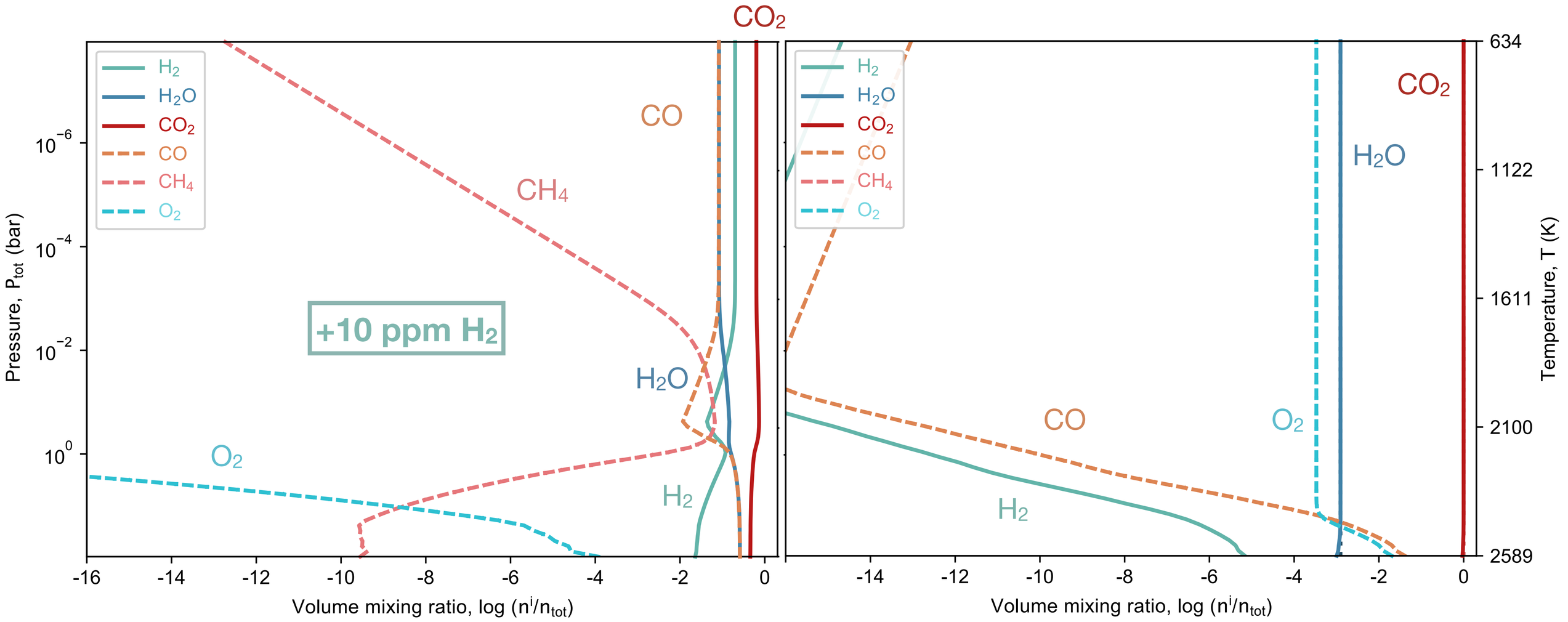
Earliest atmospheric chemistry



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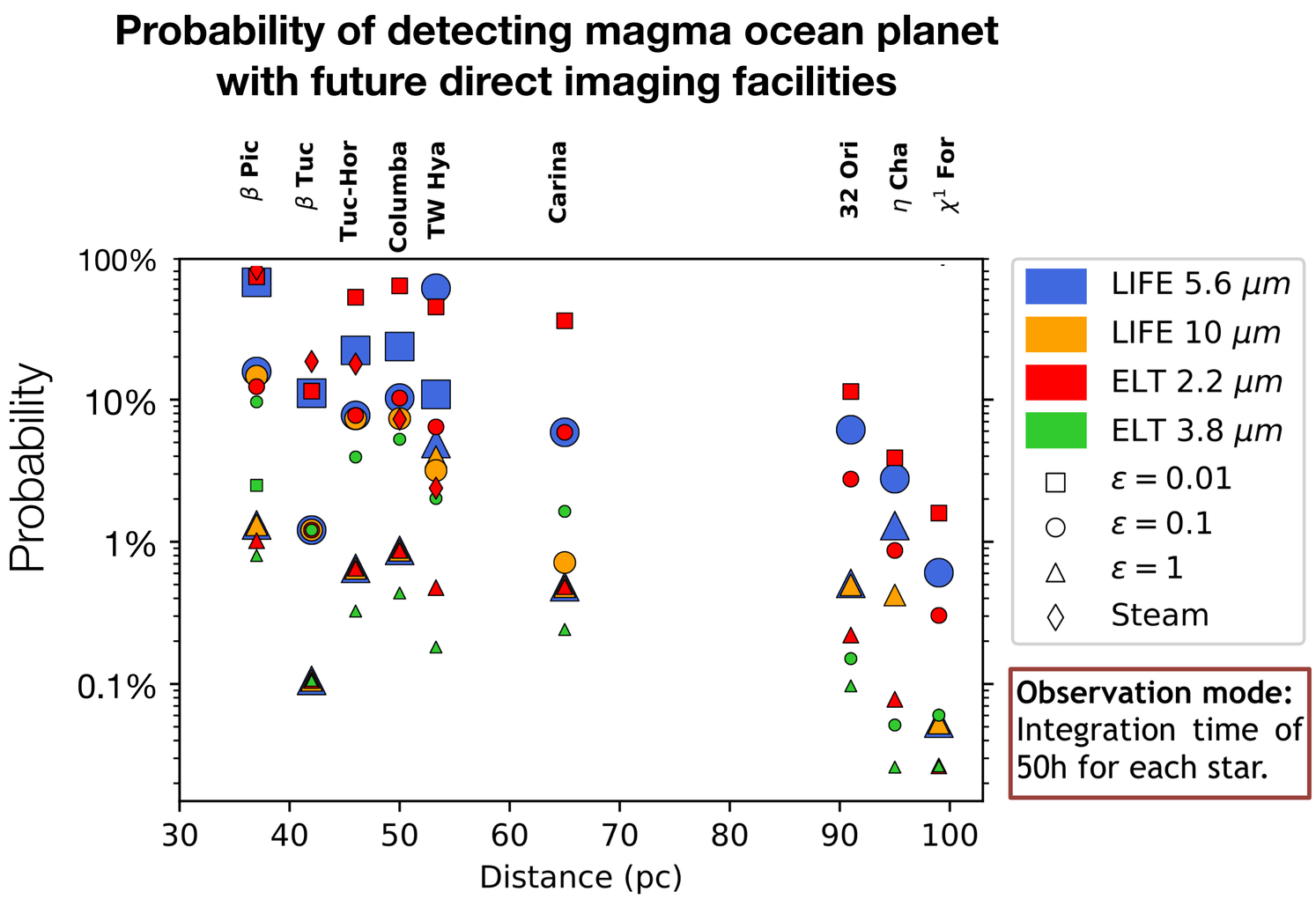
Directly image magma ocean planets?



Bonati, **Lichtenberg**+ 19

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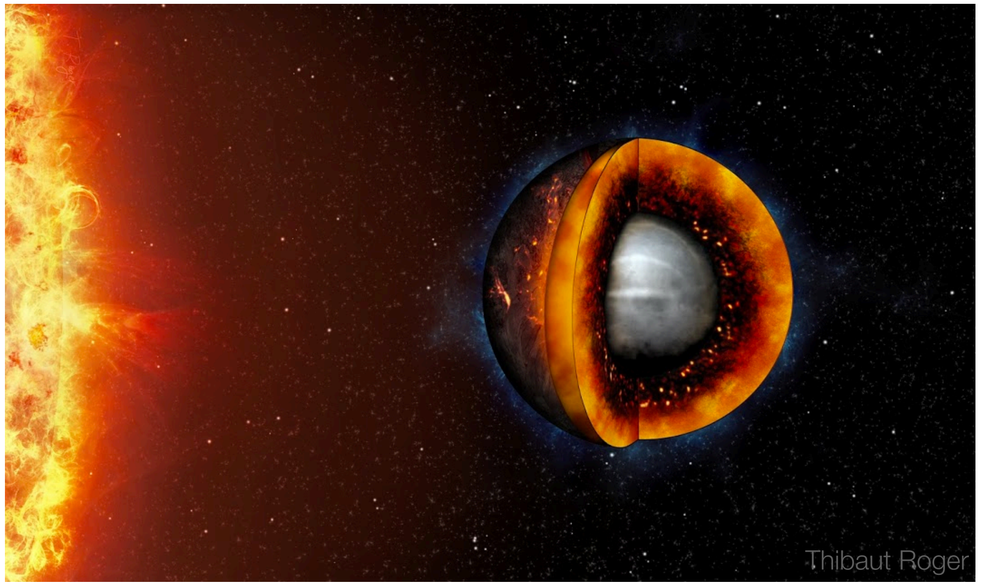

- Magma ocean-atmosphere coupling shapes earliest atmospheric and upper mantle (geo-)chemistry

  ➡ Barrier from planet formation to early planetary evolution

  ➡ Crucially defines volatile fractionation and atmospheric chemistry

  ➡ Stationary + runaway MO planets may reveal diversity of rocky planetary atmospheres

- Connect w/ space missions and laboratory studies