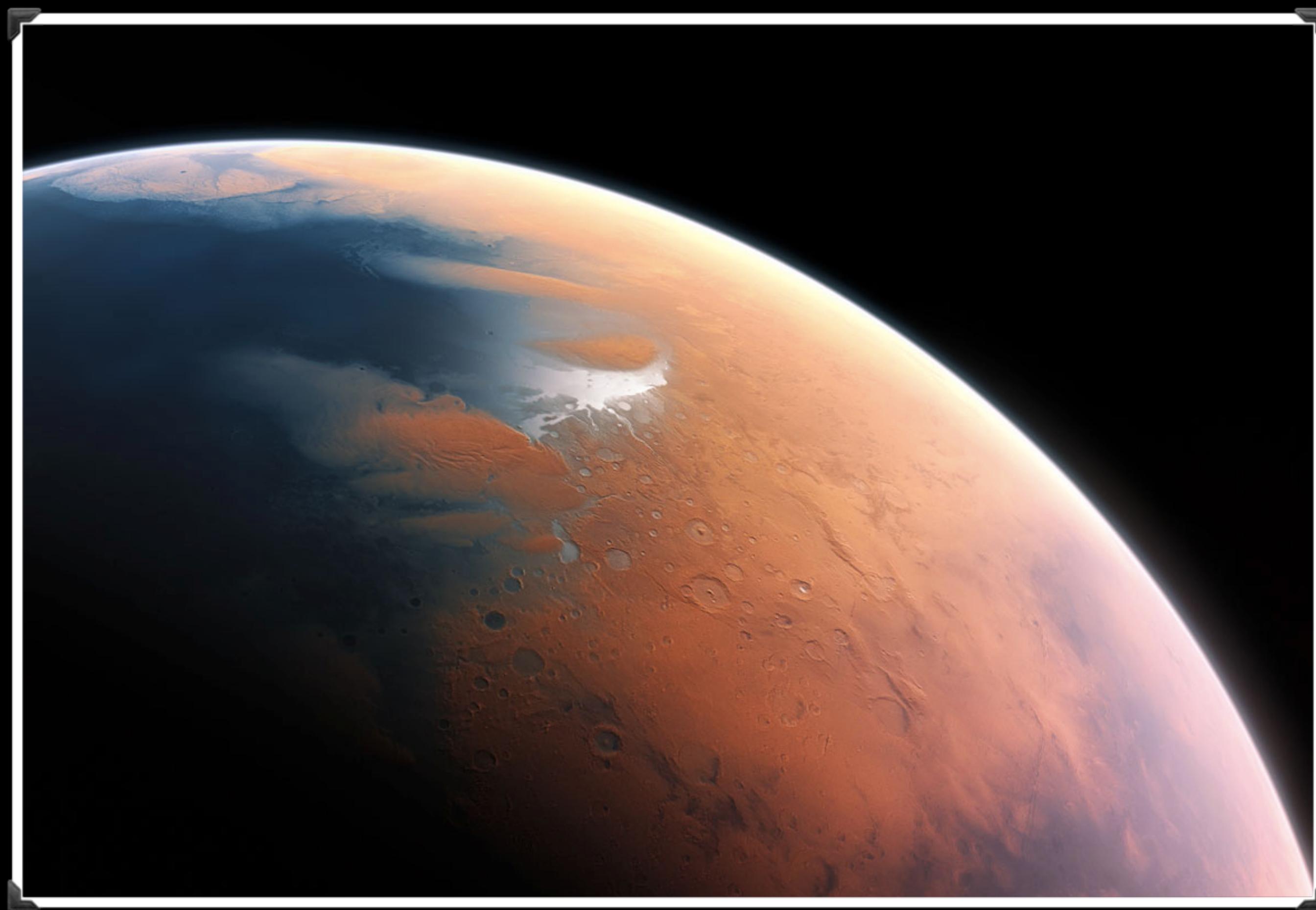
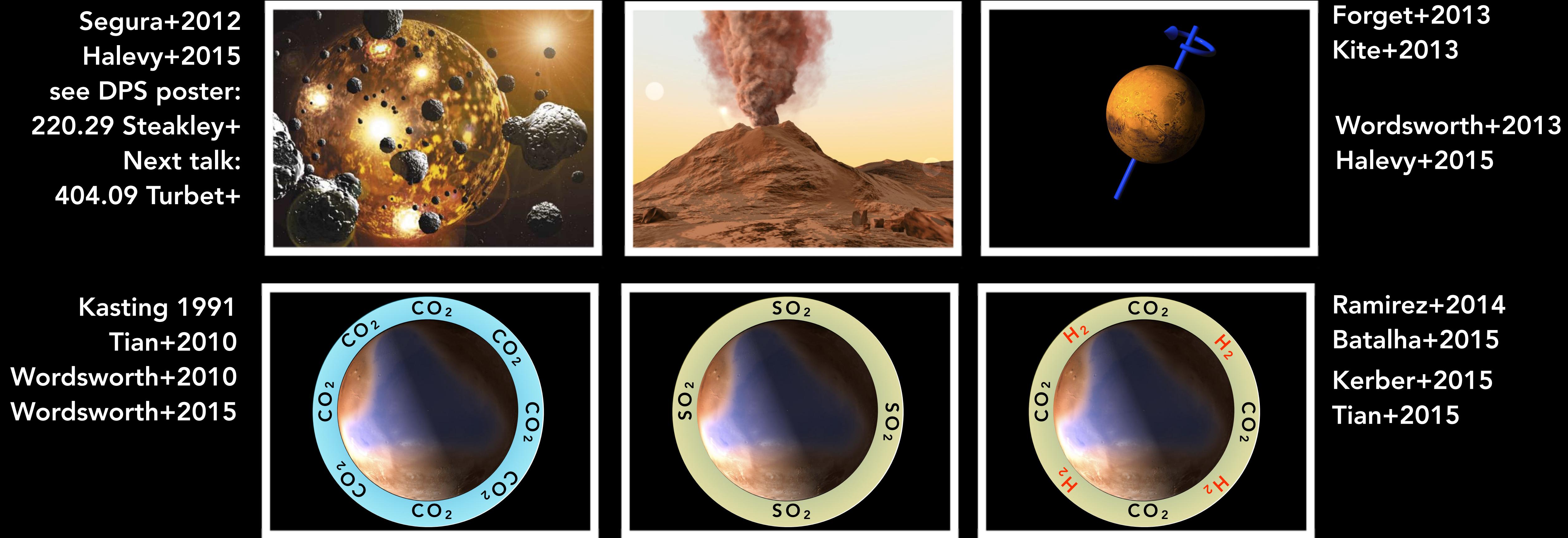


THERE IS PERVASIVE EVIDENCE FOR SURFACE LIQUID WATER 3.8 BILLION YRS AGO ON MARS

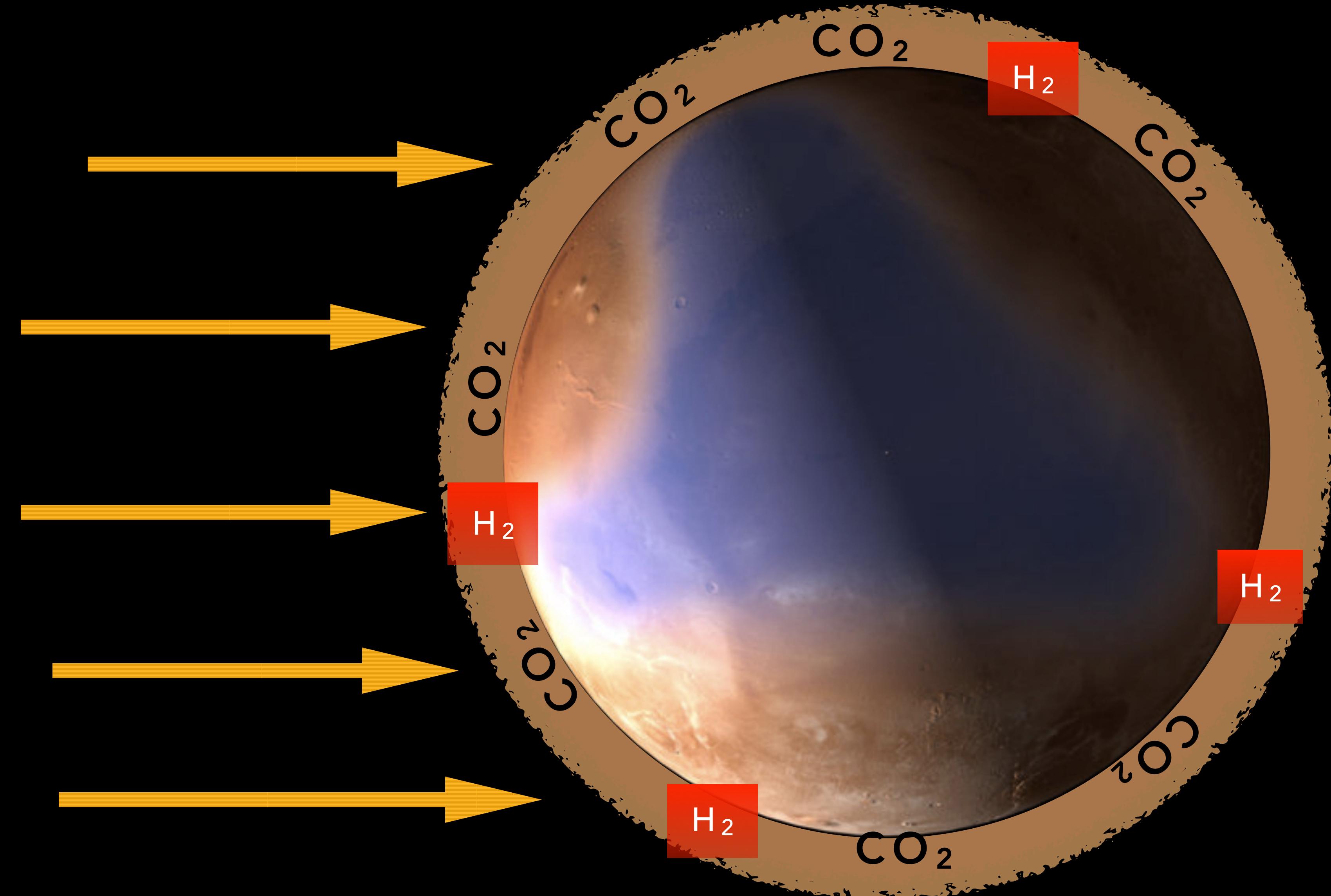


Masursky+1977
Cabrol and Grin 2001
Irwin+2008
Hynek+2010
Goldspiel & Squyres 1991
Poulet+2005
Grotzinger+2015
.... and many more!

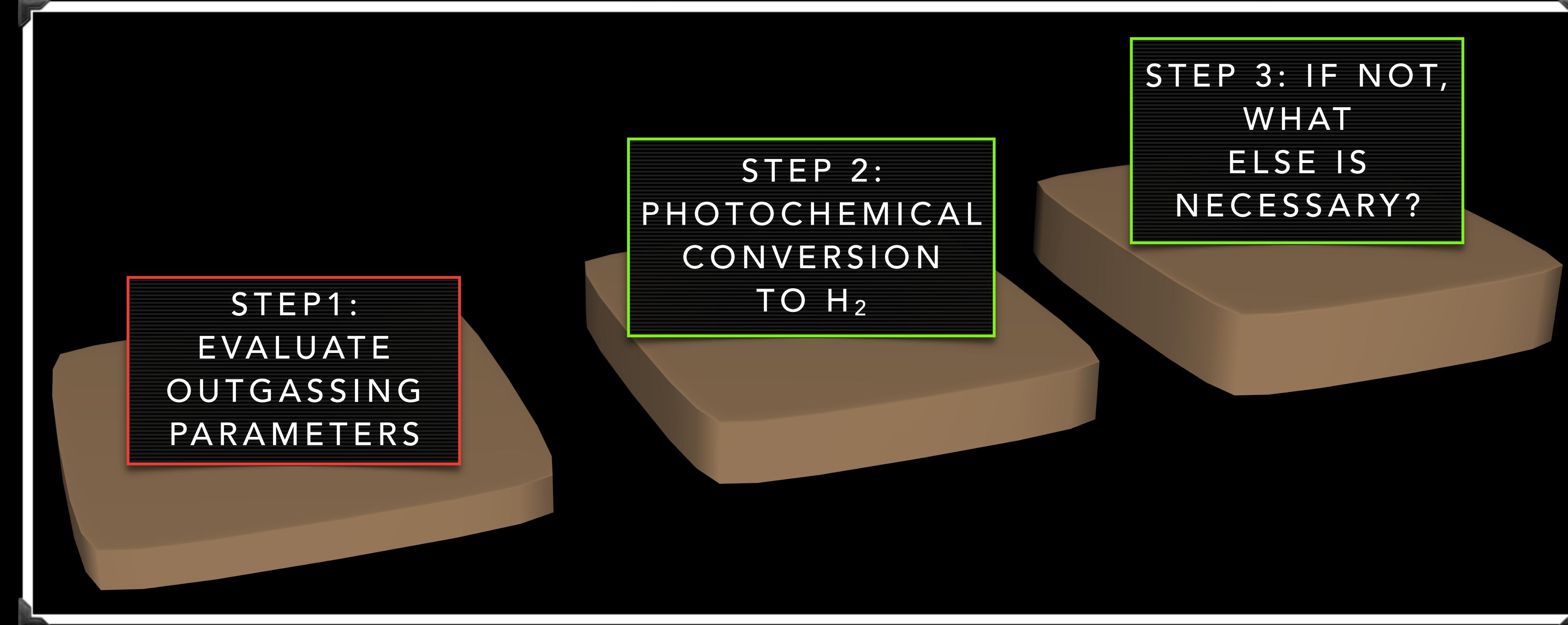
BUT HOW WAS THIS POSSIBLE?



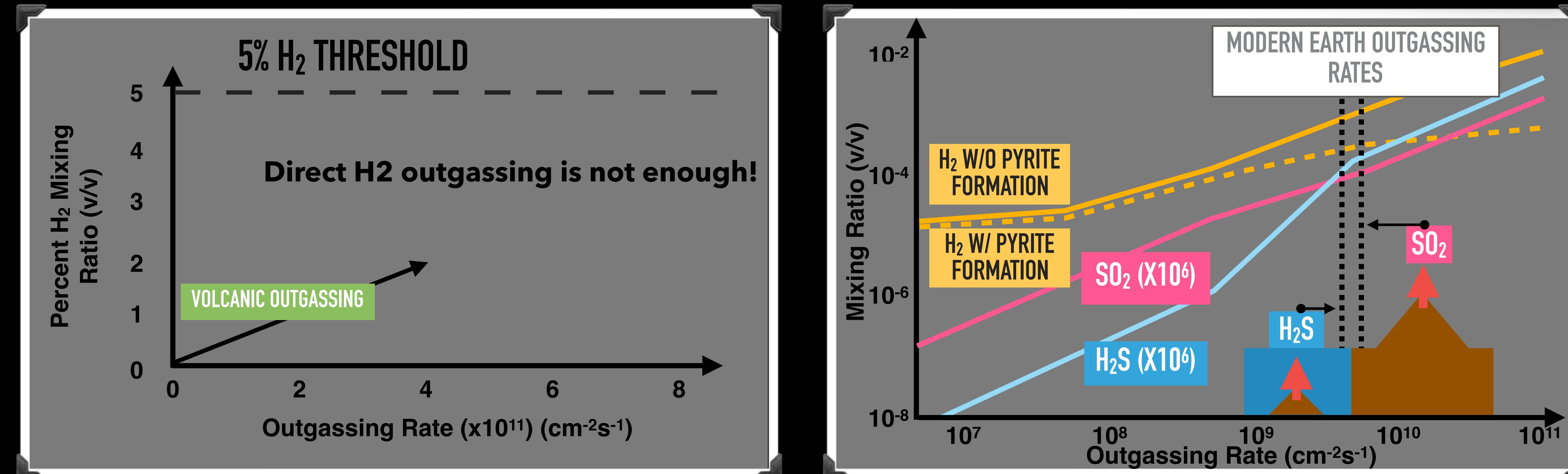
WE FOCUS ON TESTING THE HYPOTHESIS THAT EARLY MARS WAS WARMED BY A THICK H₂-CO₂ GREENHOUSE ATMOSPHERE



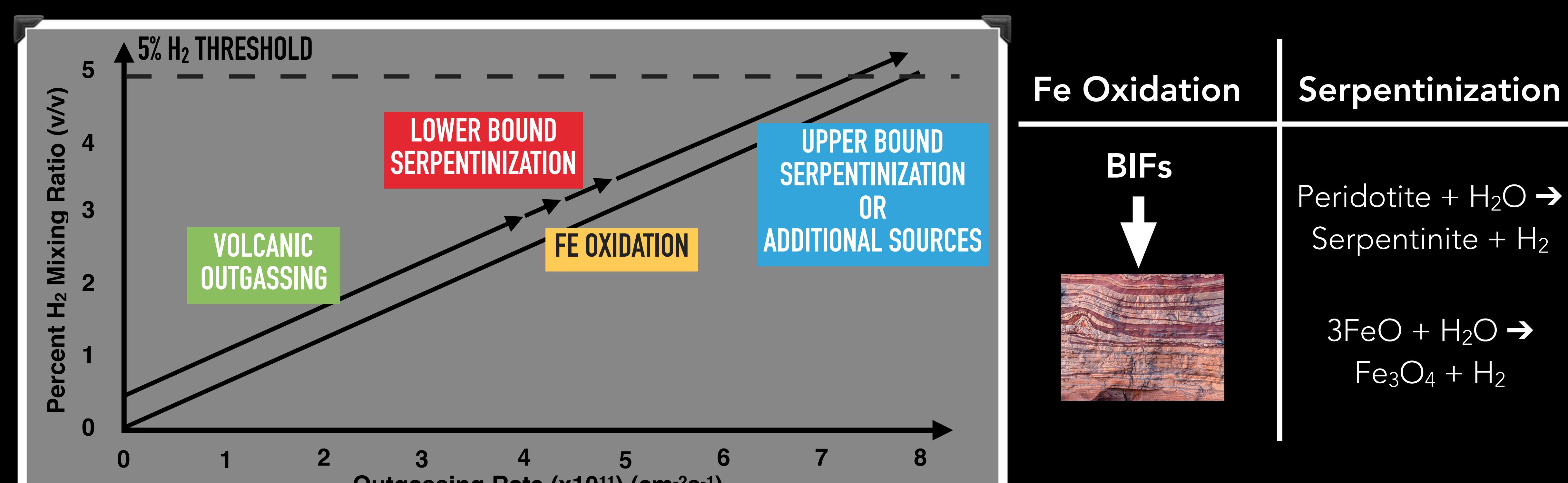
WE ASK: WHAT IS **NEEDED** TO **SUSTAIN** A 5% H₂ ATMOSPHERE ON EARLY MARS?



WE FIND THAT INJECTING DIRECT OUTGASSING IS NOT ENOUGH!

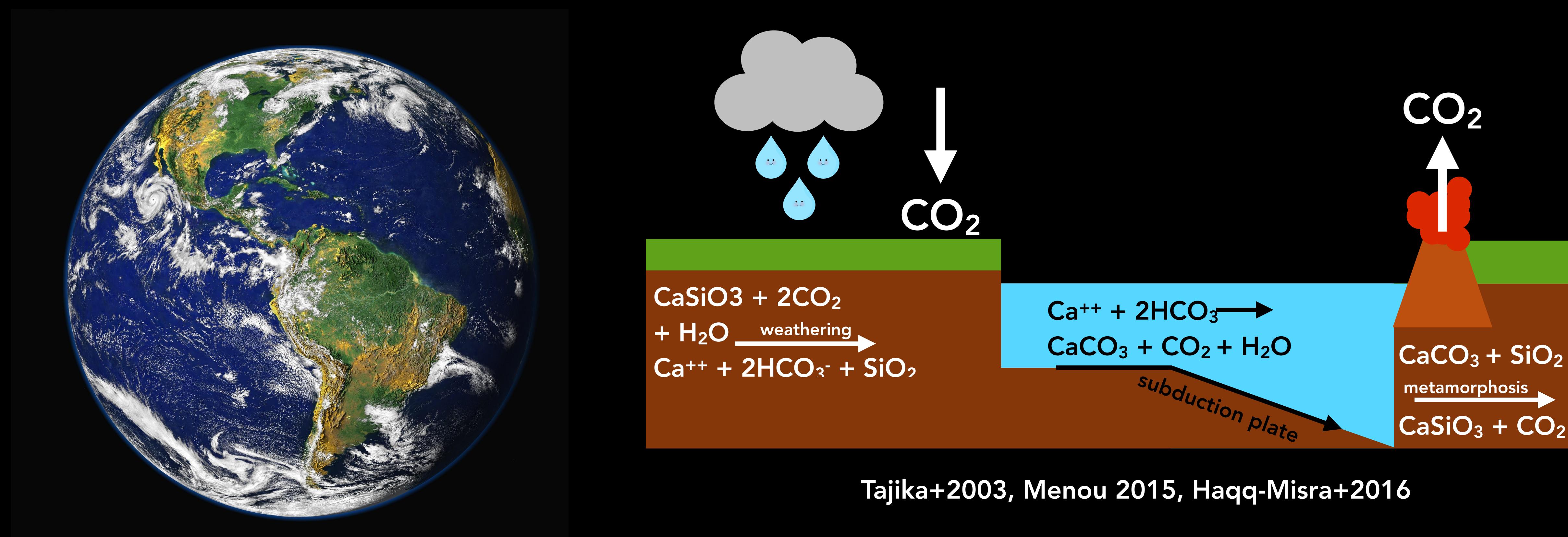


WE DEFINE WHAT ELSE IS NECESSARY FOR THE H₂-CO₂ GREENHOUSE HYPOTHESIS TO WORK



ON PRESENT-DAY EARTH...

THE CARBONATE-SILICATE CYCLE REGULATES THE CONCENTRATION OF ATMOSPHERIC CO₂



ON EARLY-MARS...

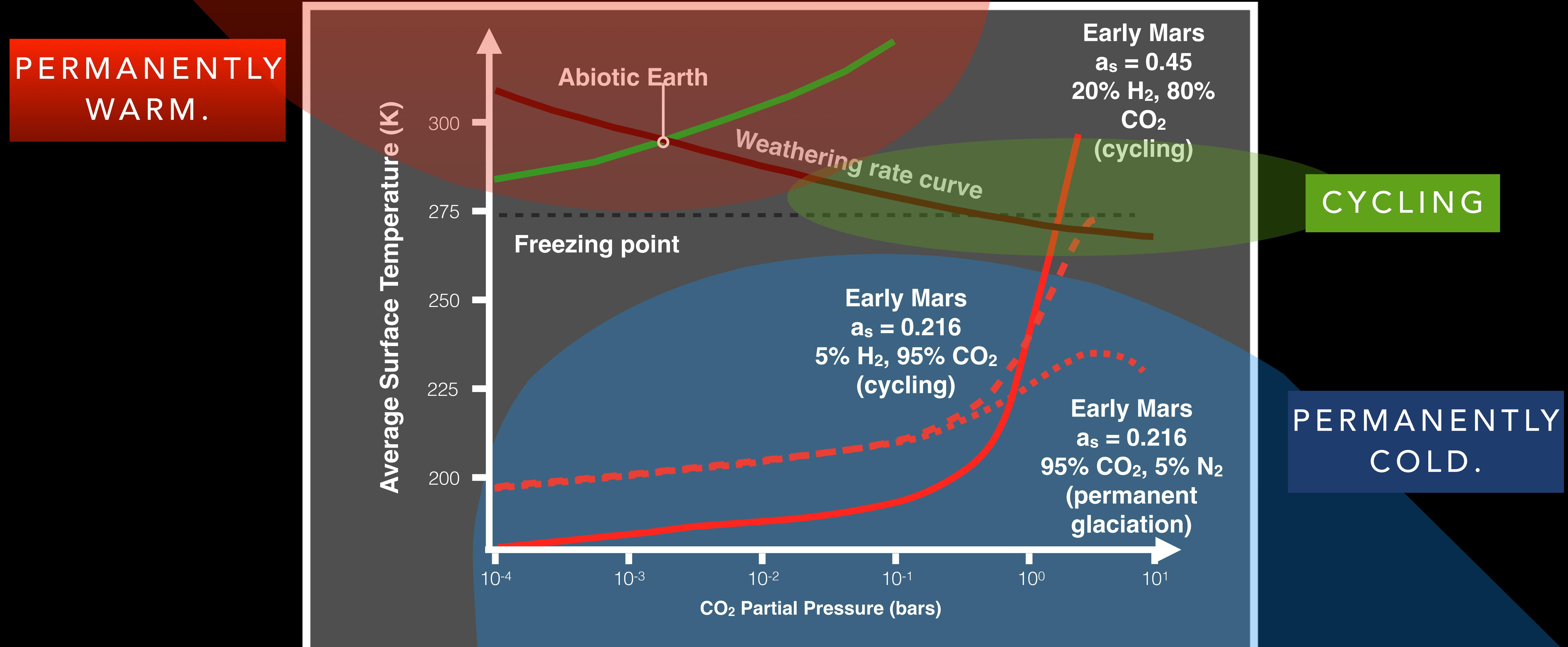
THE CARBONATE-SILICATE CYCLING WOULD'VE BEEN DIFFERENT IF MARS WERE ALSO RECYCLING VOLATILES AND IF THERE WAS SUBSTANTIAL CO₂ OUTGASSING



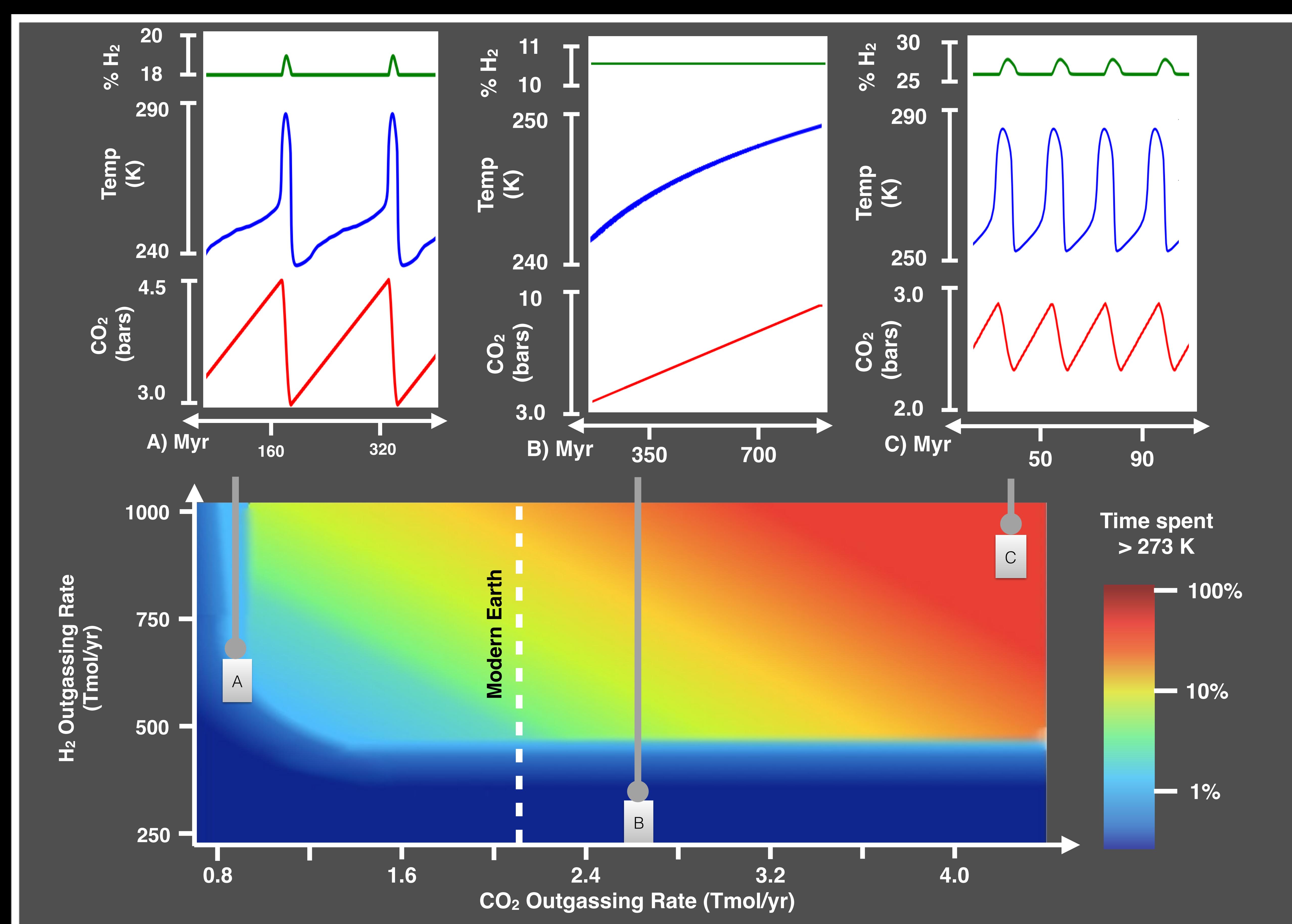
Weathering is dependent on temperature and concentration of CO₂:

Temperature is cooler → Weathering slows down → CO₂ builds up → Temperature starts to increase

REGIONS WHERE CLIMATE CYCLING MIGHT HAPPEN



WE DEFINE REGIONS OF PARAMETER SPACE WHERE CLIMATE CYCLING ON MARS MIGHT HAPPEN



A FLIP FLOPPING CLIMATE ON EARLY MARS COULD IMPLY MARS, 3.8 BILLION YEARS AGO, WAS BOTH WARM AND WET, AND COLD AND FROZEN