Atmospheric and Evolutionary Models with Disequilibrium Chemistry for the JWST Era

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Jonathan Fortney (UCSC), Daniel Thorngren (JHU)

PICASO v 3.0

New Open-Source 1D Radiative-convective Models capturing all of this complexity

Mukherjee et al. (2022 b, in press)

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New Open-Source 1D Radiative-convective Models capturing all of this complexity

Legacy past 30 years in the field

(e.g., Marley and Mckay (1999), Marley et al. (1996), Morley et al. (2012,2014), Fortney et al. (2005,2007,2008), Marley et al. (2021) and many more...)

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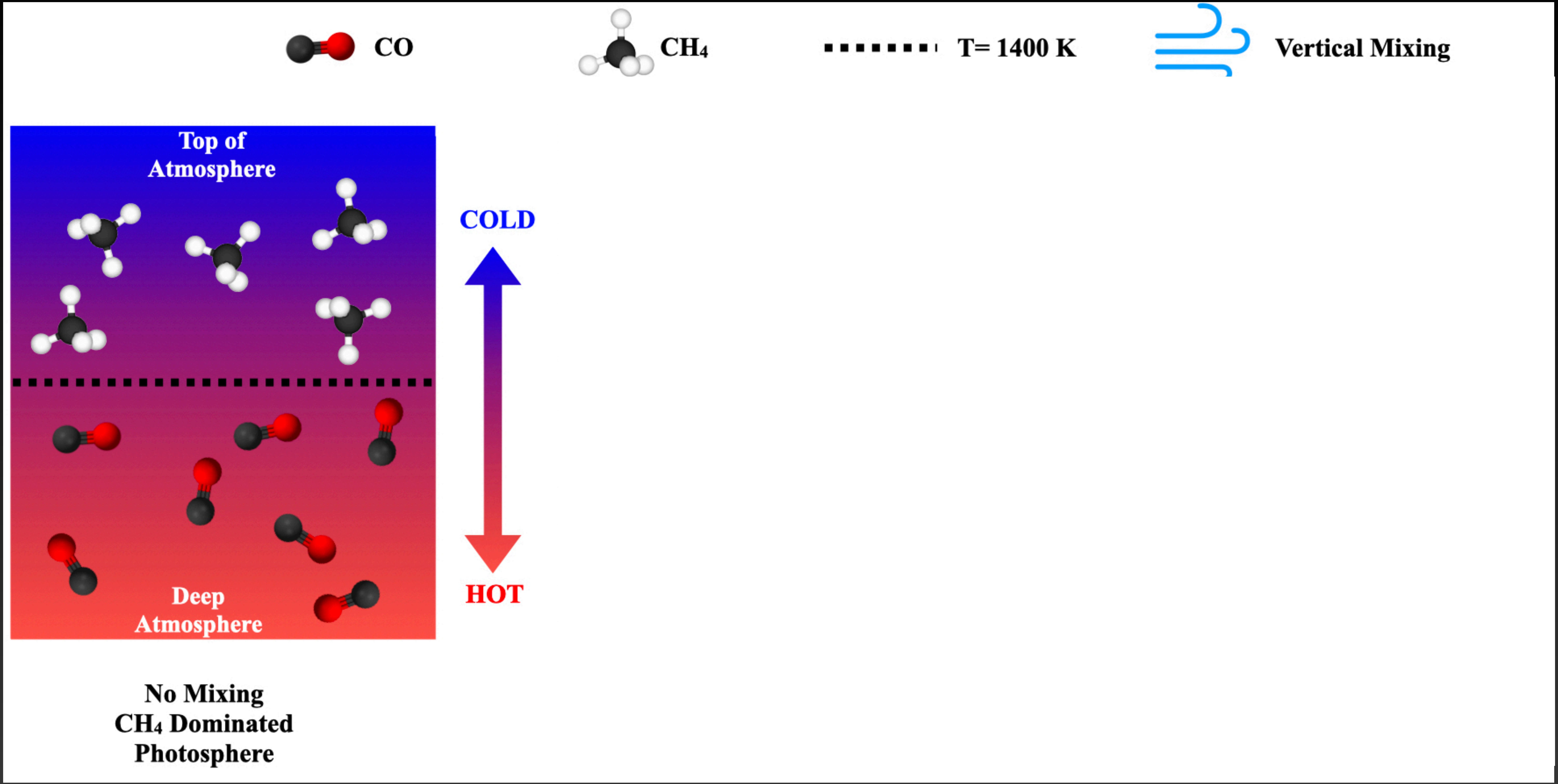
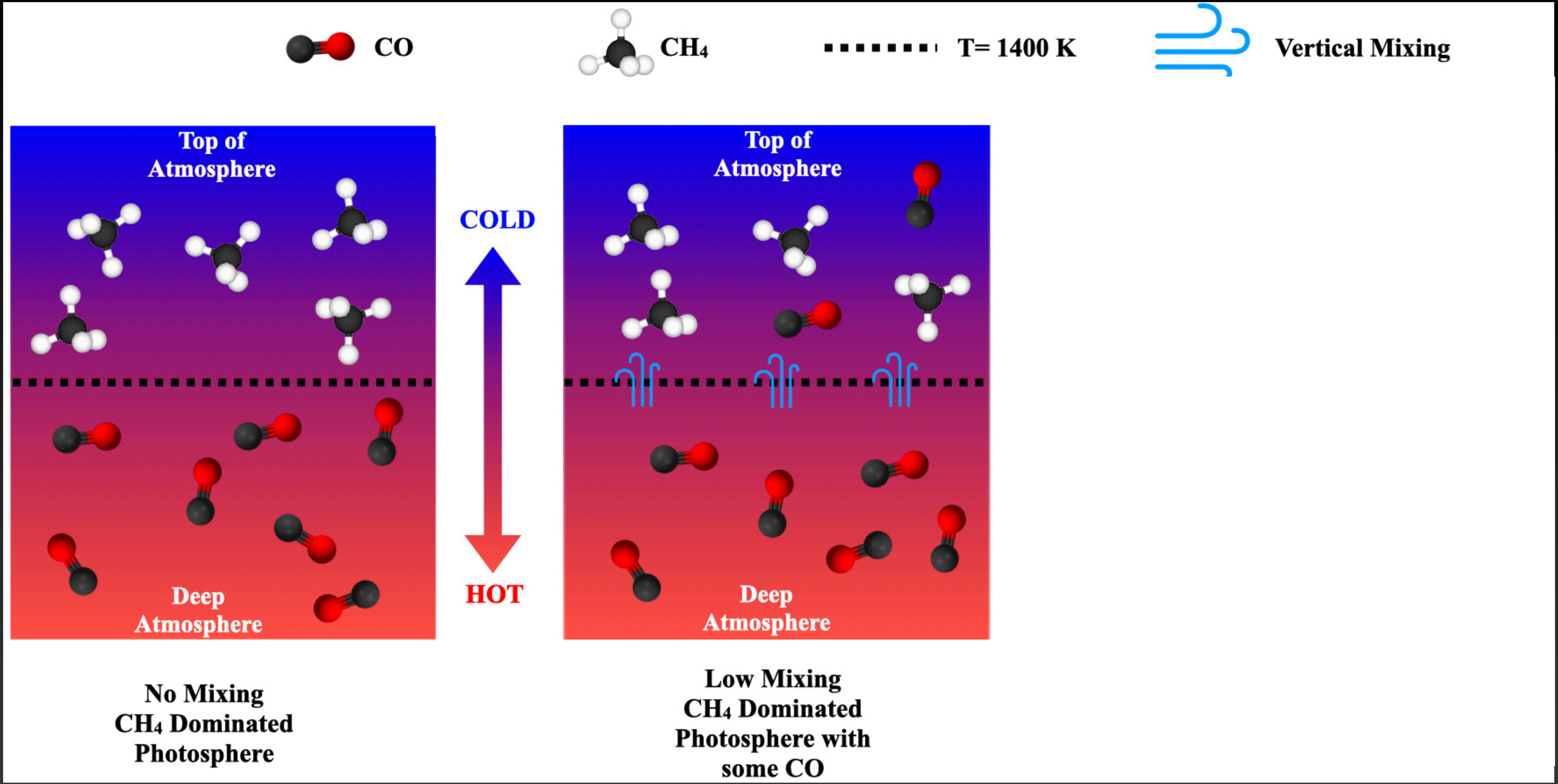
Fully Open-Source

Includes Self-consistent treatment of Disequilibrium Chemistry

Mukherjee et al. (2022 b, in press)


CO
CH4
T= 1400 K
Vertical Mixing
Top of Atmosphere
COLD
HOT
Deep Atmosphere
No Mixing
CH4 Dominated
Photosphere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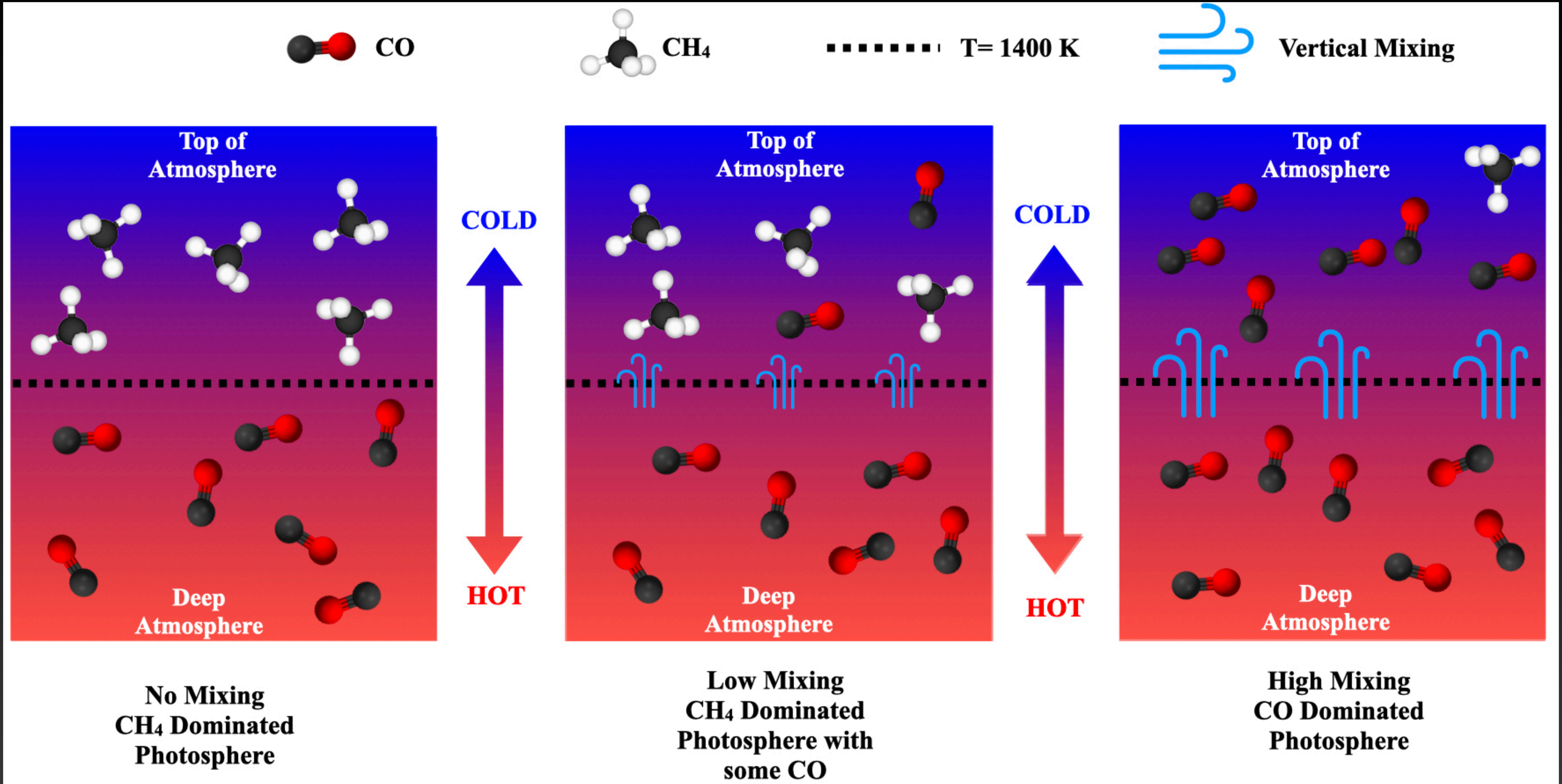
Photosphere with
some CO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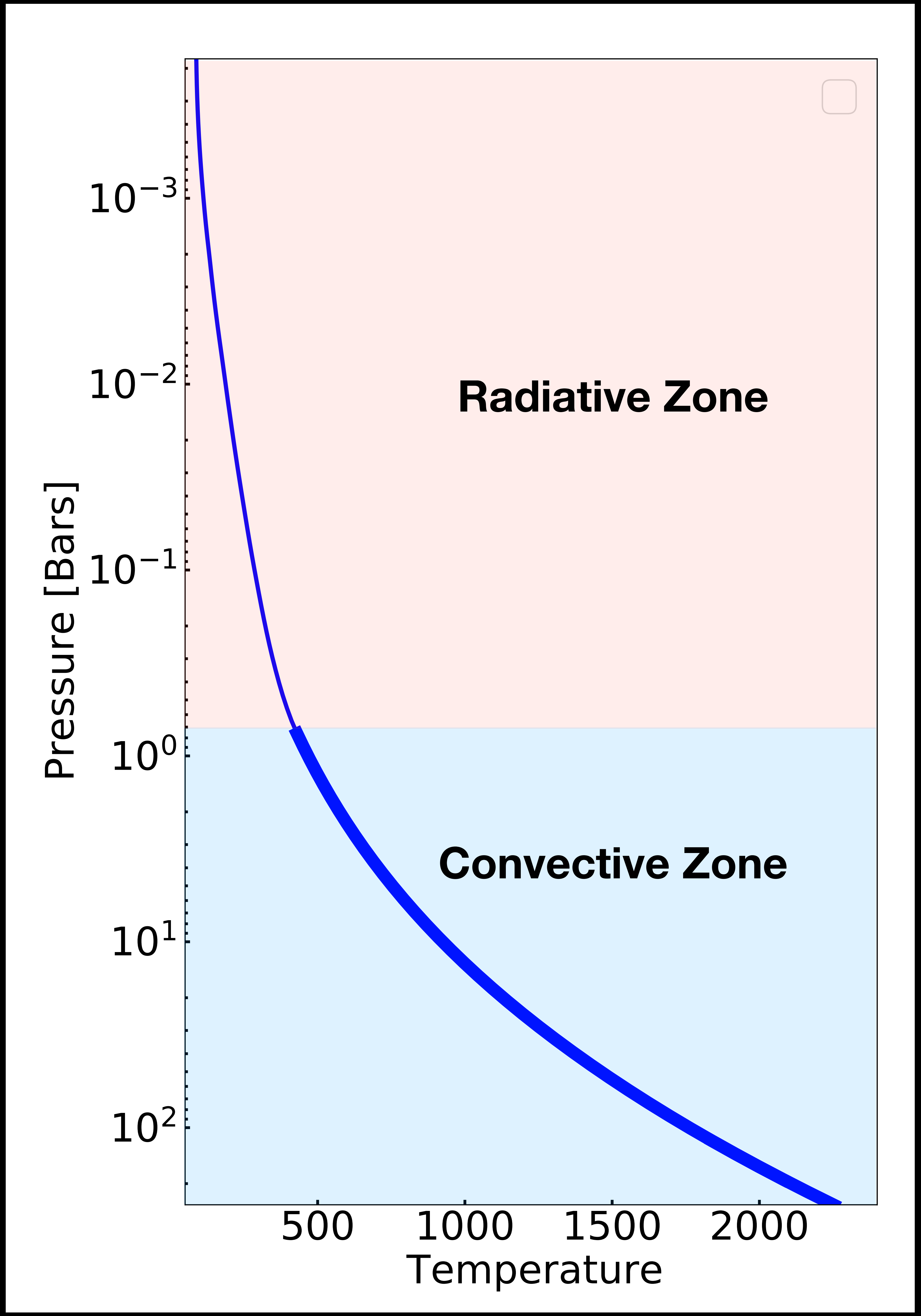
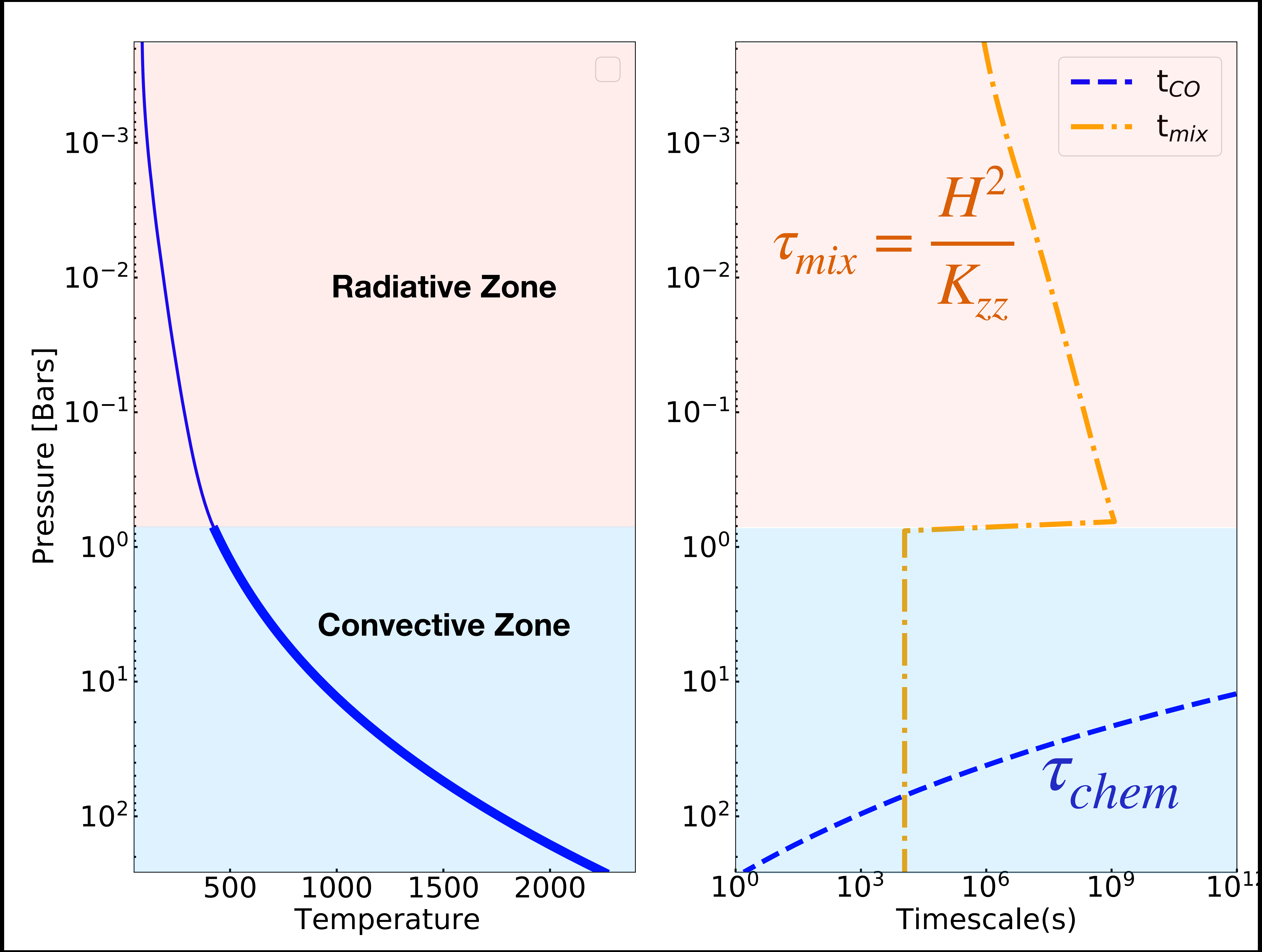
Photosphere



Mukherjee + (2022a)



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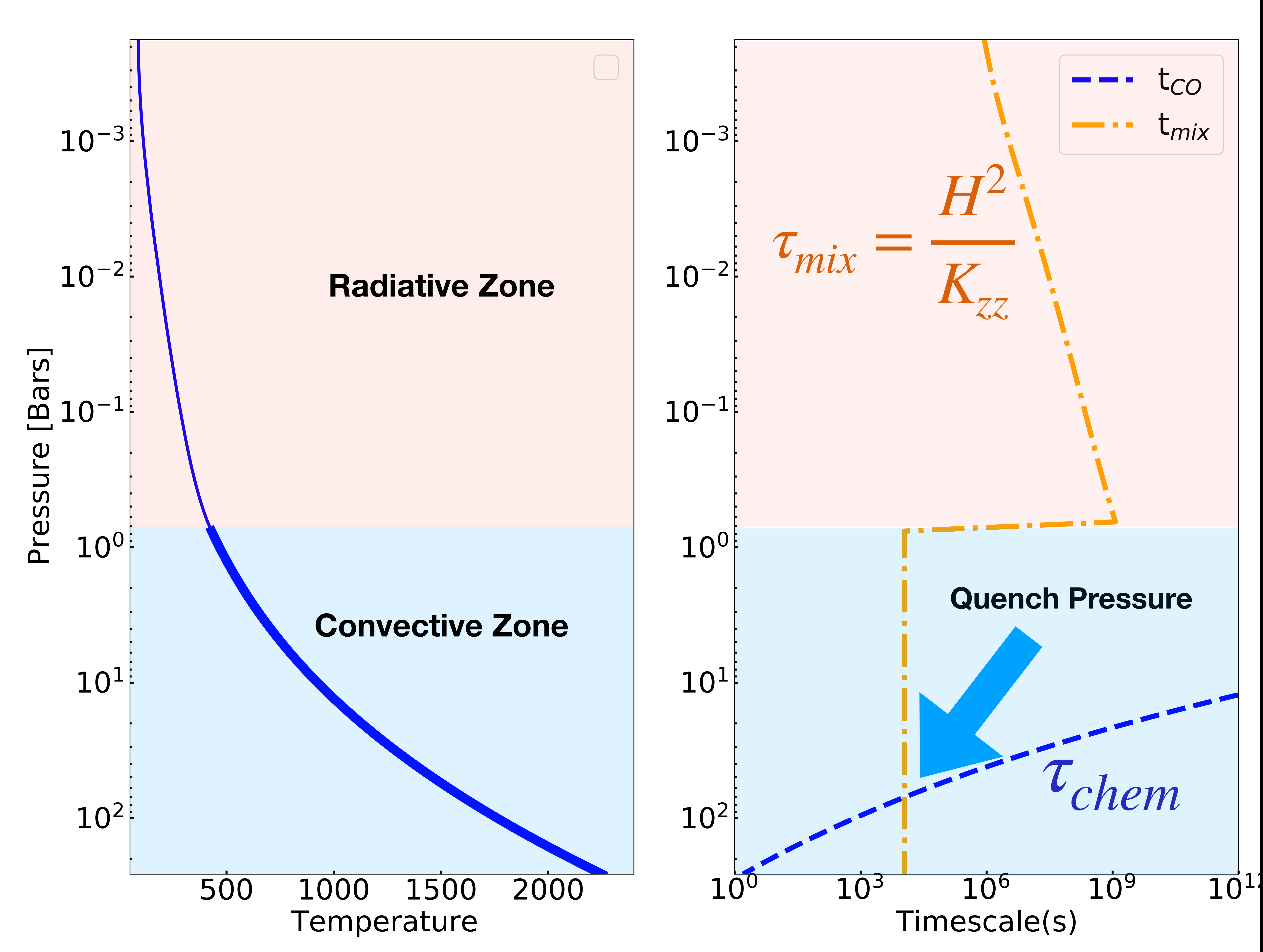
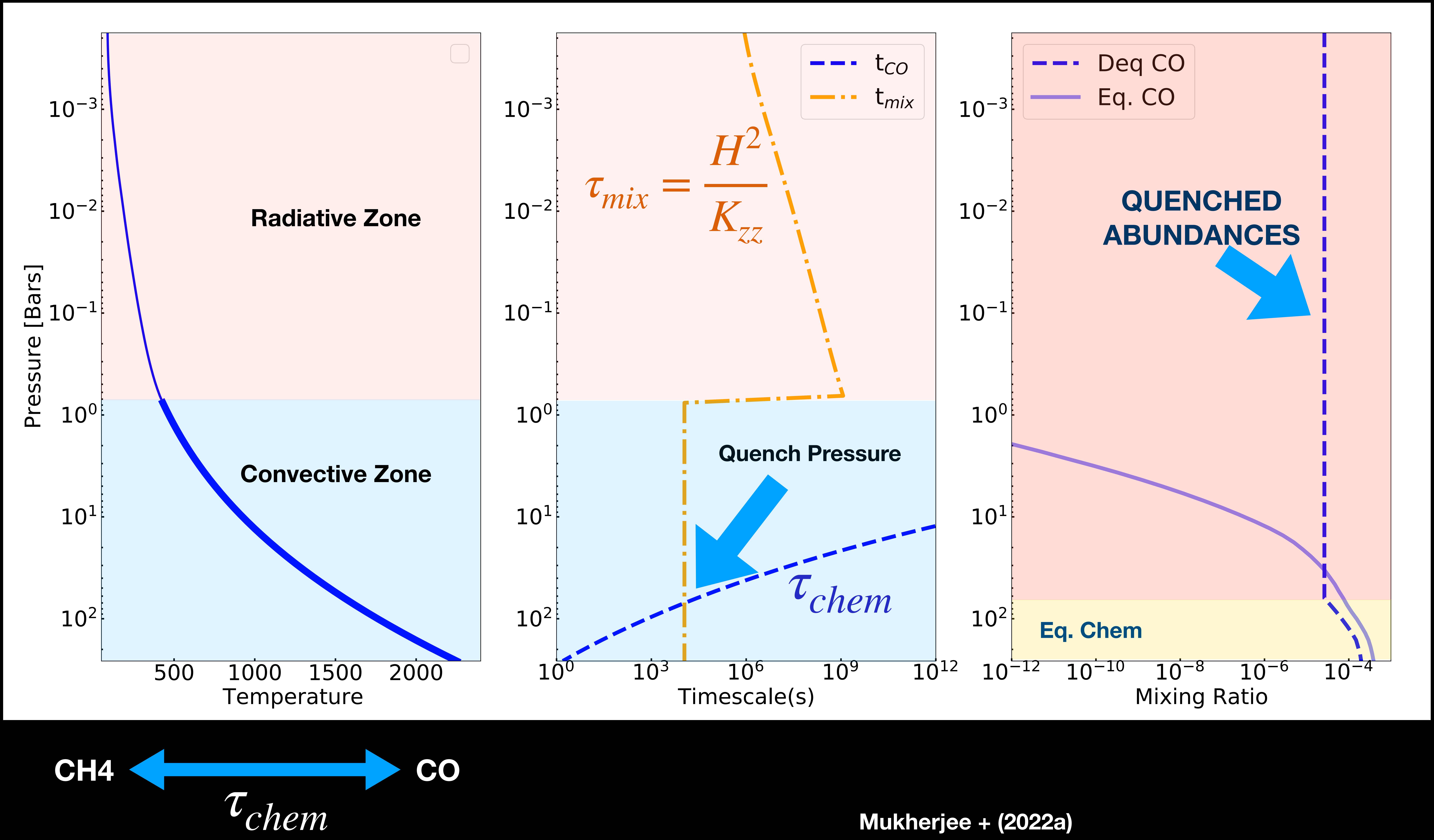


CH4 ⟷ **CO**

τ_{chem}

Mukherjee + (2022a)



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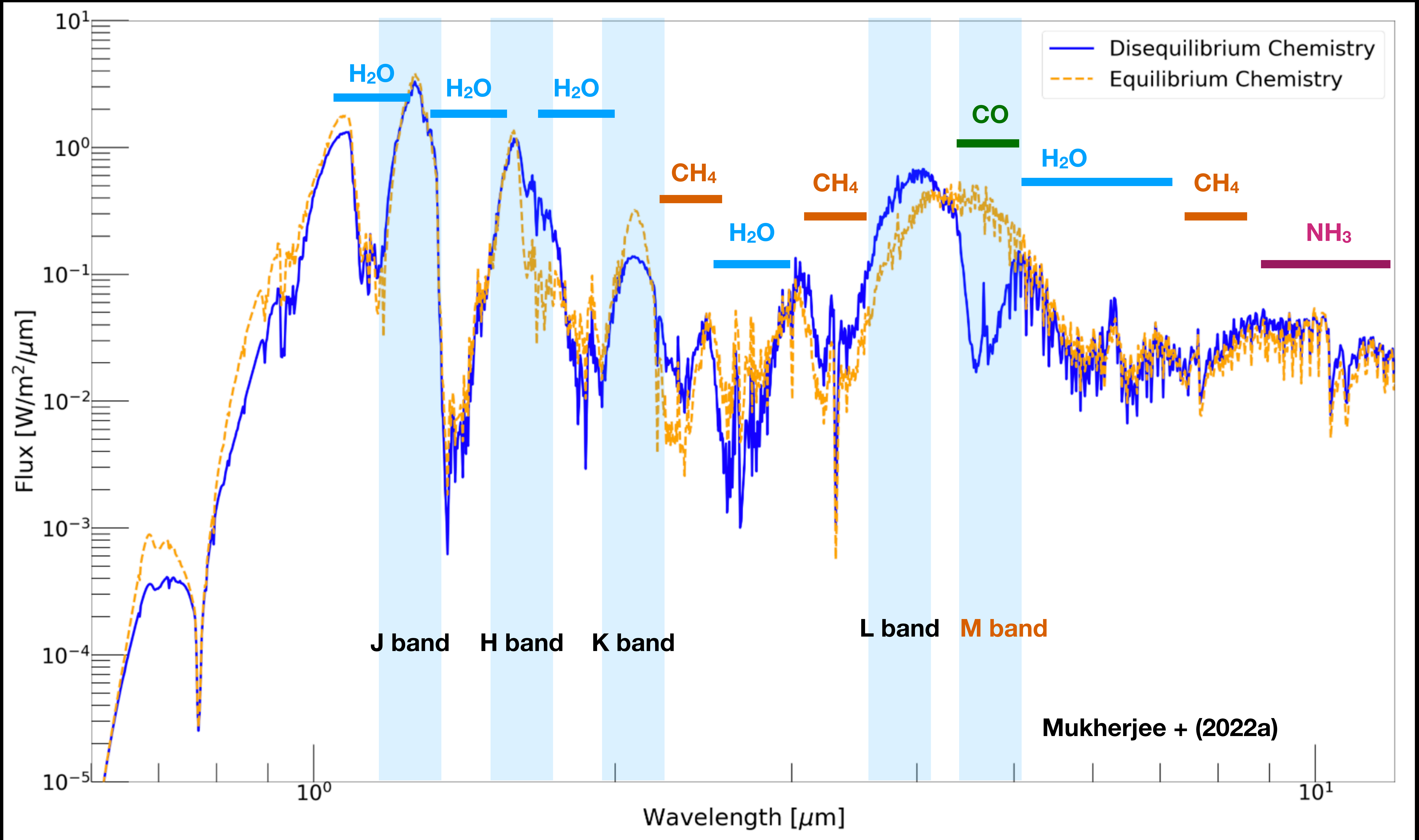
Large Effect of Disequilibrium Chemistry on Thermal Spectra of Brown Dwarfs



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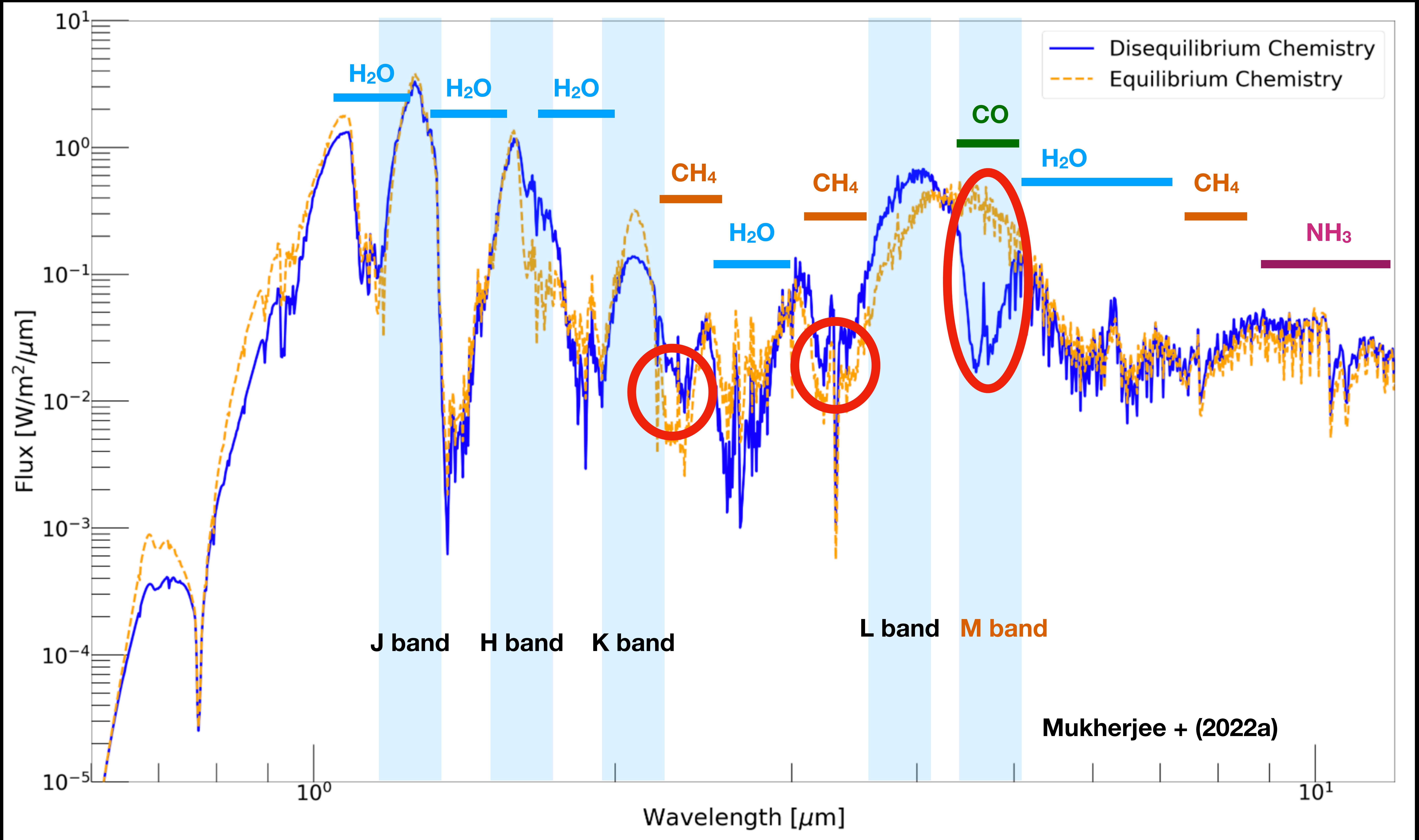

Key Questions

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How does disequilibrium chemistry impact the thermal structure of exoplanets and brown dwarfs across various metallicities?

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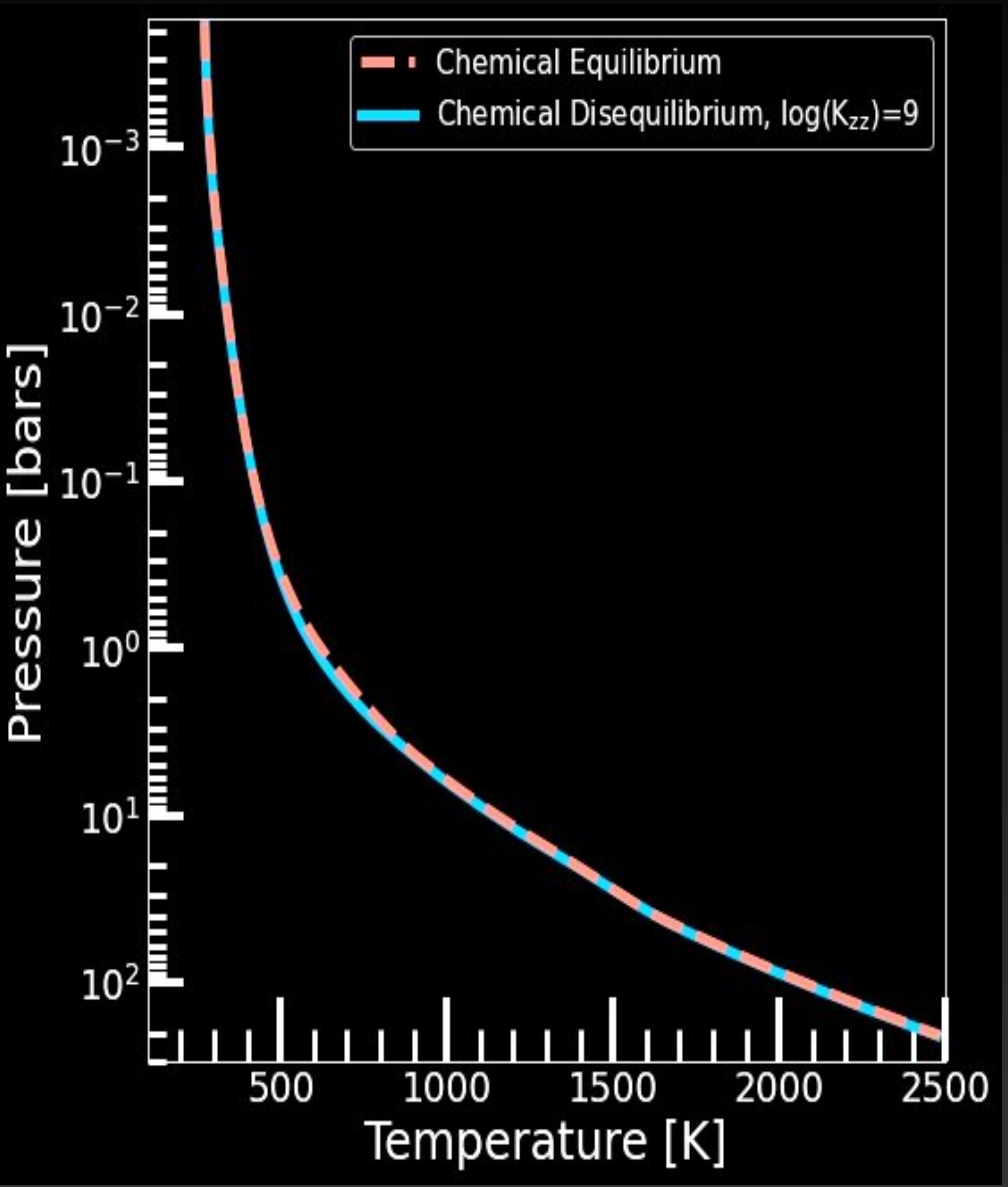
How does disequilibrium chemistry impact the evolution of exoplanets and brown dwarfs?

Diseq. Chemistry, T(P) profiles, and Metallicity

Metallicity = 0.1xsolar



Diseq. Chemistry, T(P) profiles, and Metallicity

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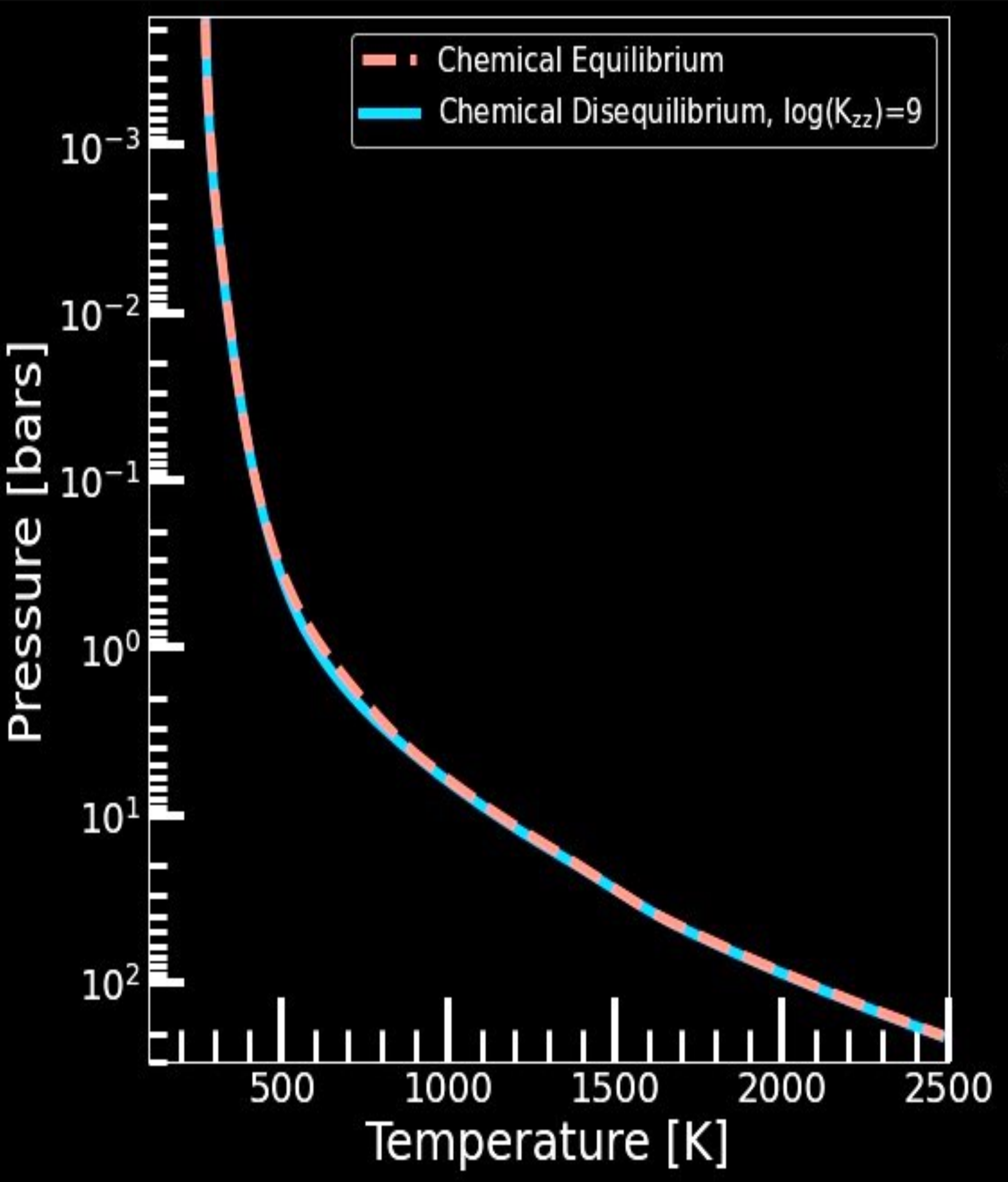
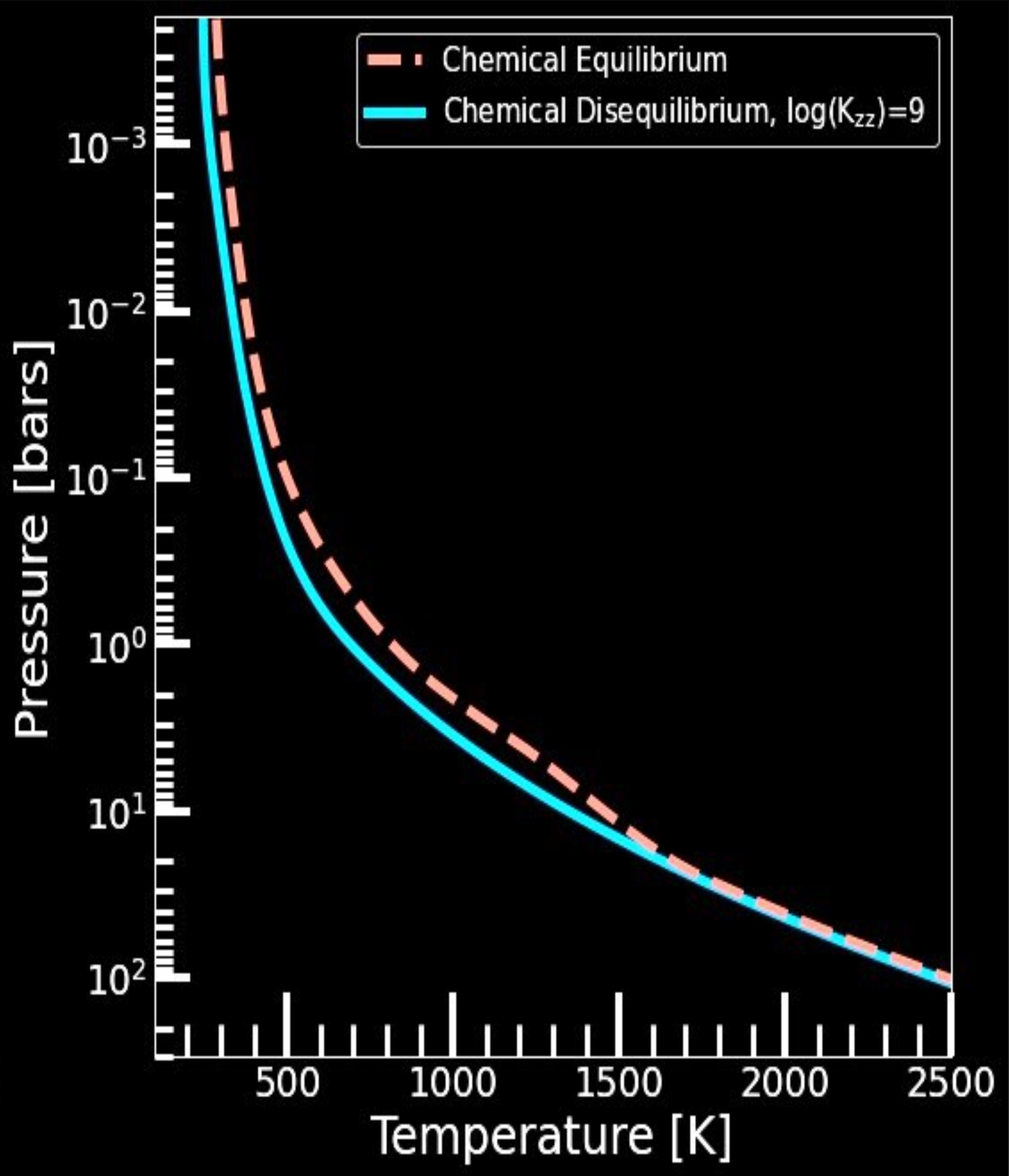
Metallicity = 1xsolar





Diseq. Chemistry, T(P) profiles, and Metallicity

Metallicity = 0.1xsolar **Metallicity = 1xsolar** **Metallicity = 10xsolar**

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Disequilibrium Chemistry alters the T(P) profile by a large amount at super-solar metallicities

Diseq. Chemistry and the Deeper Atmosphere

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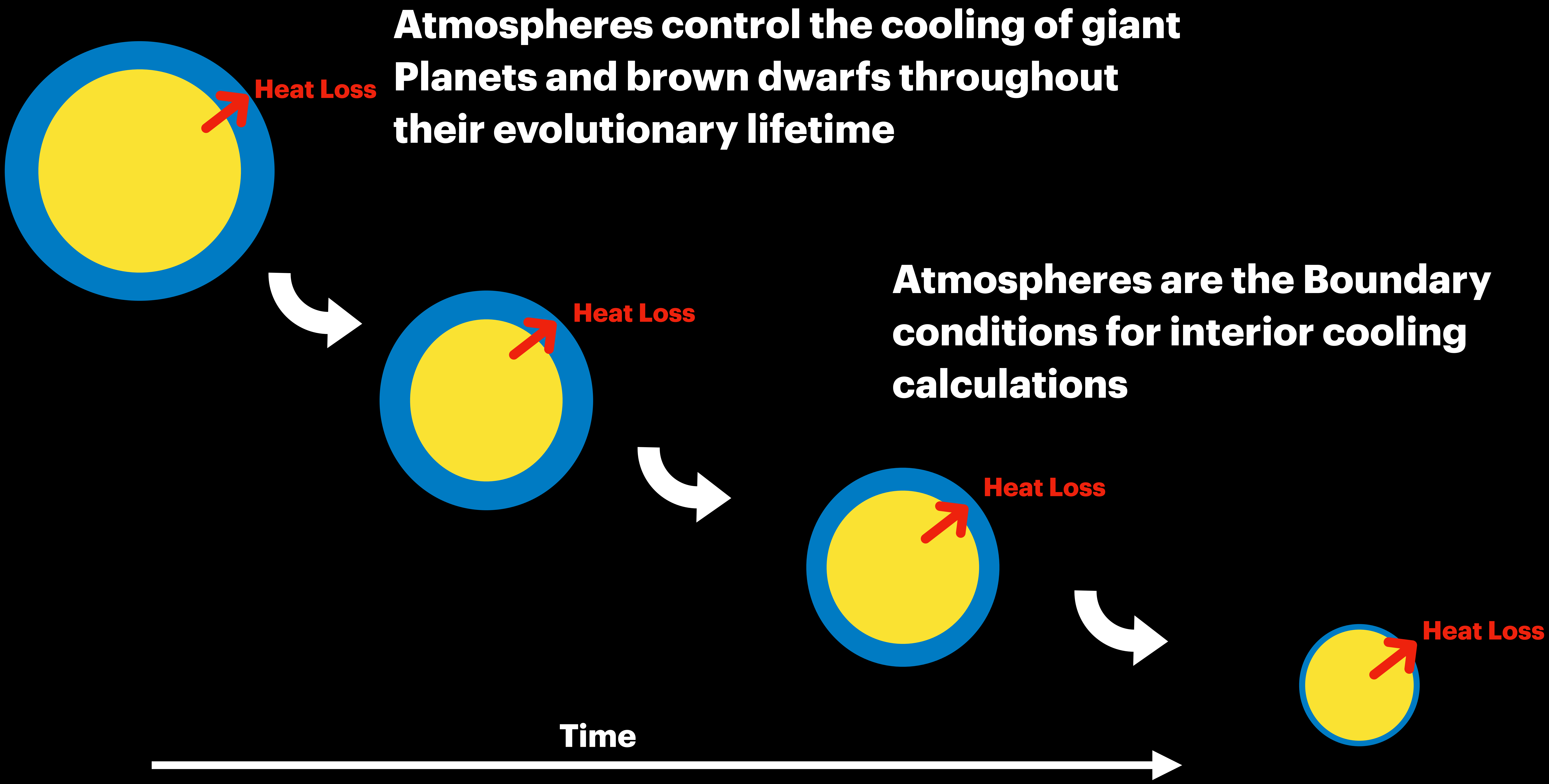
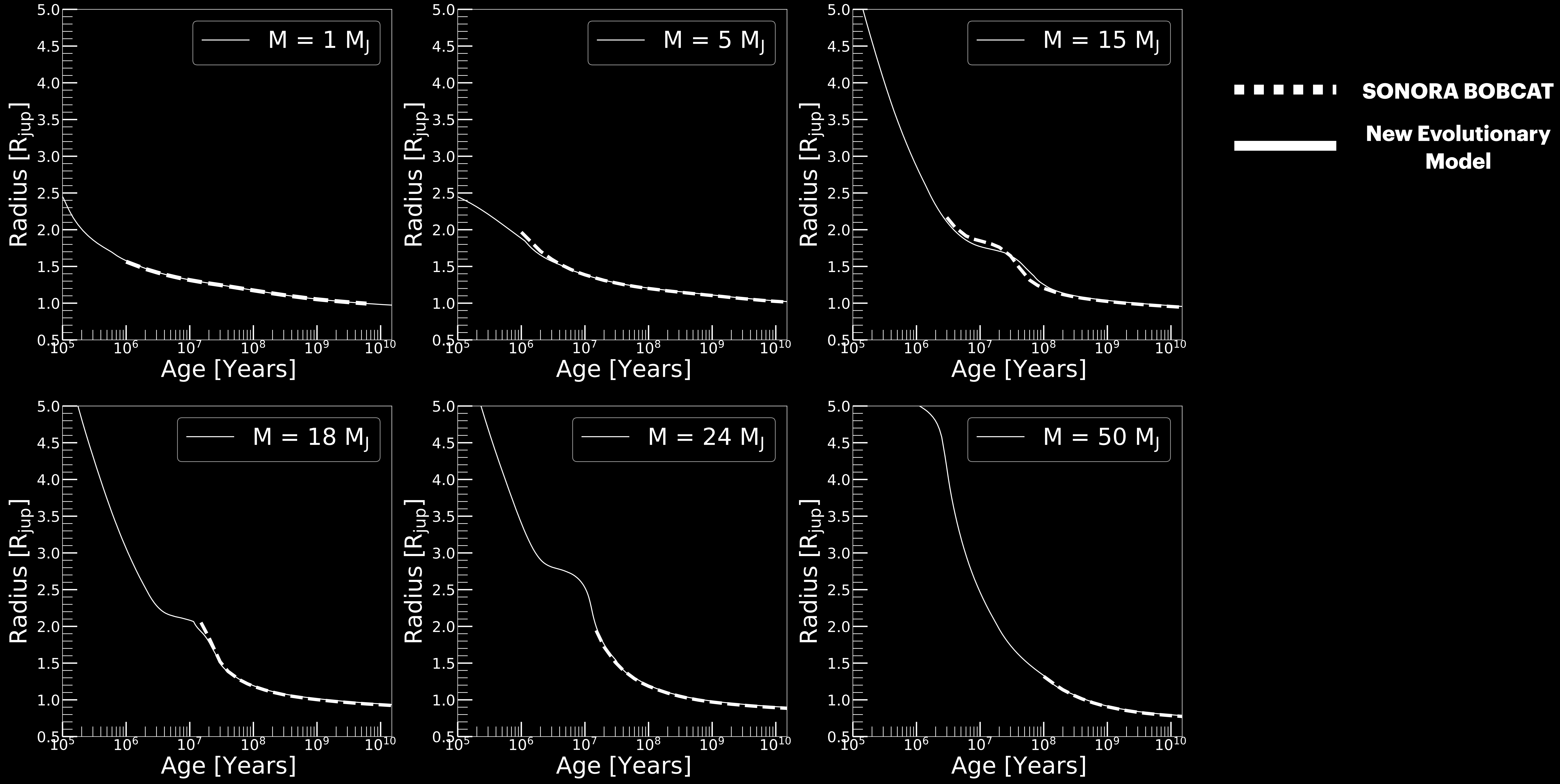
Disequilibrium Chemistry cools down the deeper atmosphere significantly for super-solar metallicities


Atmospheres control the cooling of giant Planets and brown dwarfs throughout their evolutionary lifetime
Atmospheres are the Boundary conditions for interior cooling calculations
Heat Loss
Heat Loss
Heat Loss
Heat Loss
Time

New Evolutionary Model —> Adding Nuclear Fusion to Thorngren et al. Evolutionary Model

Benchmarking



New Grid of Atmospheric Models

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Equilibrium Chemistry Models

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Equilibrium Chemistry Models

39 Effective Temperature from 200 K to 2400 K

11 Gravity values from 10 m/s/s to 3160 m/s/s

4 Metallicity values between 1x to 10x solar

3 C/O ratios of 0.22 and 1.2

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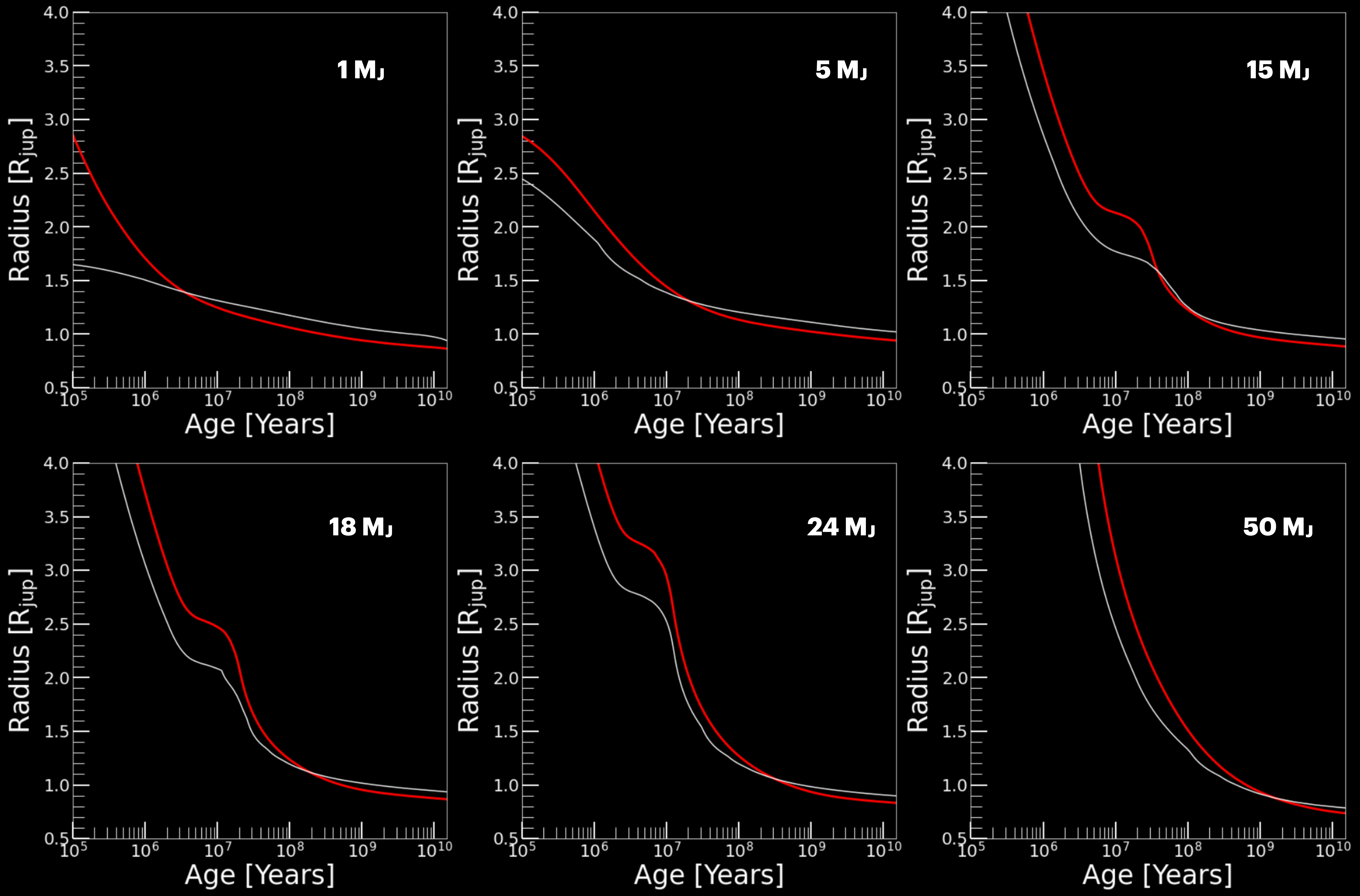
5 log(Kzz) values between 2,4,7,8 and 9

Solar Metallicity Evolutionary Model vs. 10xSolar Metallicity Evolutionary Model

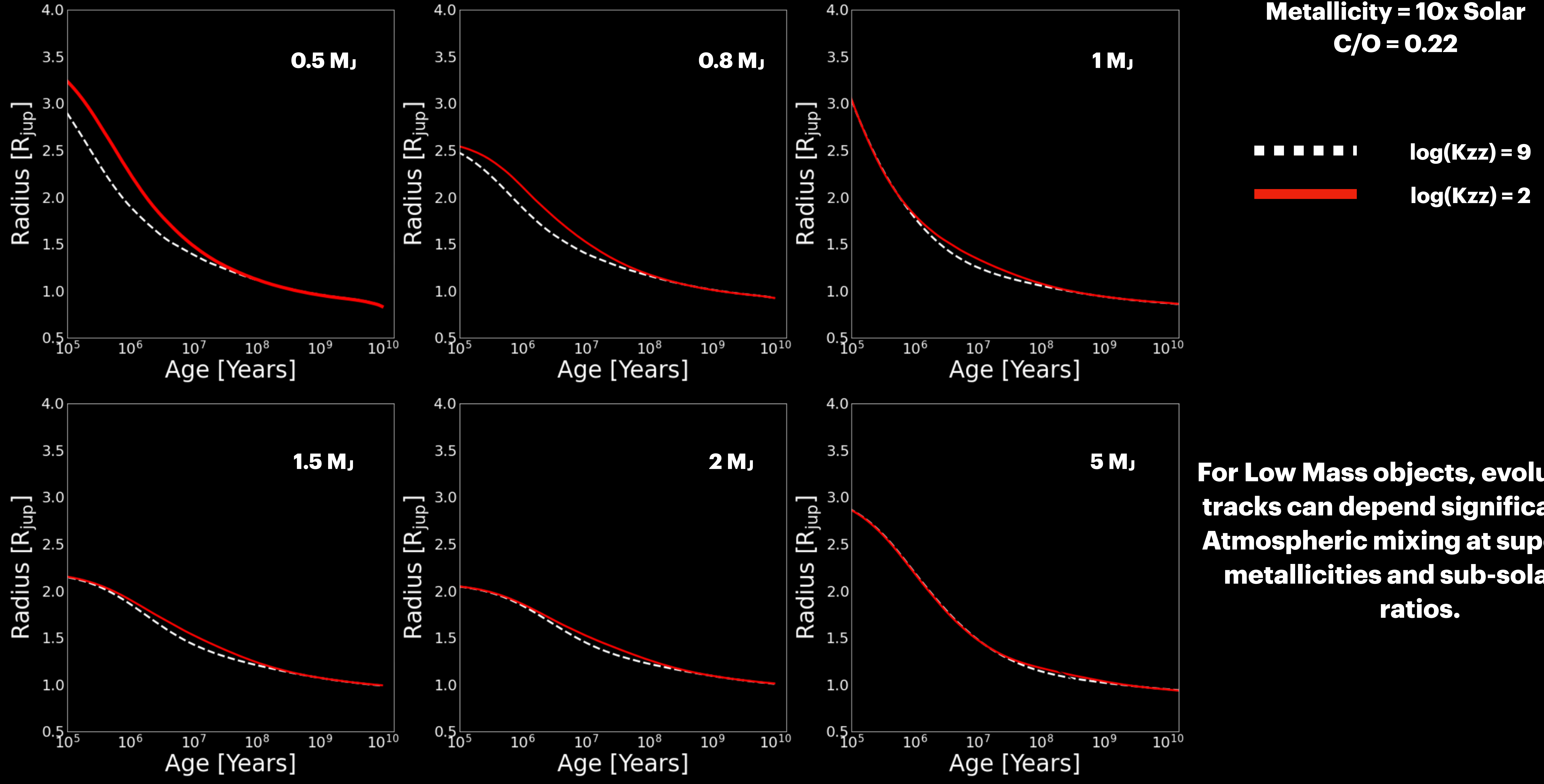


Solar Metallicity

10xSolar Metallicity

For higher metallicity, objects should be bigger in earlier ages and then switch to smaller radii in late ages compared to solar metallicities.

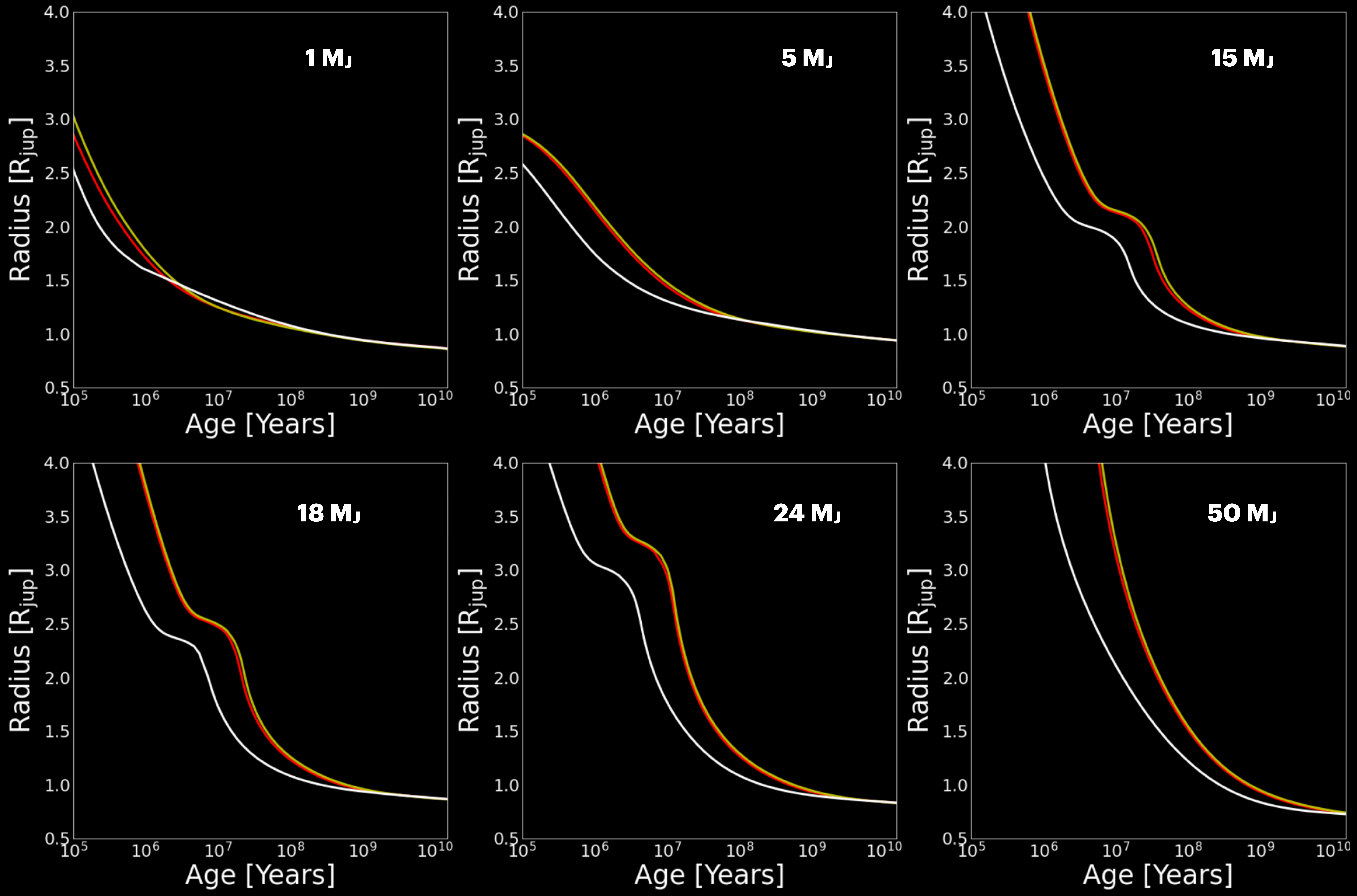
Dependence of Evolutionary Tracks on Kzz



Metallicity = 10x Solar
C/O = 0.22

For Low Mass objects, evolutionary tracks can depend significantly on Atmospheric mixing at super solar metallicities and sub-solar C/O ratios.

Solar C/O Evolutionary Model vs. 2.5xSolar C/O Evolutionary Model



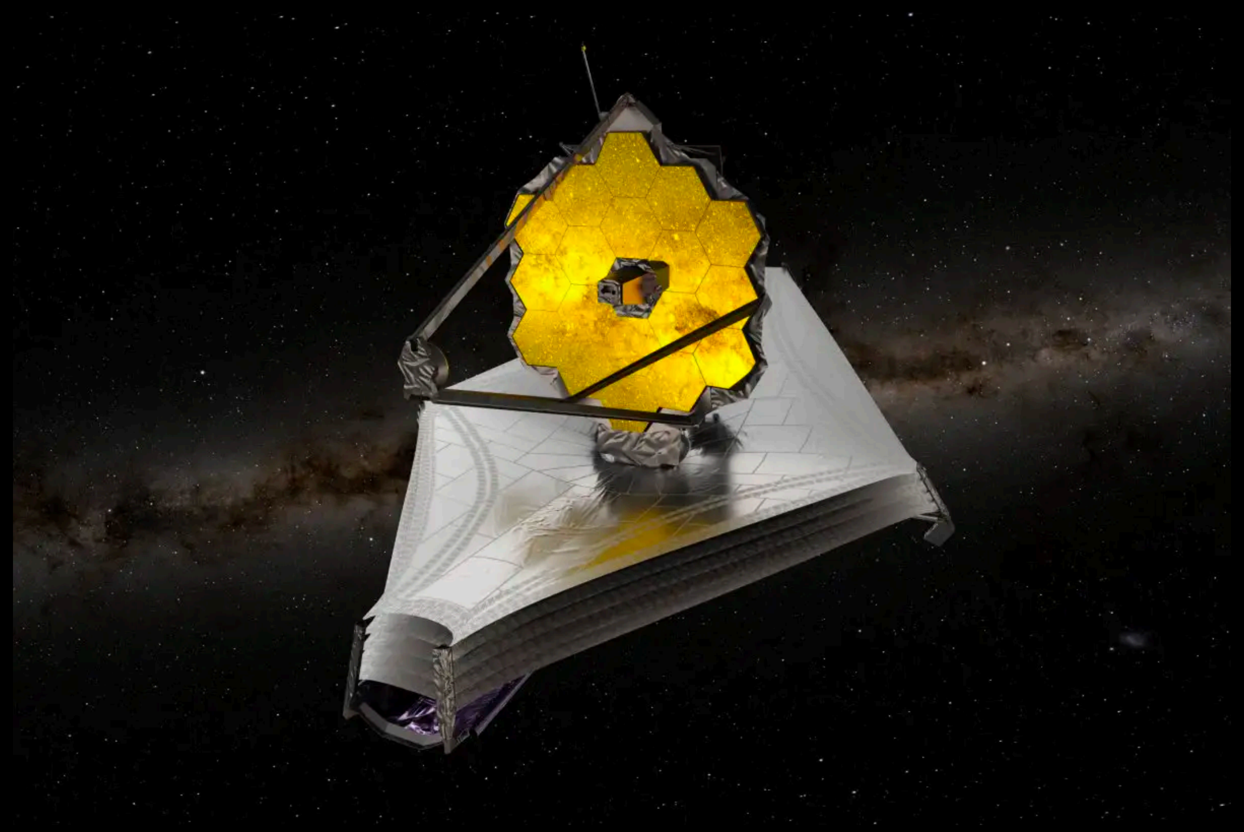
Metallicity = 10xSolar
log(Kzz) = 9

0.5xSolar C/O
1xSolar C/O
2.5xSolar C/O

C/O ratio < 1 tracks are almost similar

C/O ratio > 1 can heavily influence evolutionary tracks

With JWST for the first time a lot of detailed measurements will be made



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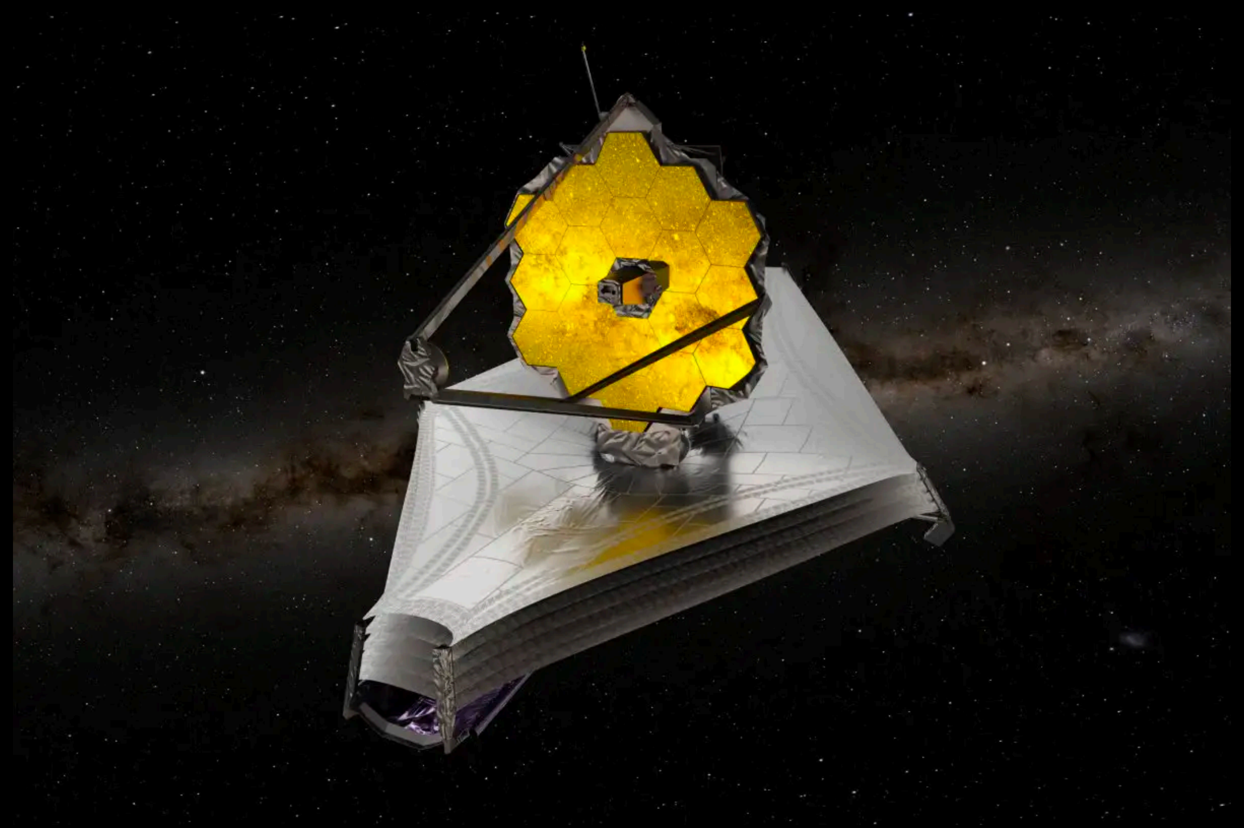
Atmospheric
Chemical Abundances



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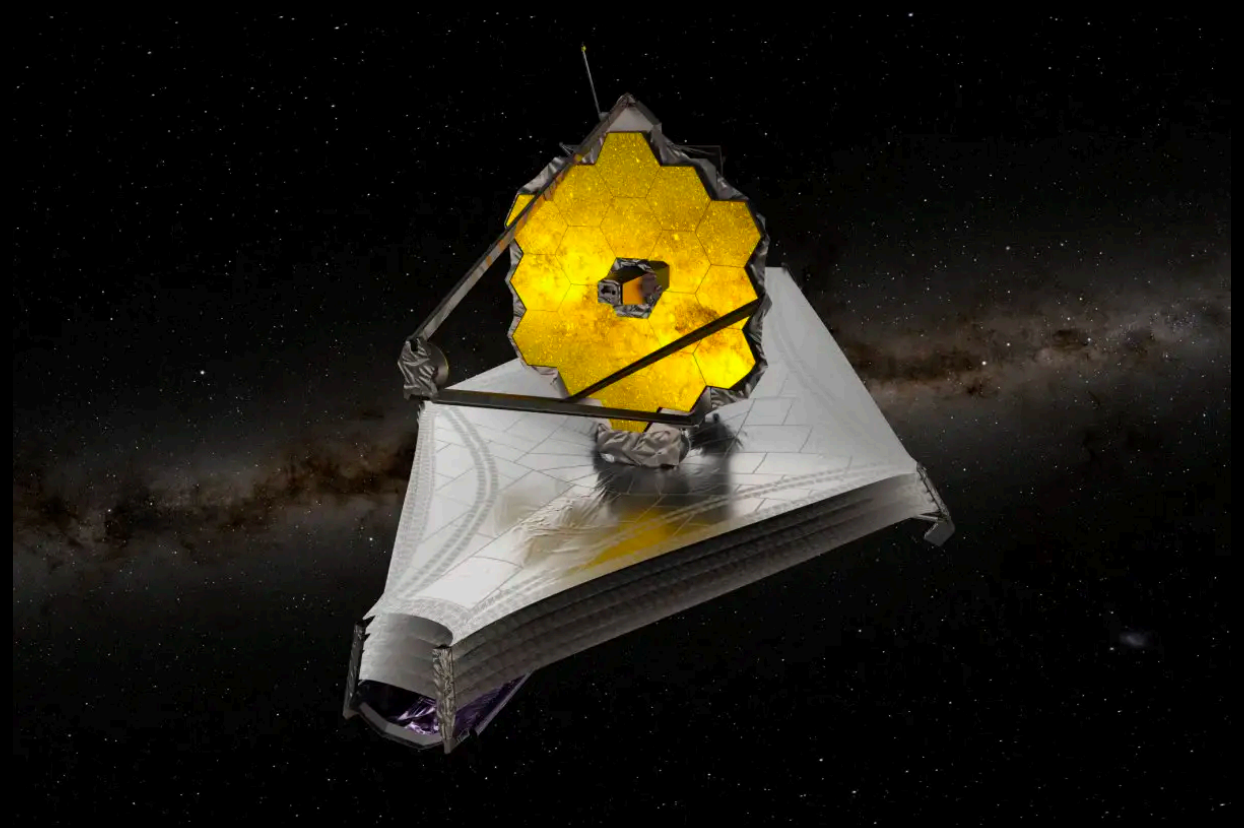

Luminosities
Effective Temperatures

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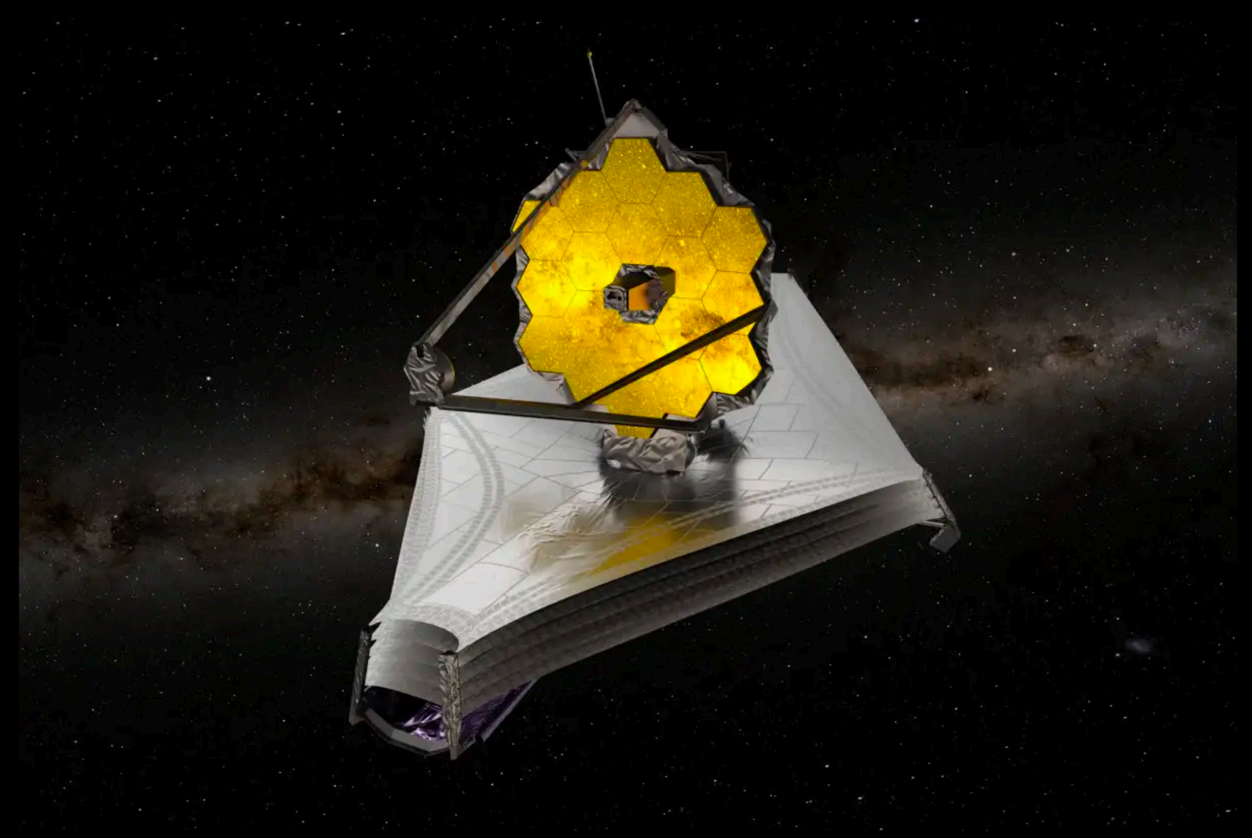

Atmospheric
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Luminosities
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Very Large Atmospheric Model Grids
with varying metallicities, C/O ratios, and Kzz values

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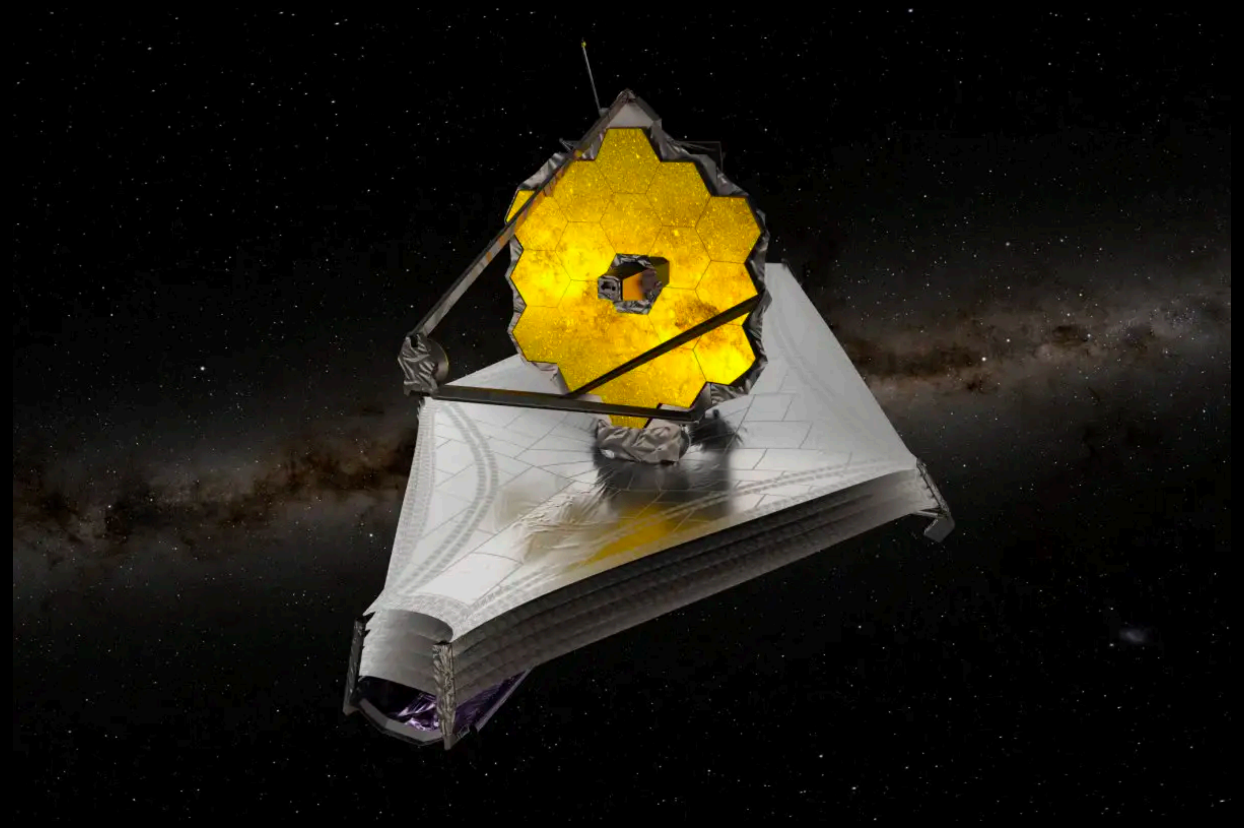
Atmospheric Chemical Abundances

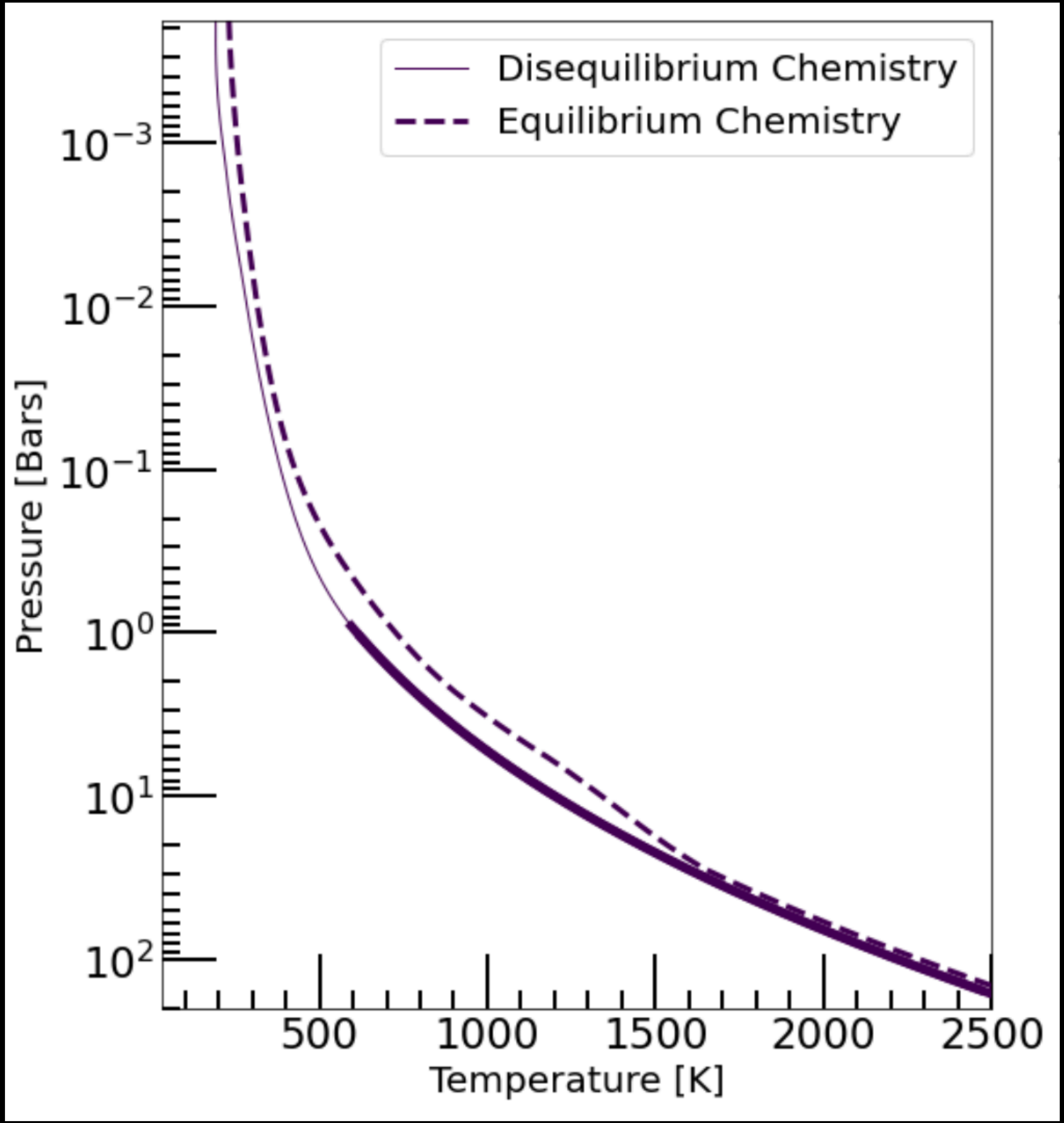


Luminosities Effective Temperatures

Very Large Atmospheric Model Grids with varying metallicities, C/O ratios, and Kzz values

New Generation of evolutionary tracks which are dependant on metallicity, C/O ratio, and Kzz for planets and brown dwarfs

Caution !



Try to avoid post-processing Disequilibrium chemistry on equilibrium chemistry forward models.
This can lead to effective temperature errors of about 100-300 K.

Mukherjee + (2022a)

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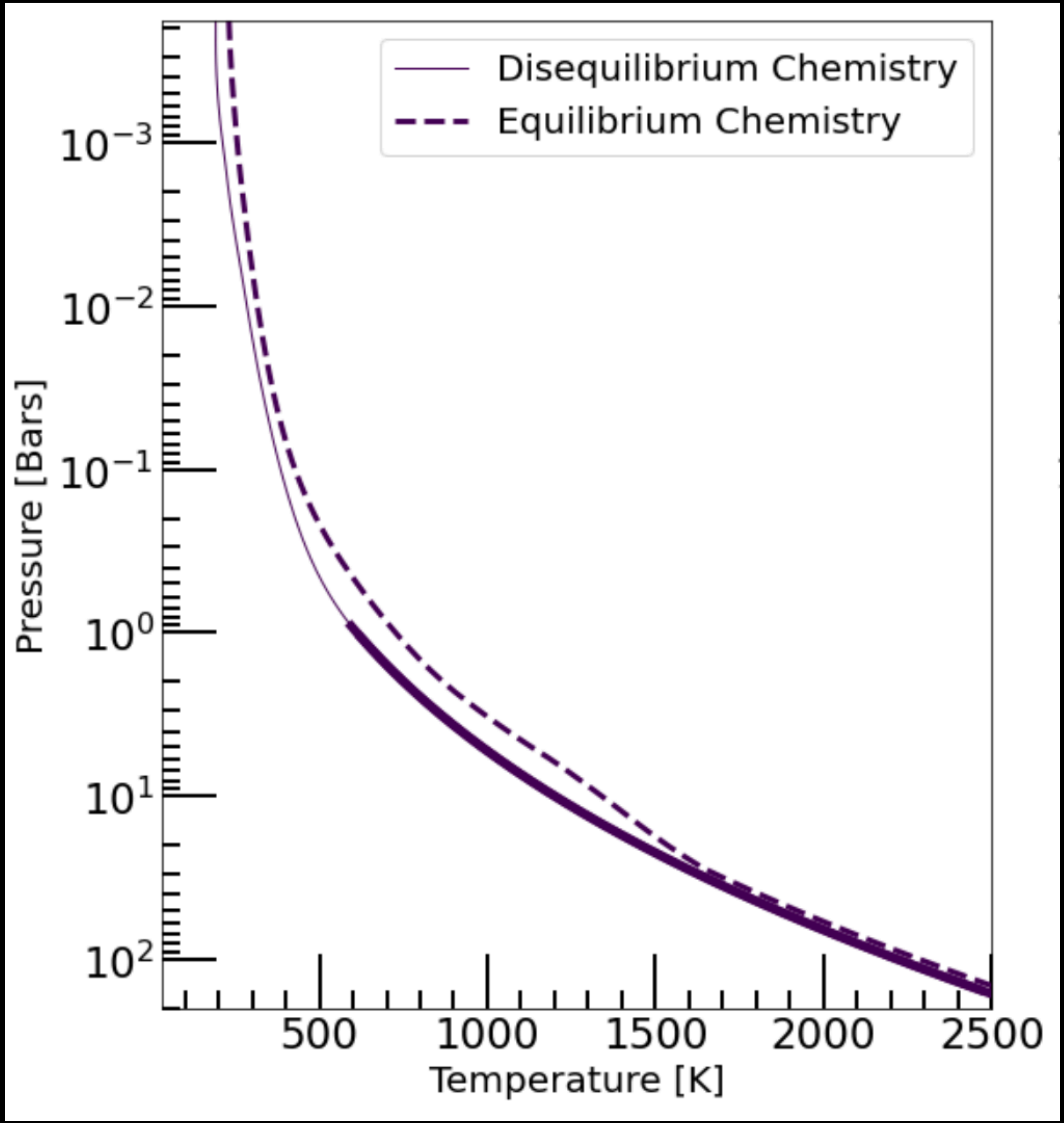

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Use now available self-consistent disequilibrium chemistry models instead.

Mukherjee + (2022a)

1D Model for Substellar Atmospheres

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Temperature structure

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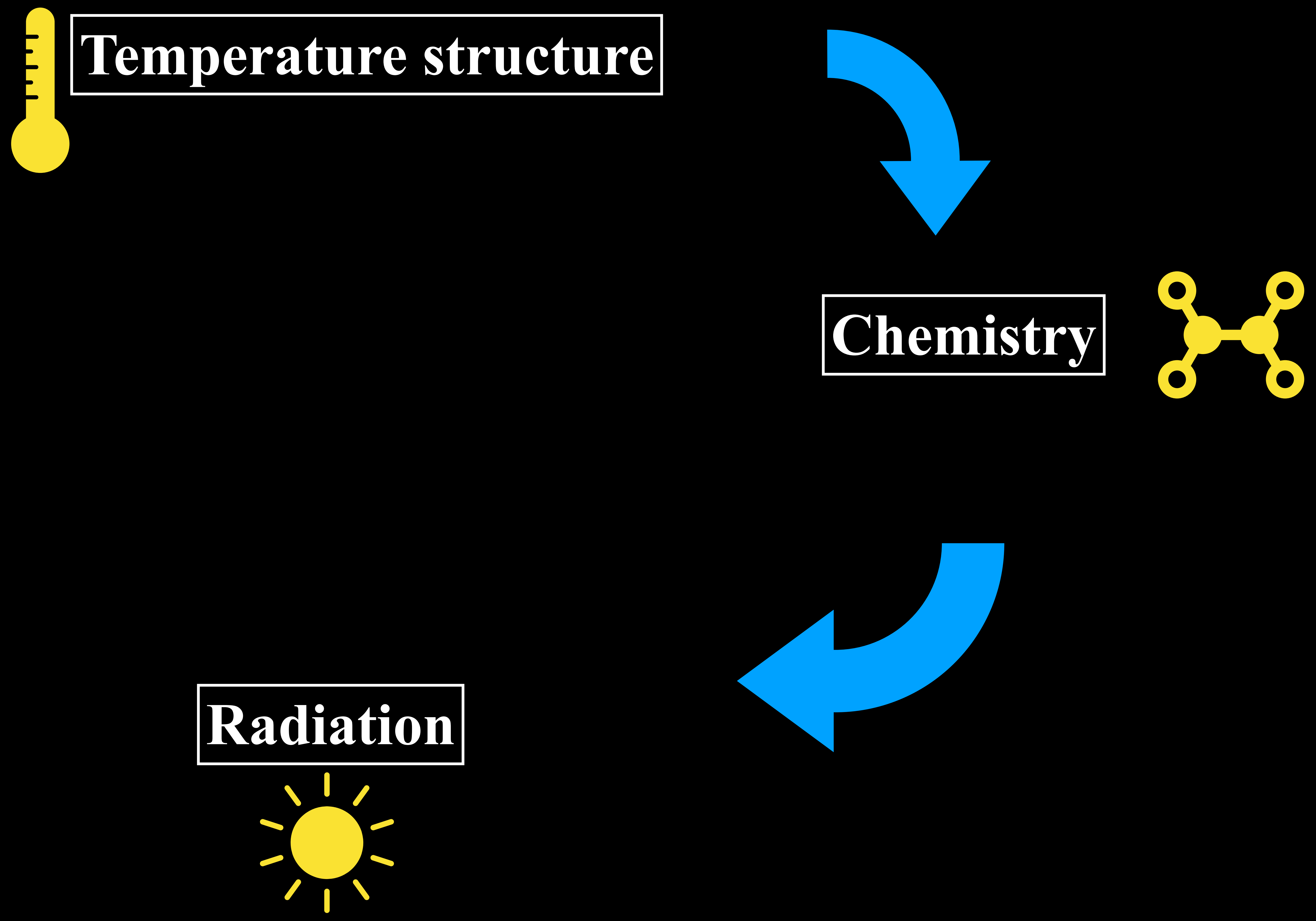
Temperature structure

Chemistry

1D Model for Substellar Atmospheres



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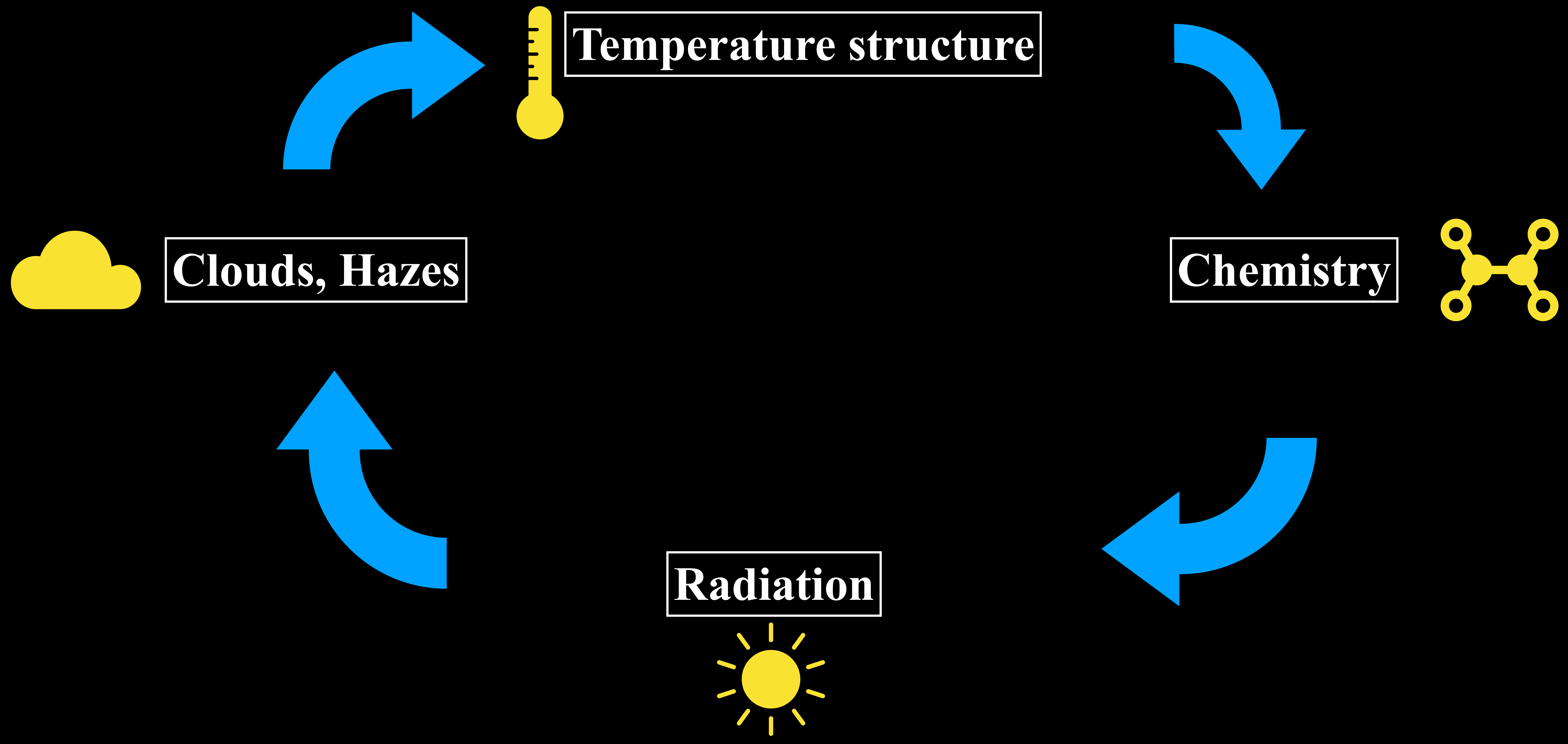

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