Assessment of He I triplet absorption at 10830 Å in escaping atmospheres of hot gaseous exoplanets

Anna Taylor[1], Tommi Koskinen[1], Luca Argenti[2], Nicolas Lewis[2]

[1] The University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, USA
[2] The University of Central Florida, Department of Physics, Orlando, FL 32816, USA

annartaylor@arizona.edu

Introduction

Understanding escape is crucial for exoplanet:

- Demographics and habitability
- Chemical/physical atmospheric processes
- Host star interactions [1]

He I 10830 Å line has been detected on many Hot Jupiters

- Lower level is He metastable (2^3S) state
- Half-life of ~7800 seconds [2]
- Can be observed from the ground
- Proven difficult to interpret

Parker wind models used to interpret transit depths [3,4]

- Models are typically isothermal
- Sub-solar He/H ratios used to fit data [3]

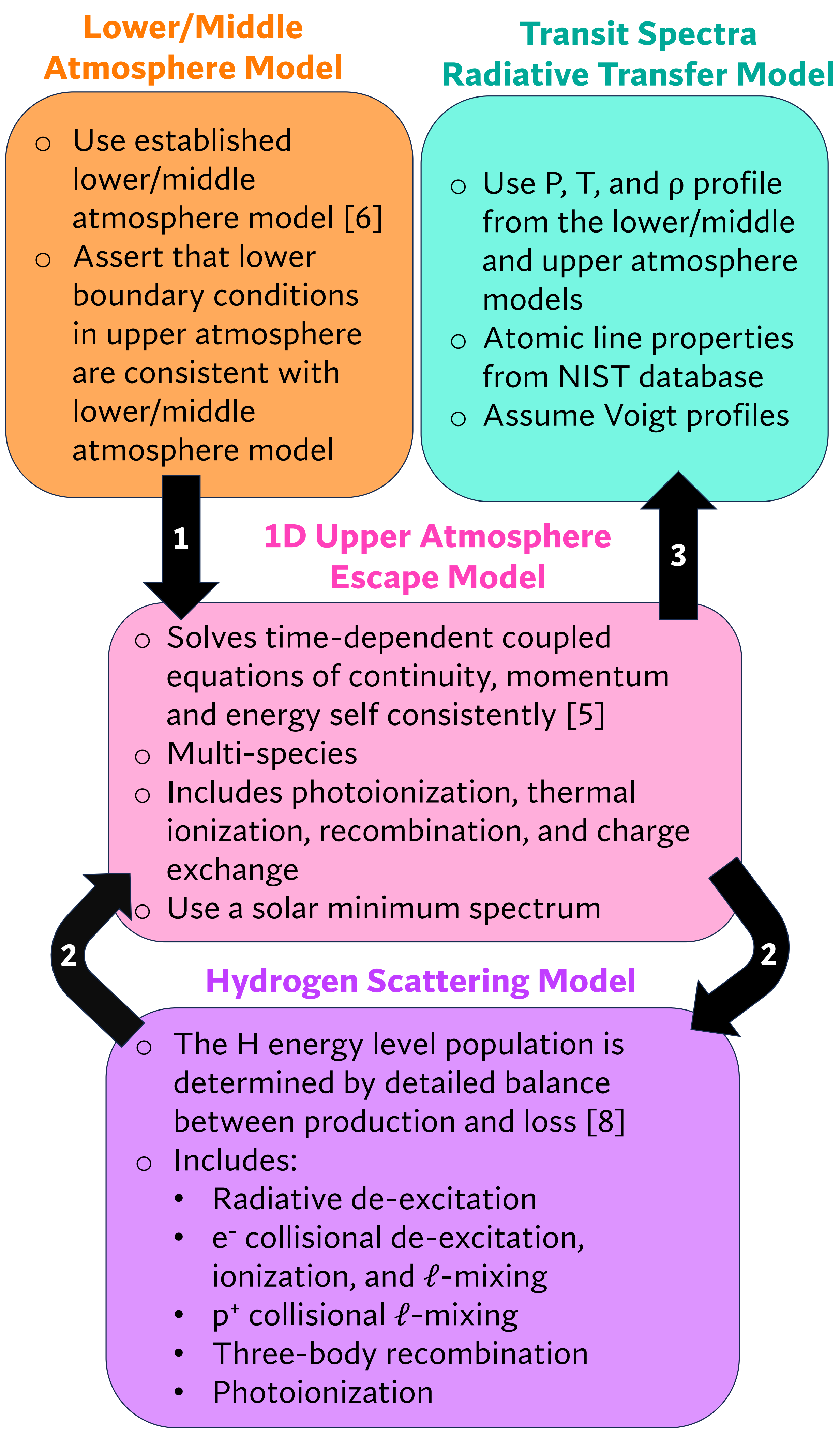
Many models in the literature are using outdated rate coefficients that are updated in this work

We present an updated model of He I (2^3S) transit depth

- Investigate HD209458b - will apply to other systems
- Updated excitation/de-excitation reaction rates
- Include photoelectrons which are the most important production rate in Earth's atmosphere
- Using escape model that is multi-species [5]
- Including modeling for the H I Balmer lines

We successfully fit the He I 10830 Å transit depth with solar He/H ratios, a solar minimum spectra and updated excitation chemistry which we compare to previous excitation chemistry [3, 9, 10]

Model



Lower/Middle Atmosphere Model

- Use established lower/middle atmosphere model [6]
- Assert that lower boundary conditions in upper atmosphere are consistent with lower/middle atmosphere model

Transit Spectra Radiative Transfer Model

- Use P, T, and ρ profile from the lower/middle and upper atmosphere models
- Atomic line properties from NIST database
- Assume Voigt profiles

1D Upper Atmosphere Escape Model

- Solves time-dependent coupled equations of continuity, momentum and energy self consistently [5]
- Multi-species
- Includes photoionization, thermal ionization, recombination, and charge exchange
- Use a solar minimum spectrum

Hydrogen Scattering Model

- The H energy level population is determined by detailed balance between production and loss [8]
- Includes:
  - Radiative de-excitation
  - e^- collisional de-excitation, ionization, and ℓ-mixing
  - p^+ collisional ℓ-mixing
  - Three-body recombination
  - Photoionization

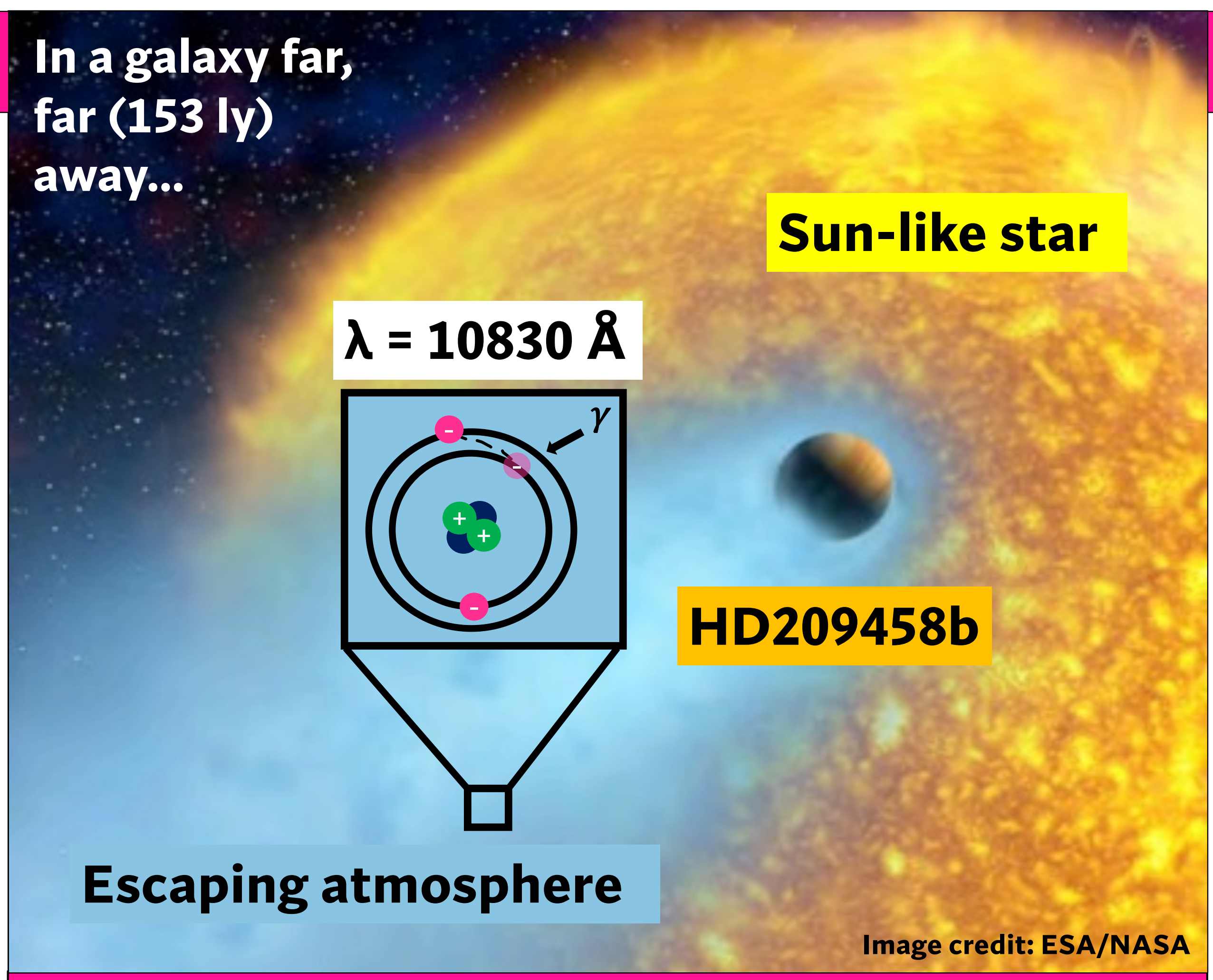


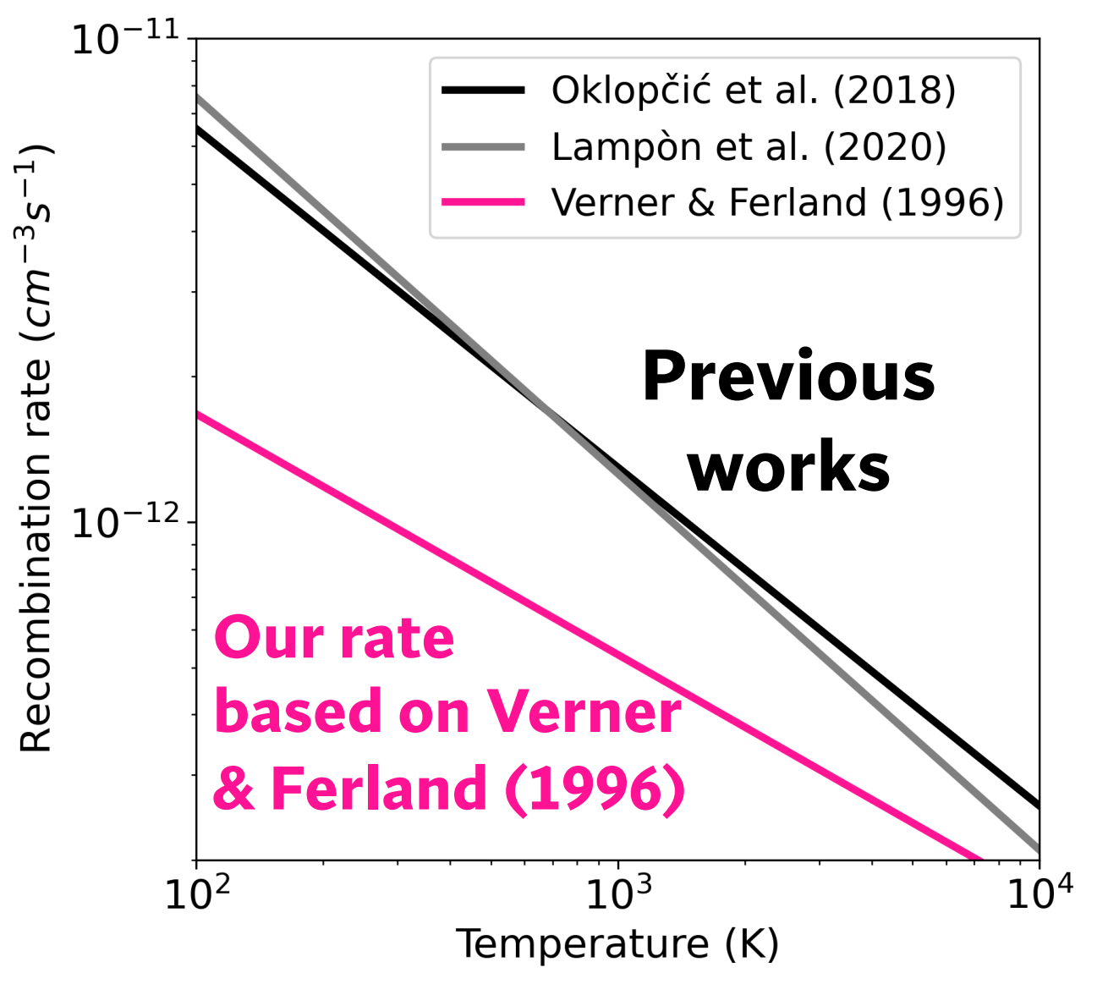
Image credit: ESA/NASA

He I (2^3S) Chemistry

Name	Formula
Recombination	$He^+ + e^- \rightarrow He(2^3S)$
Photoelectron Collisions	$He(1^1S) + e^* \rightarrow He(2^3S)$
Electron Collisions	$He(1^1S) + e^- \rightarrow He(2^3S) + e^-$
Penning Ionization	$He(2^3S) + H \rightarrow He(1^1S) + H^+ + e$
Electron Collisions	$He(2^3S) + e^- \rightarrow He(2^1S) + e^-$
Photoionization	$He(2^3S) + h\nu \rightarrow He^+ + e^-$
Radiative Decay	$He(2^3S) \rightarrow He(1^1S)$
Electron Collisions	$He(2^3S) + e^- \rightarrow He(2^1P) + e^-$
Electron De-excitation	$He(2^3S) + e^- \rightarrow He(1^1S) + e^-$
Proton De-excitation	$He(2^3S) + H^+ \rightarrow He(1^1S) + H^+$

🟦 = Not included in other exoplanet studies, 🟨 = Updated

Excitation/De-excitation reaction rates in previous models need revisions

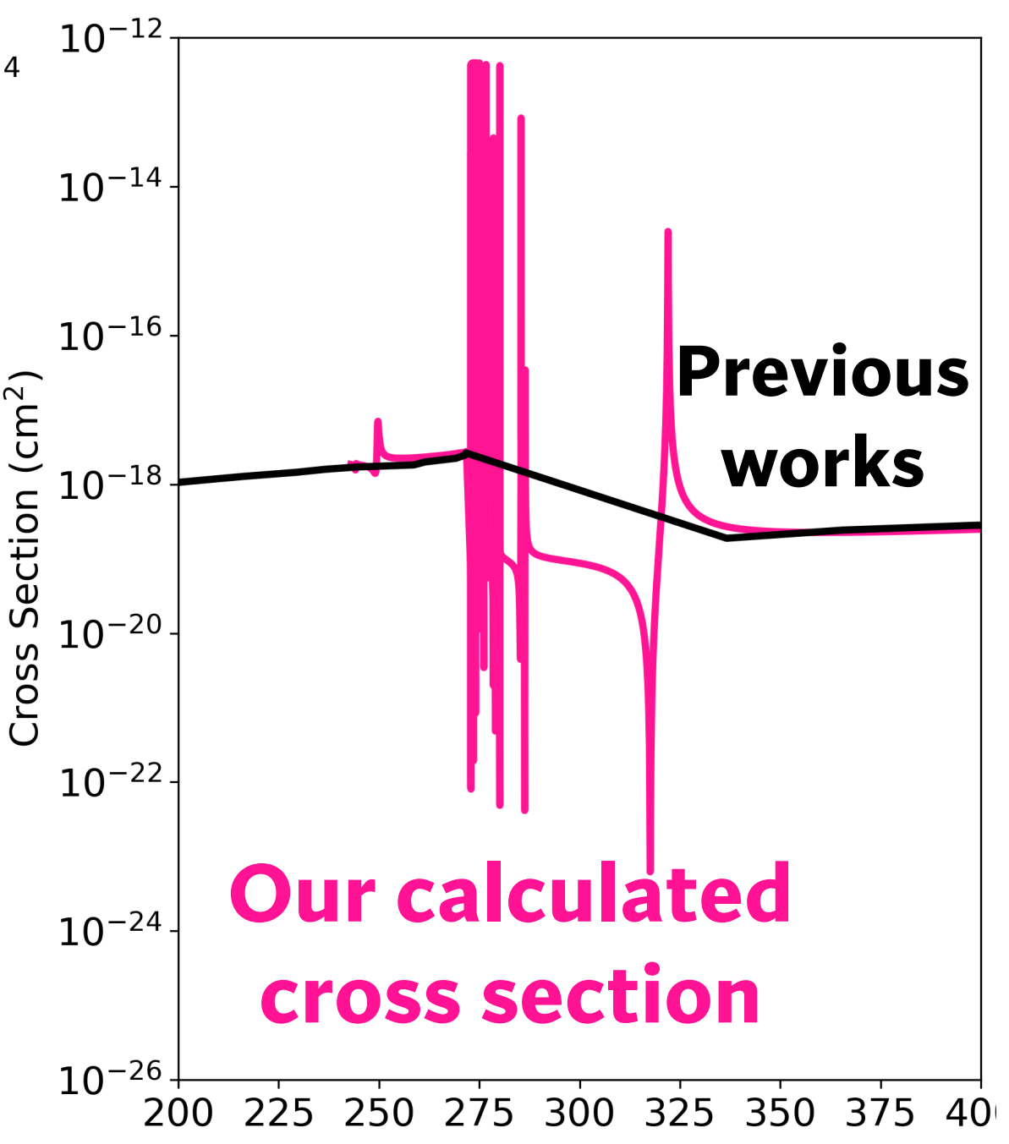


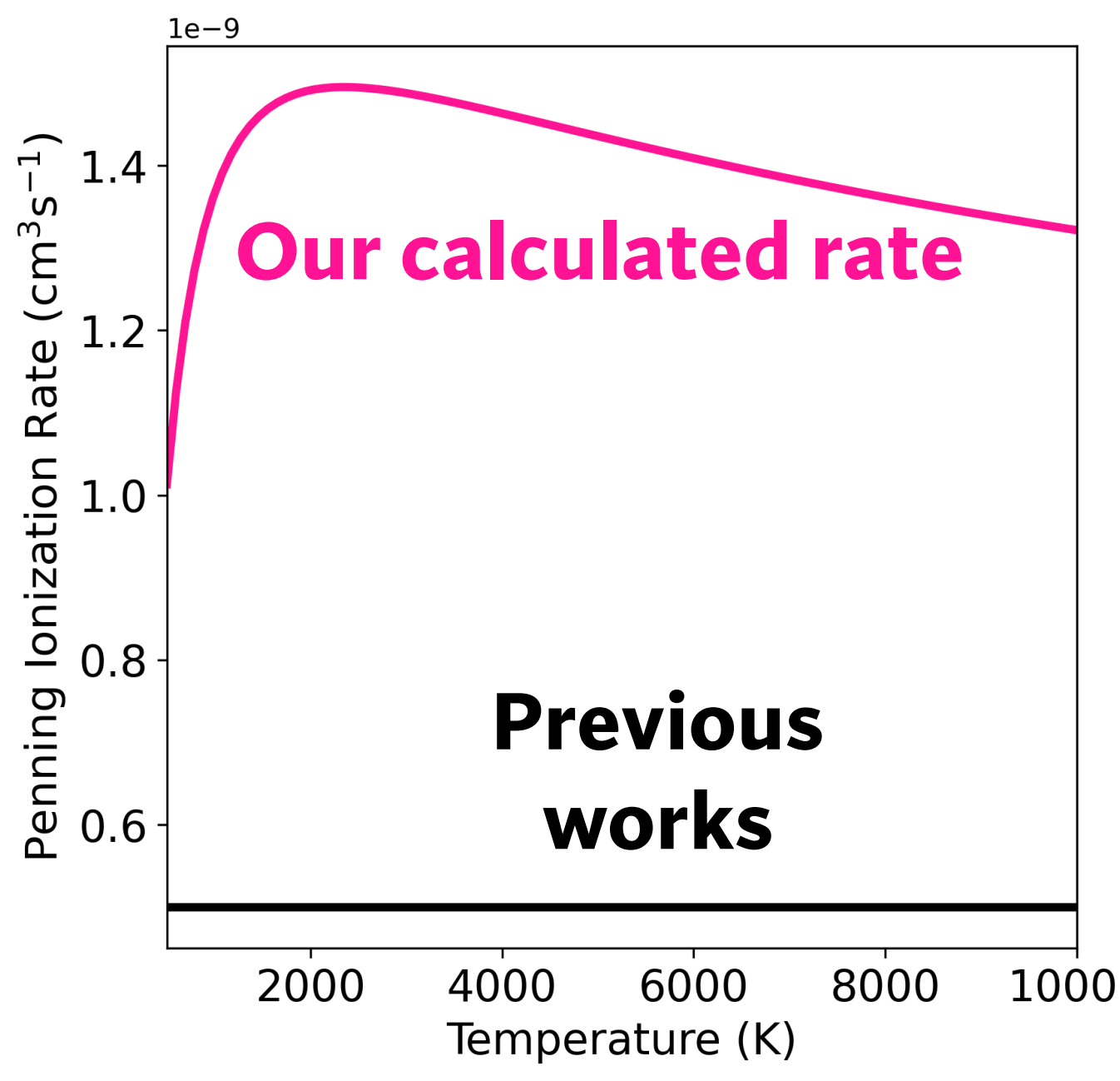
Recombination Rates

- Differ significantly
- We use a sum of Verner & Ferland (1996) recombination rates to the triplet states

Photoionization Cross Section

- Previous works use fits to Norcross (1971) which only has ~20 points and ignores resonances
- We include high resolution cross section calculated at UCF





Penning Ionization Rates

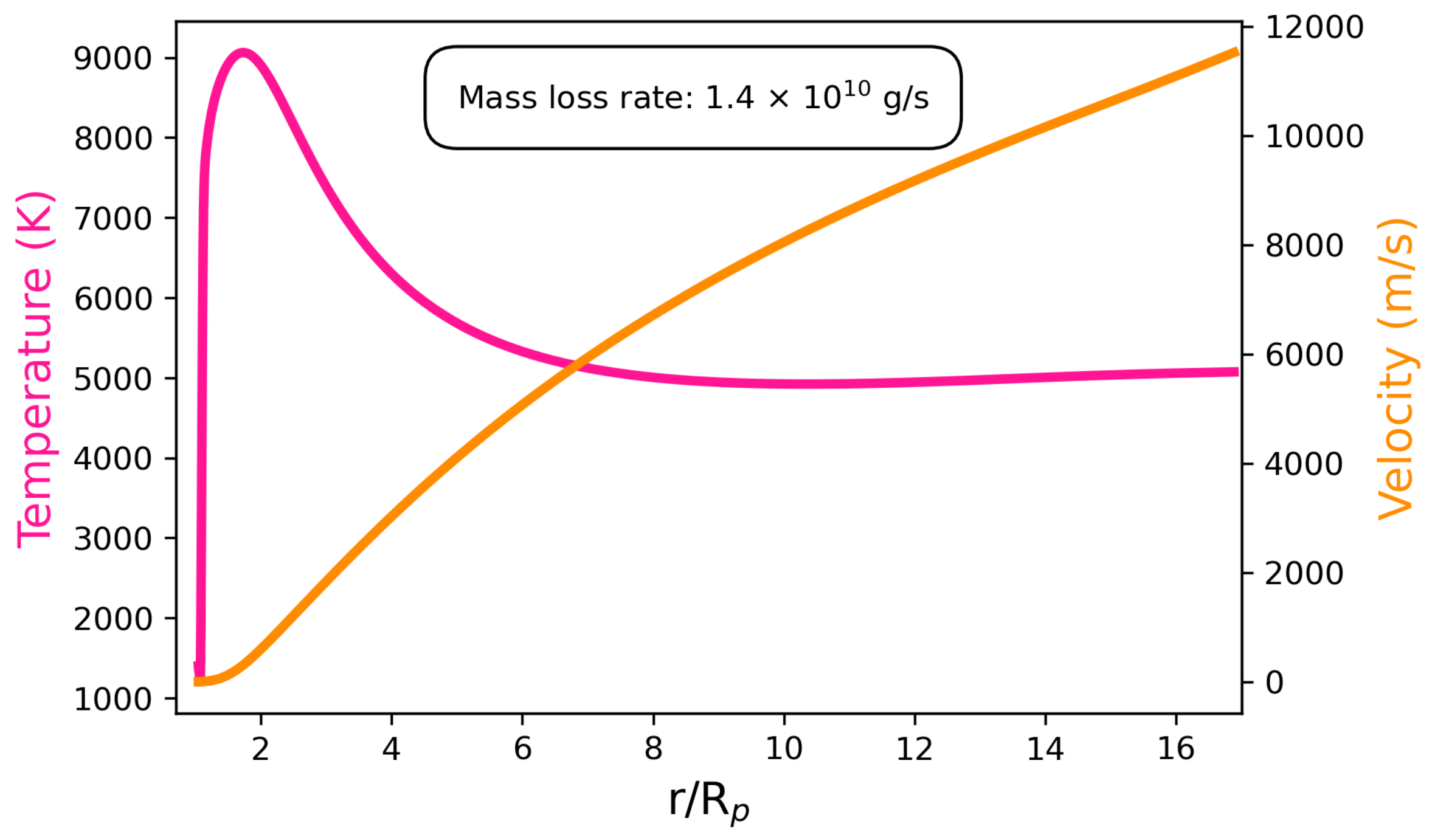
- Other works use a constant rate (5×10^{-10})
- We use available cross sections to derive a temperature-dependent rate

These changes to the reaction rates significantly reduce the He I (2^3S) population

Results

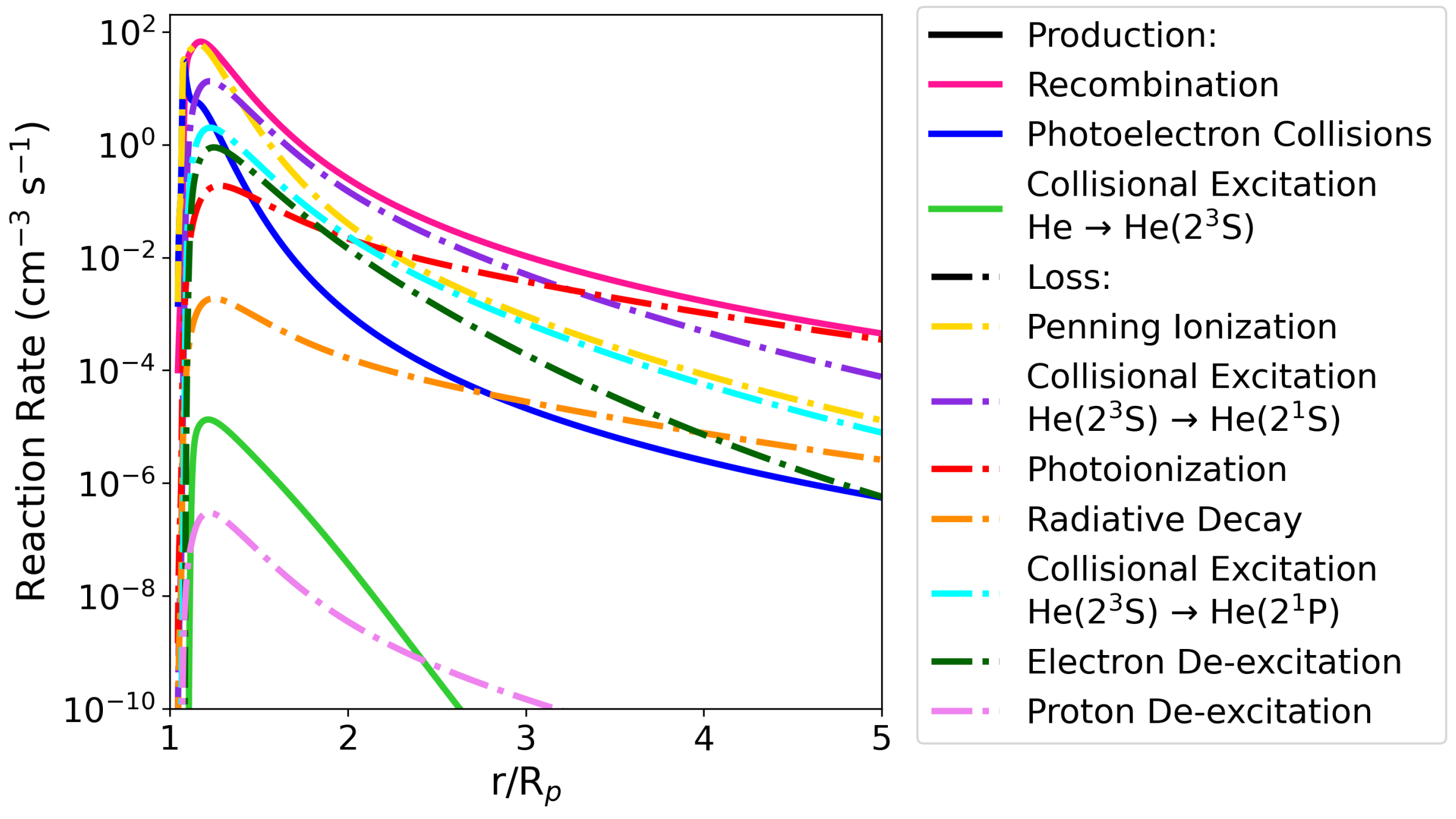
Temperature and Bulk Velocity vs. radius

- Temperature peaks at ~9000 K at r/R_p ~ 1.7
- Velocity is ~11000 m/s at top of atmosphere



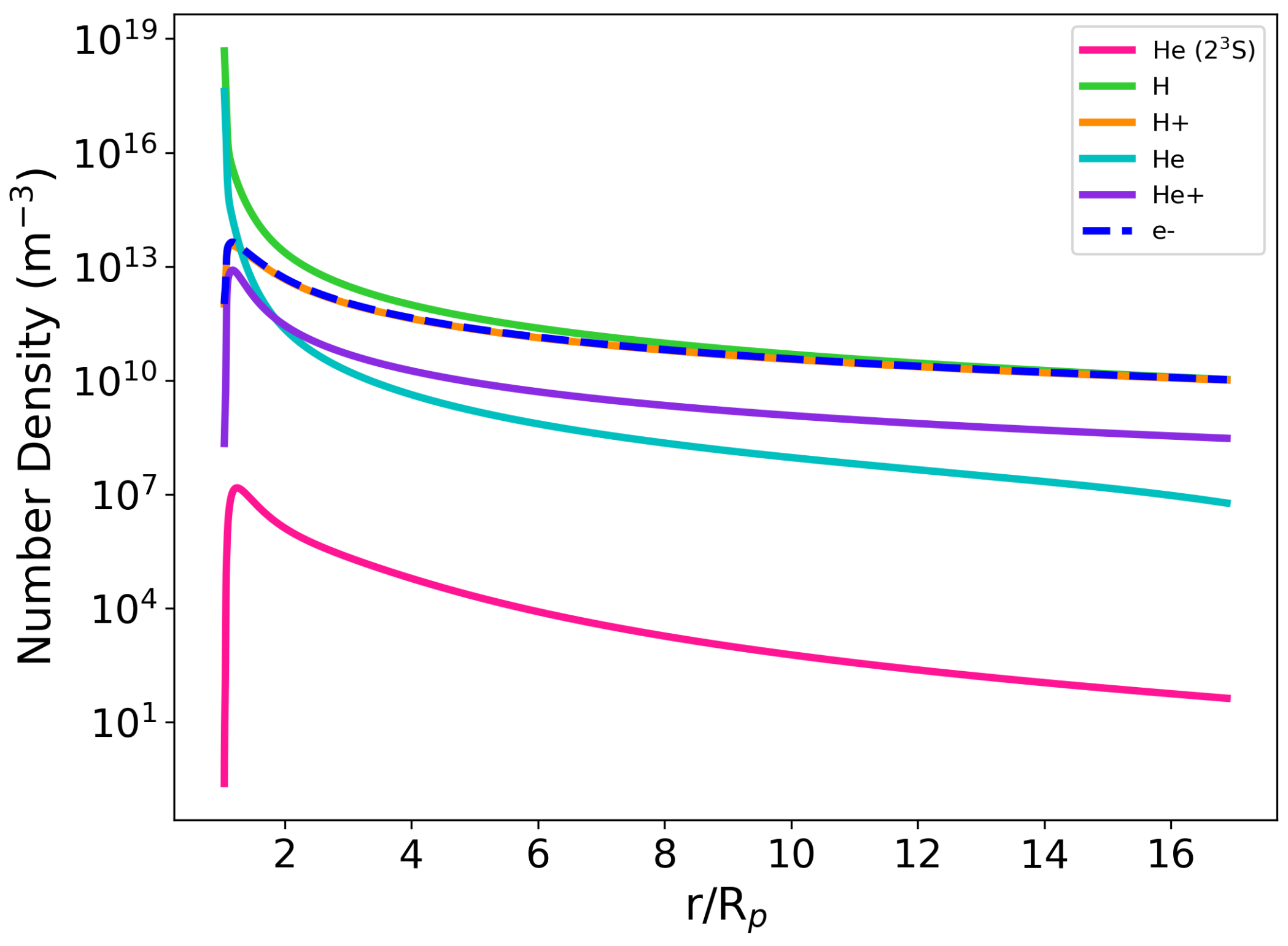
Reaction Rates vs. radius

- Recombination dominates production as expected
- Penning Ionization dominates loss $r/R_p < 1.5$
- Collisional Excitation dominates loss $1.5 < r/R_p < 3.25$
- Photoionization dominates loss $r/R_p > 3.25$



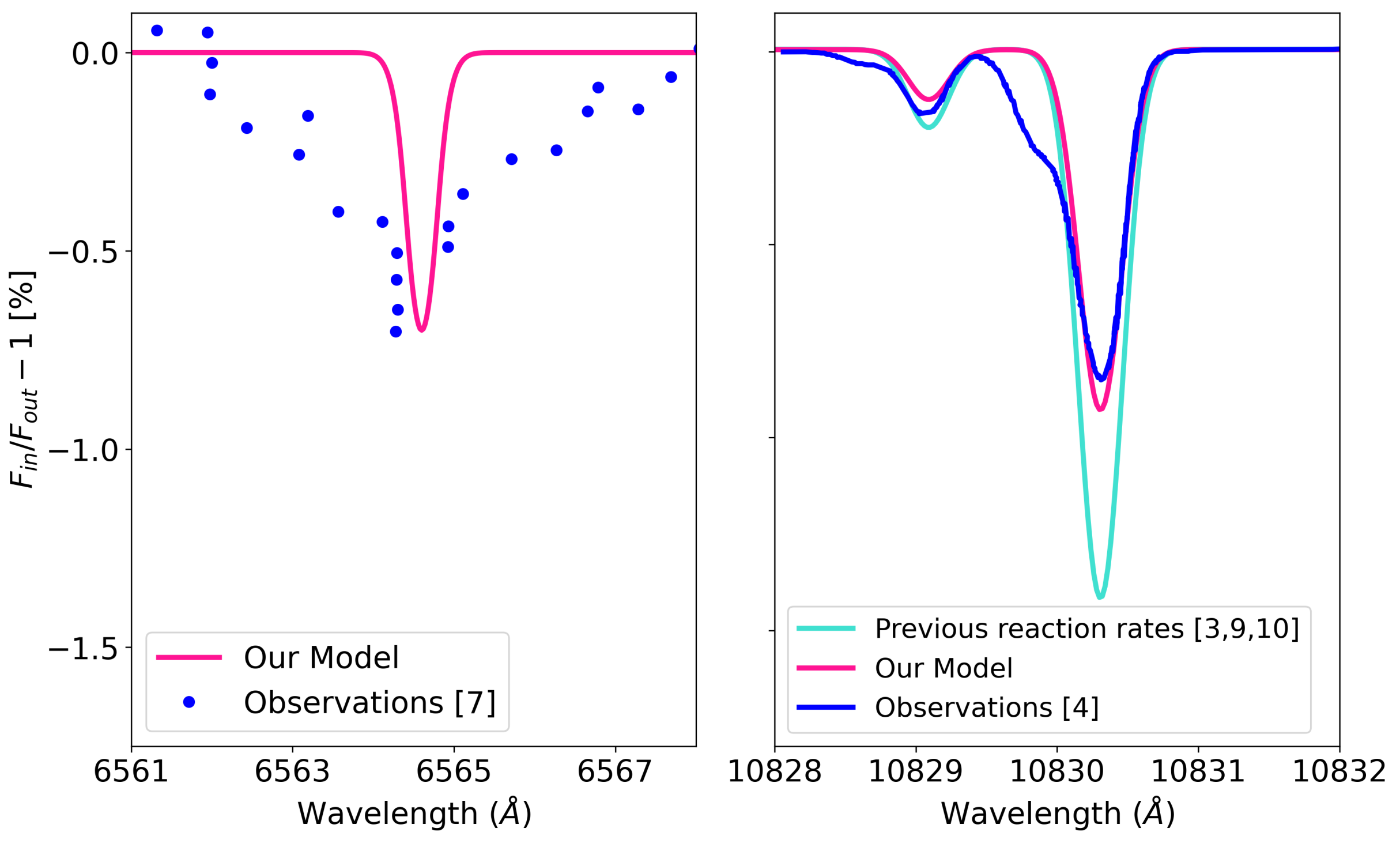
Number Density of major species vs. radius

- Updated reaction rates affects the density of He I (2^3S)



Transit depths

- We agree with He I (2^3S) observations with a solar He/H ratio, solar minimum spectrum, including lower/middle atmosphere, and updated excitation chemistry
- Some models have agreed with the data but with isothermal and H/He ratio assumptions [3, 4, 10]
- We also agree with data for the H I Balmer line [7]



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