Vibrationally excited H_2 mutes the He I triplet line at 1.08 μm on warm exo-Neptunes

(& on sub-Neptunes !)

Antonio García Muñoz

CEA Paris-Saclay, France

Sub-Neptunes are very interesting because…

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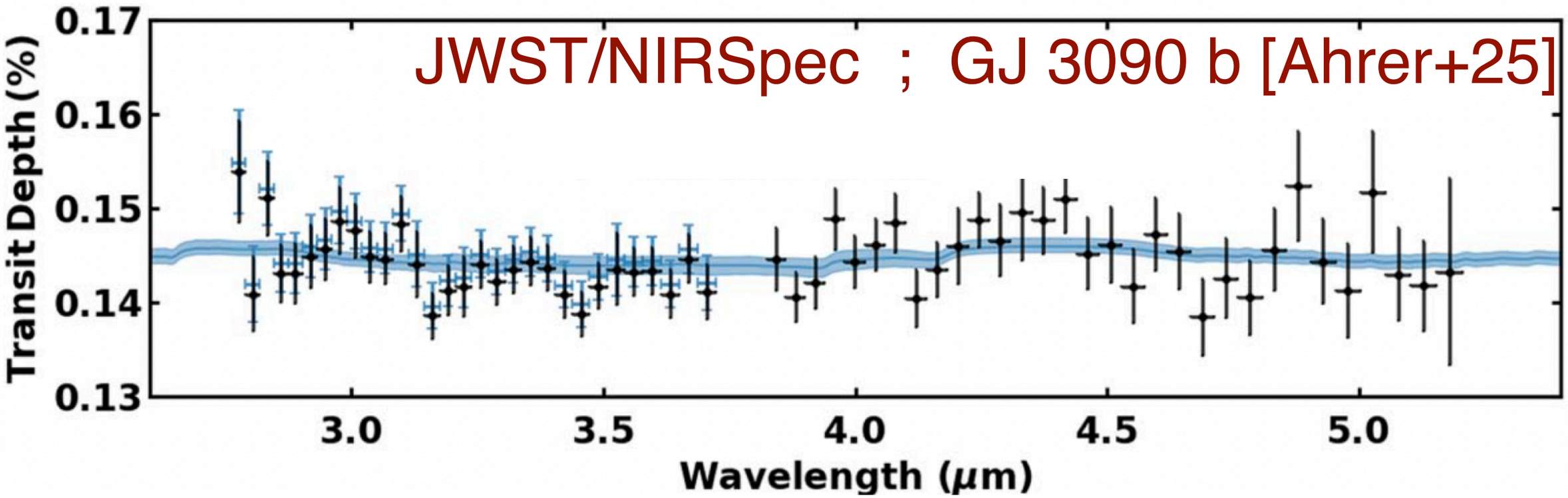
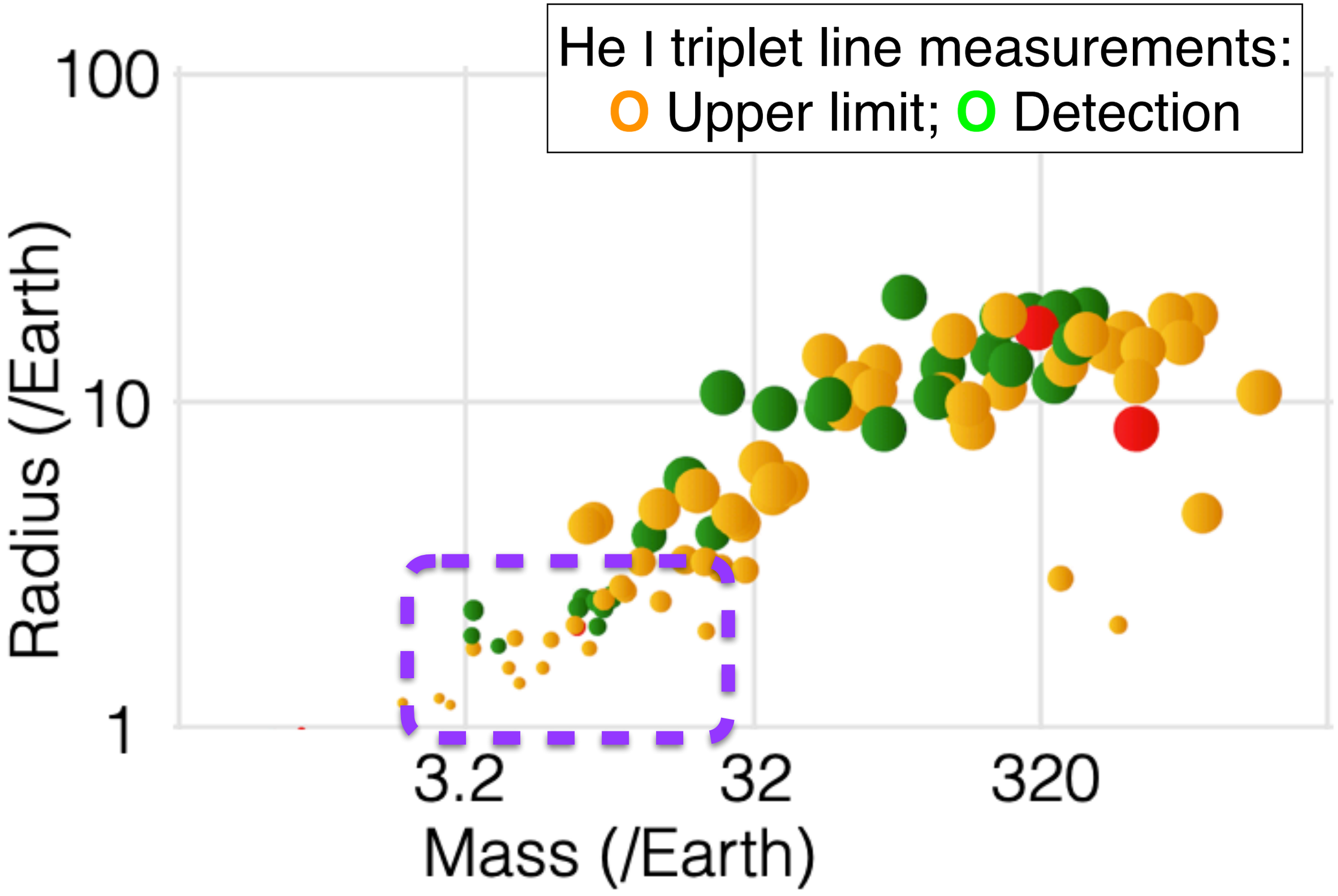
But they also like to keep their secrets away…



With (happily) some exceptions,
e.g. the **He I triplet line at 1.08 μm**



Formation of the He I triplet line at 1.08 μm

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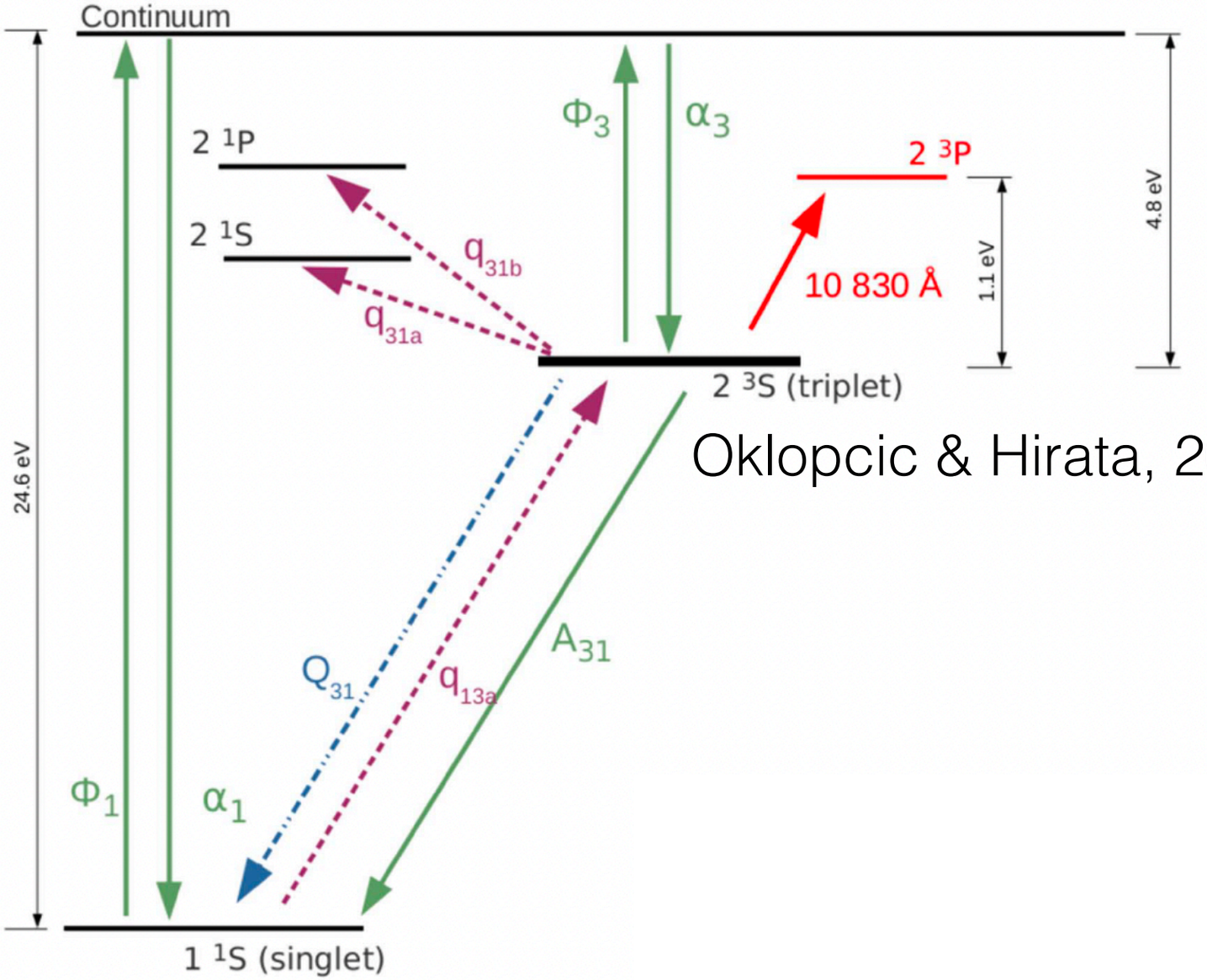

Oklopcic & Hirata, 2018

He

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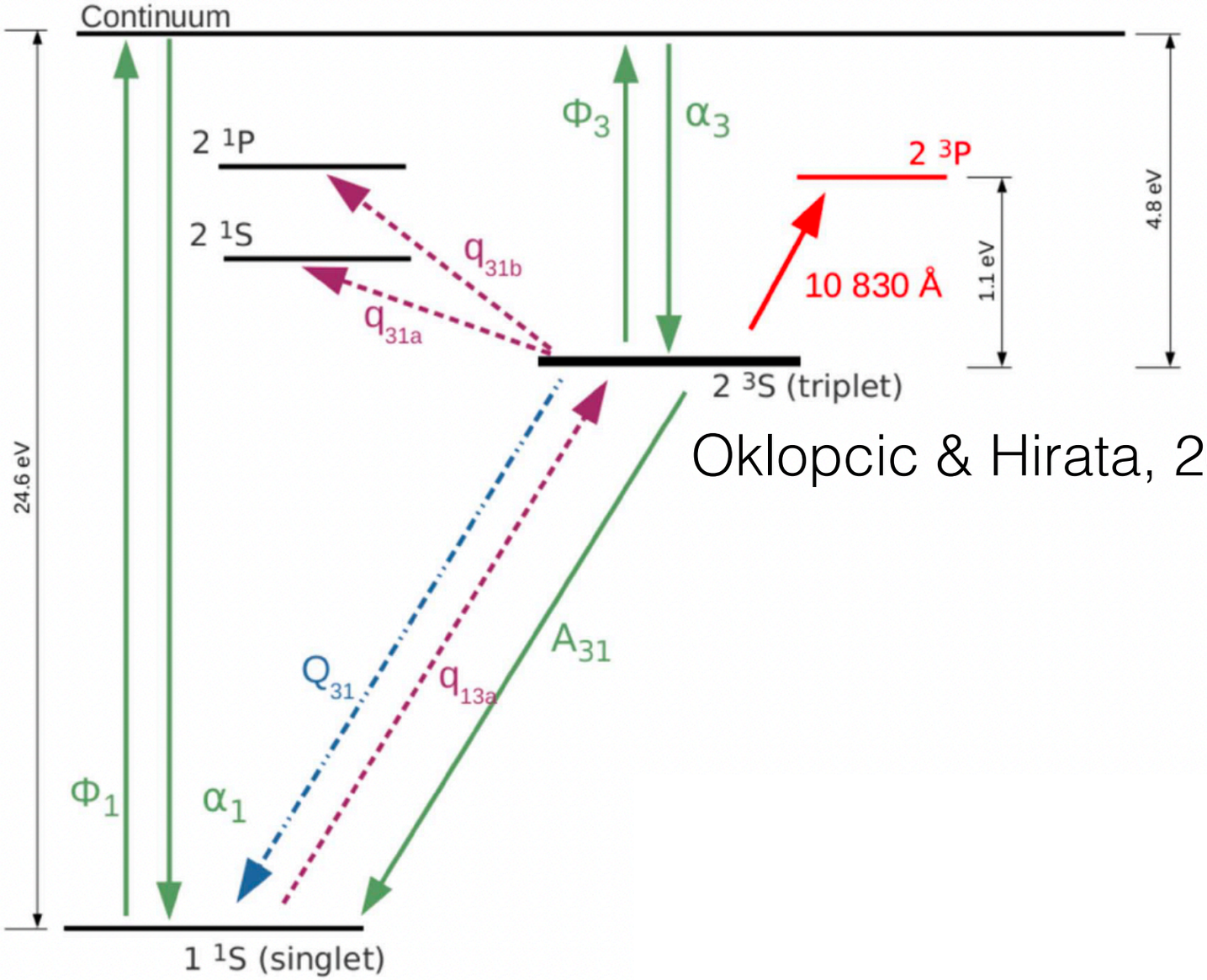

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Classical view:
low-density atomic H gas

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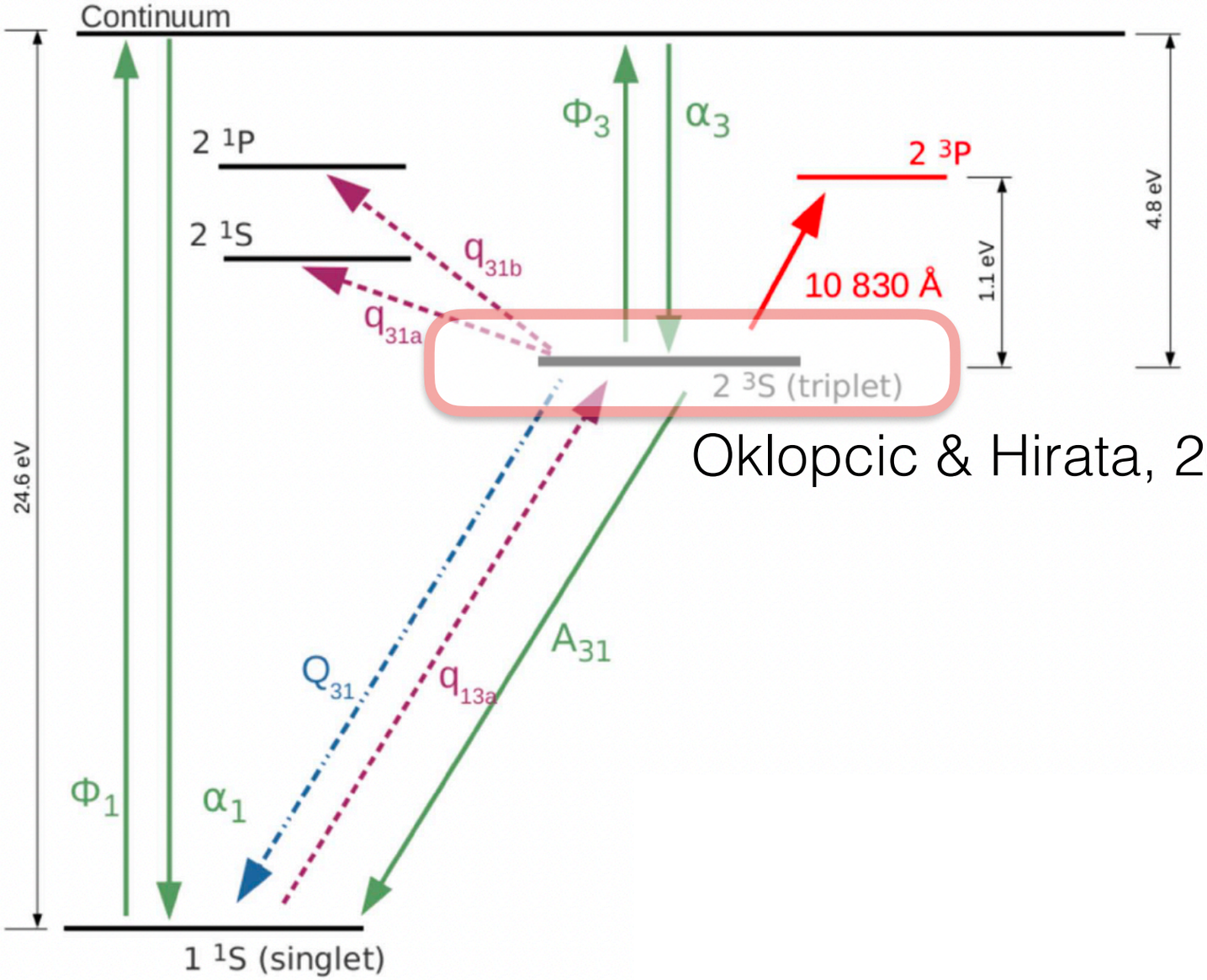

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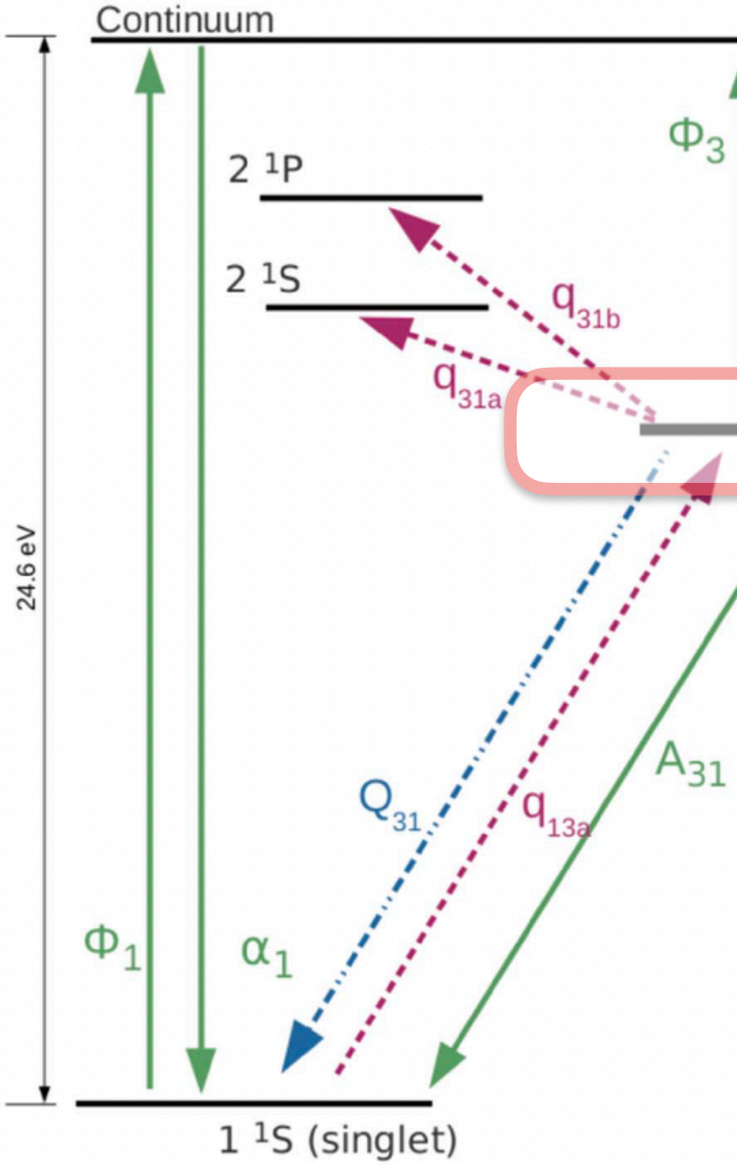

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Classical view:
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Some questions to myself. Effect of:

#1) Photoelectrons [GM25].

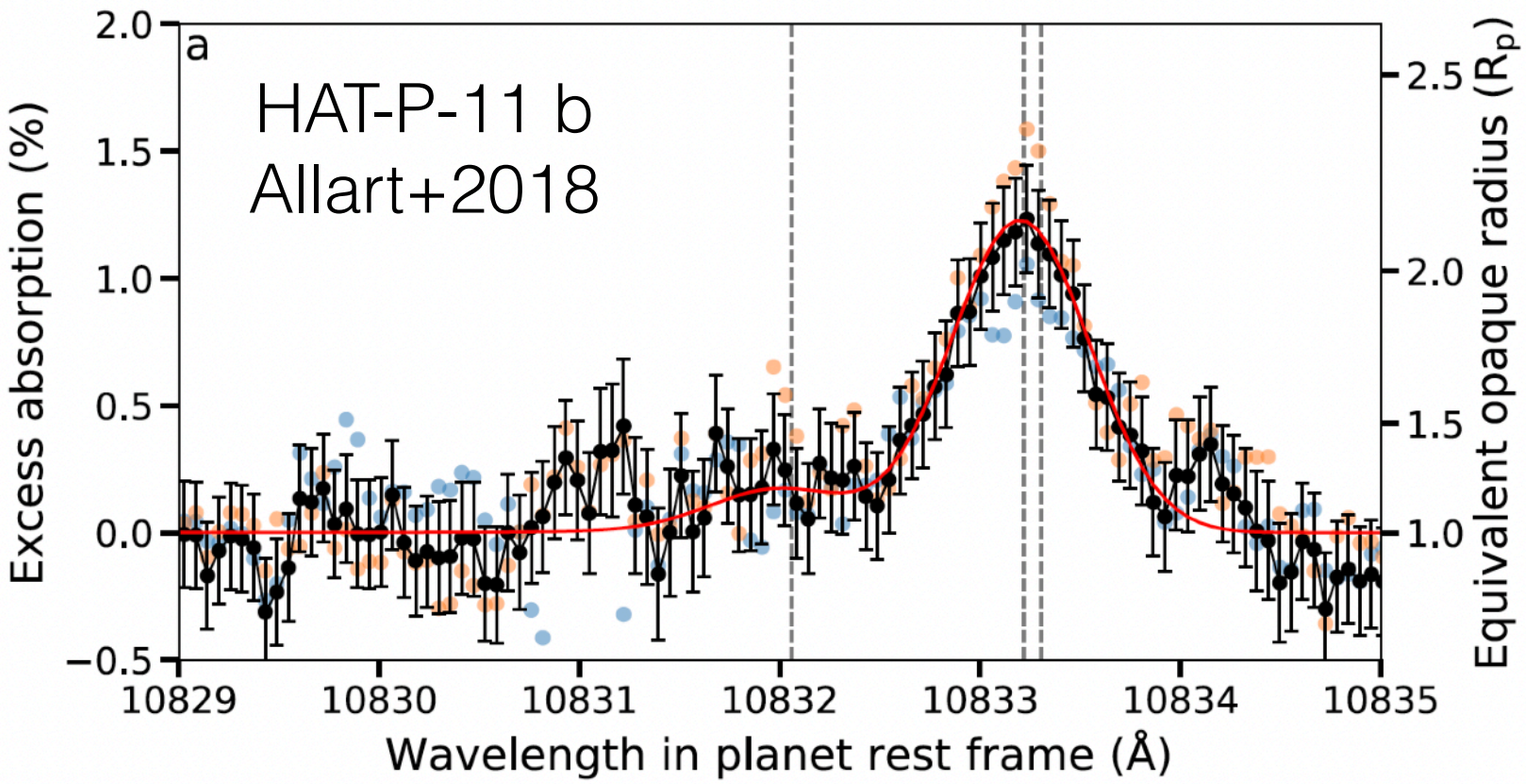
#2) Molecularity of the gas [GM+25].

#3) Metal chemistry [GM, *in prep.*].

#4) Radiative transfer in the lines.

“Molecularity”

The line traces the upper atmosphere, up to a few R_p.



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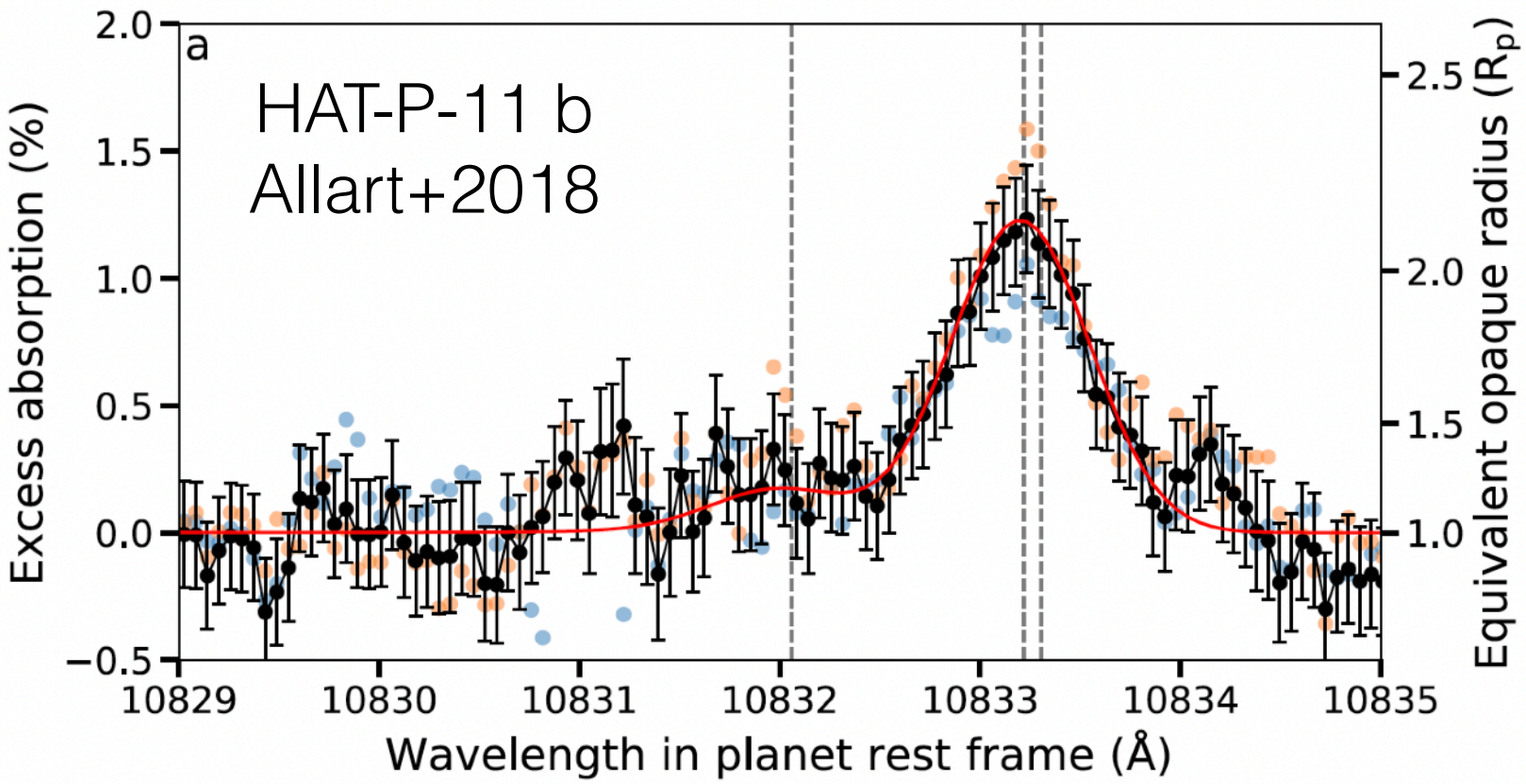

Bulk gas may or may not have transitioned from H_2 into H.

Is that important at all?

Built a molecular network [GM, A&A, 2025]

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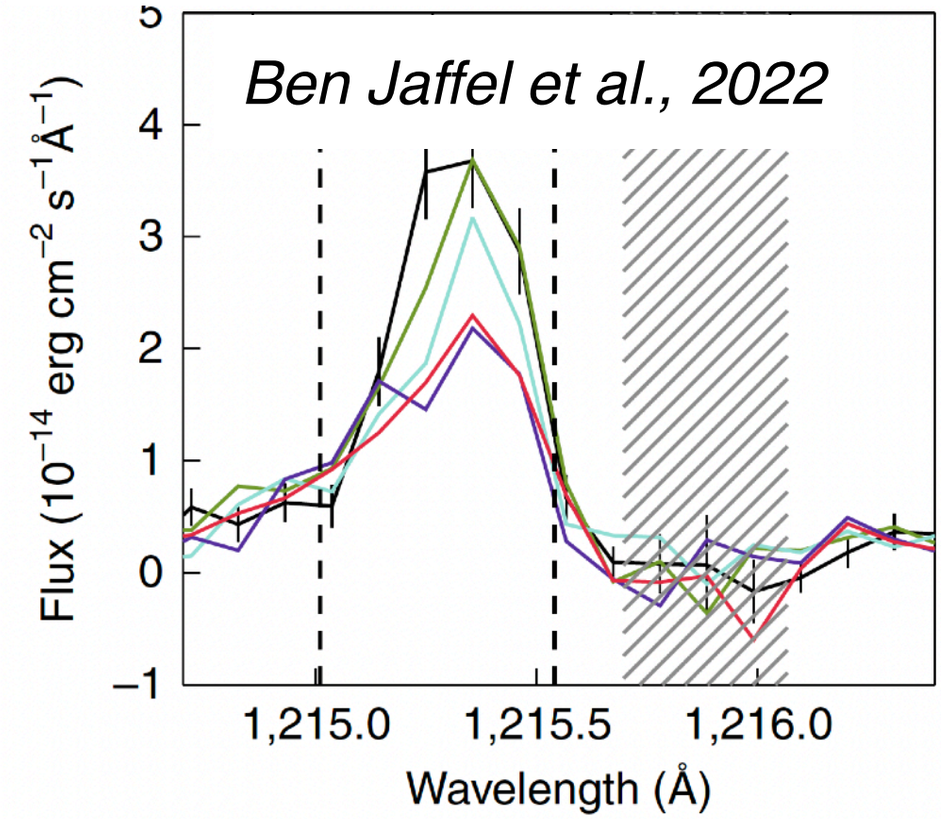

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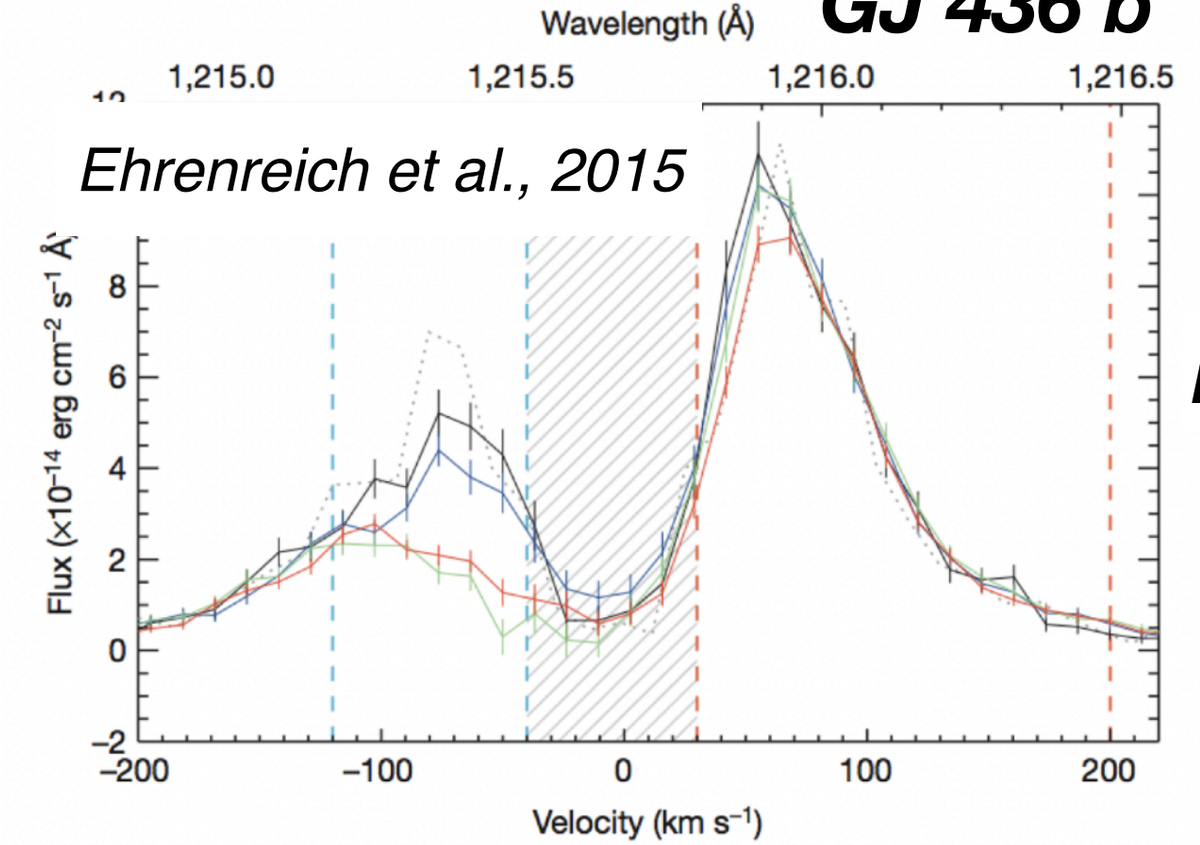
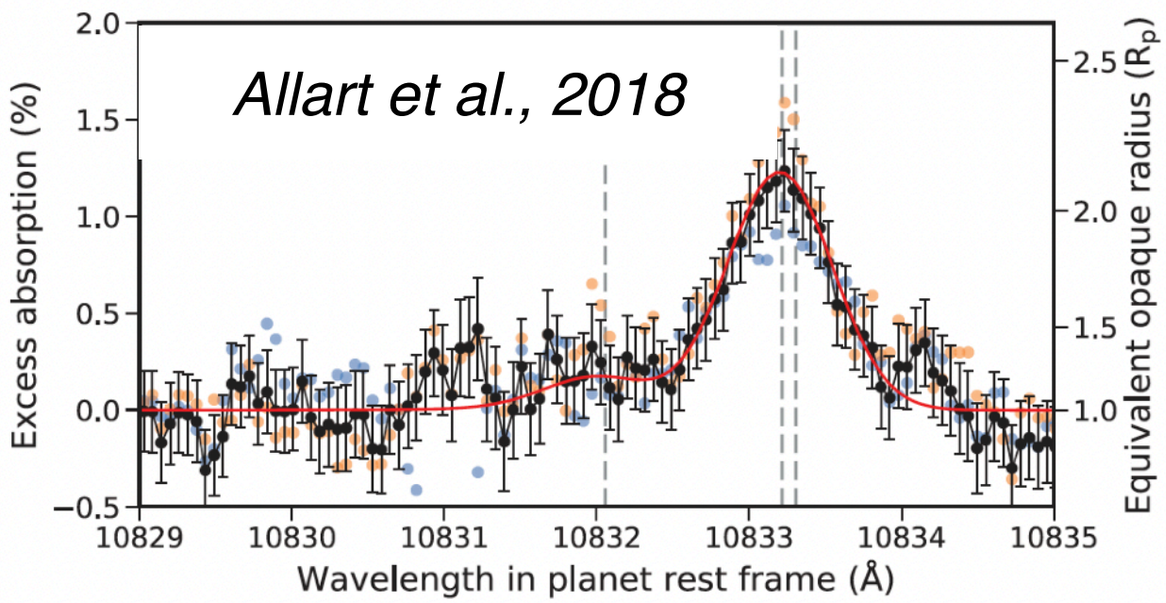
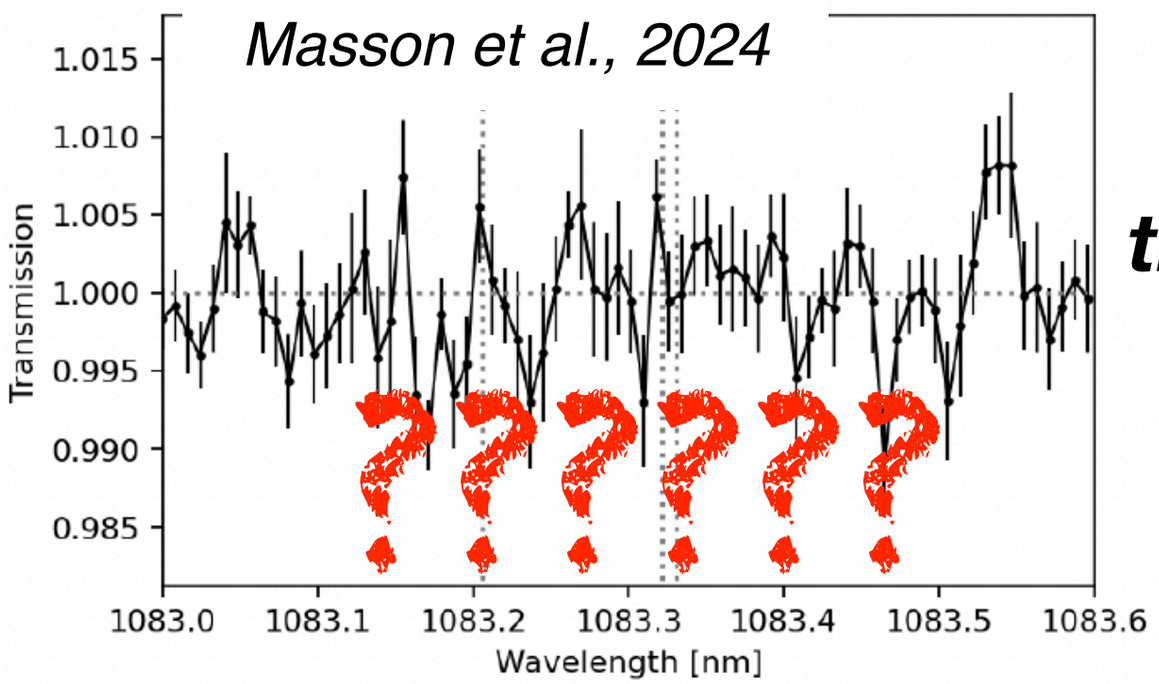


Ly-α

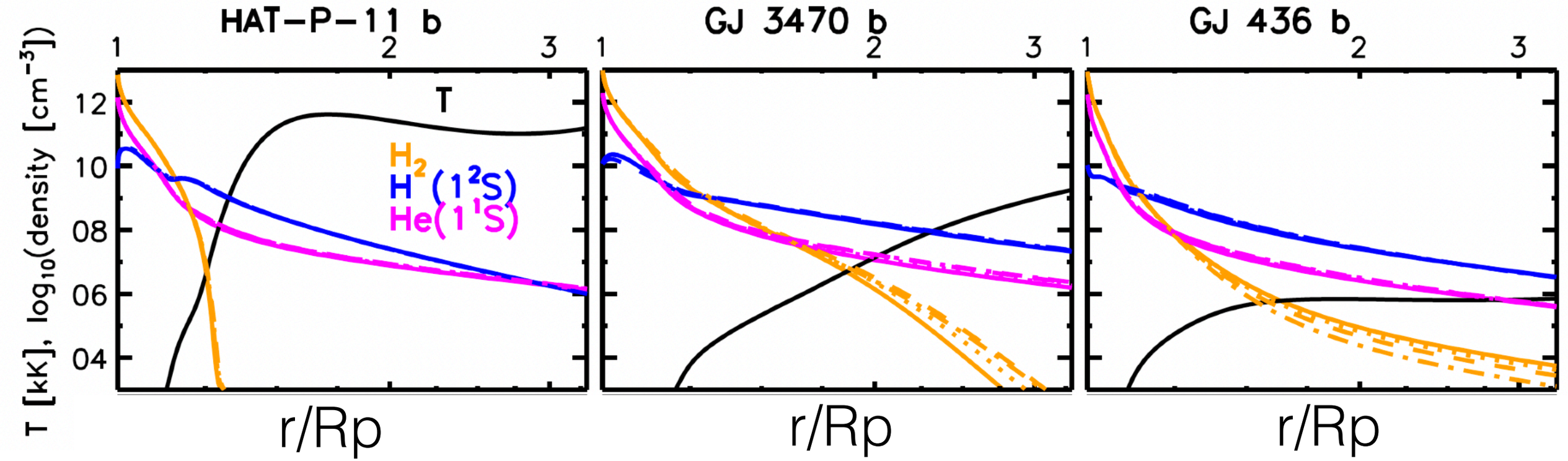




He triplet

Finding 1:

H_2 transitions into H differently at each planet



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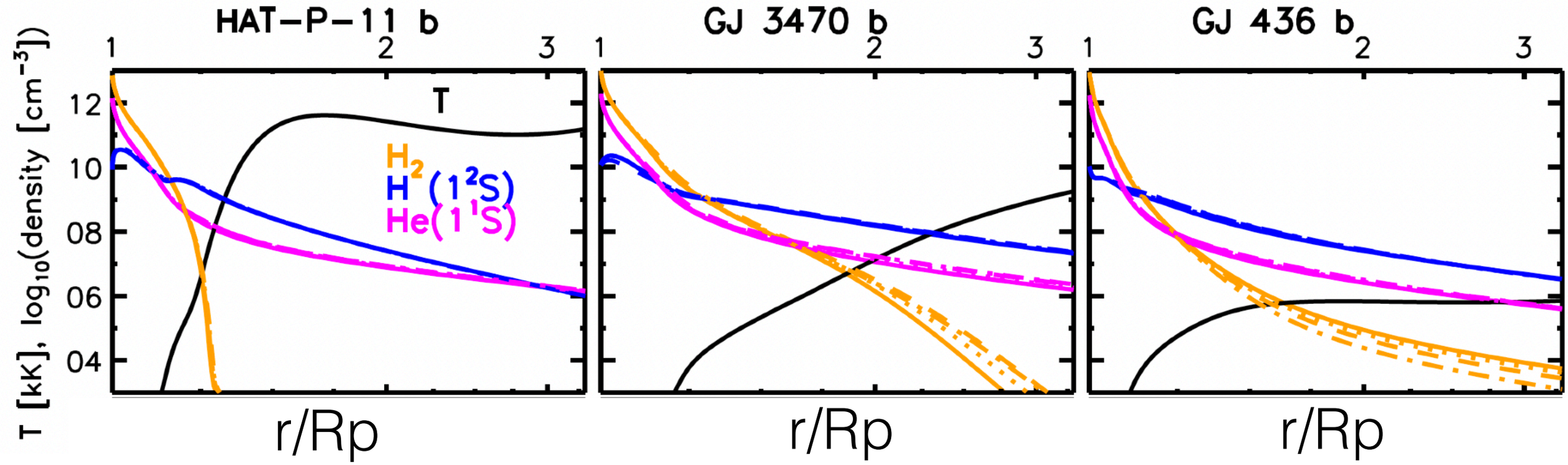

Transition specifics are connected to XUV & FUV stellar fluxes

Distance	Stellar flux [erg cm^{-2}s^{-1}] over the specified bands						
	0-100 Å	0-228 Å	0-504 Å	0-912 Å	912-1200	1214-1220 Å	912-2600 Å
HAT-P-11 b	299	647	3229	11907	4644	2512	20590
GJ 3470 b	762	1044	2029	2642	461	4239	5988
GJ 436 b	53	70	127	278	70	895	1316

Finding 2:

$He^+ + H_2\,(v) \rightarrow He + H + H^+$

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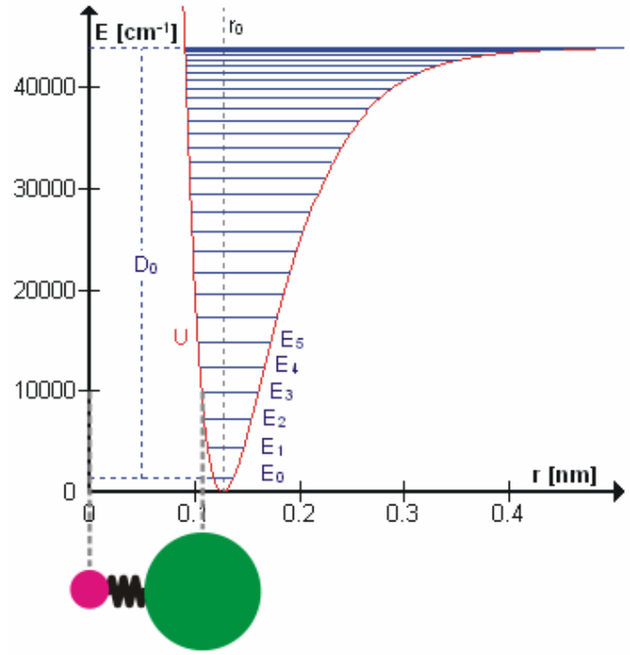

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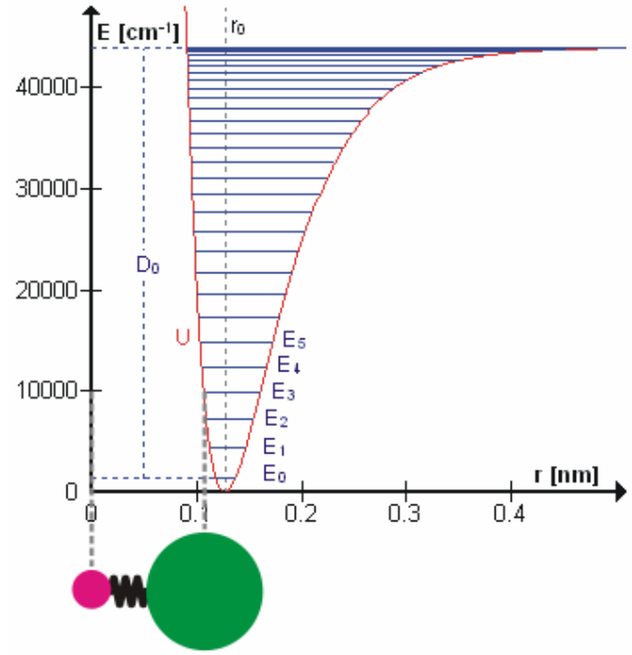

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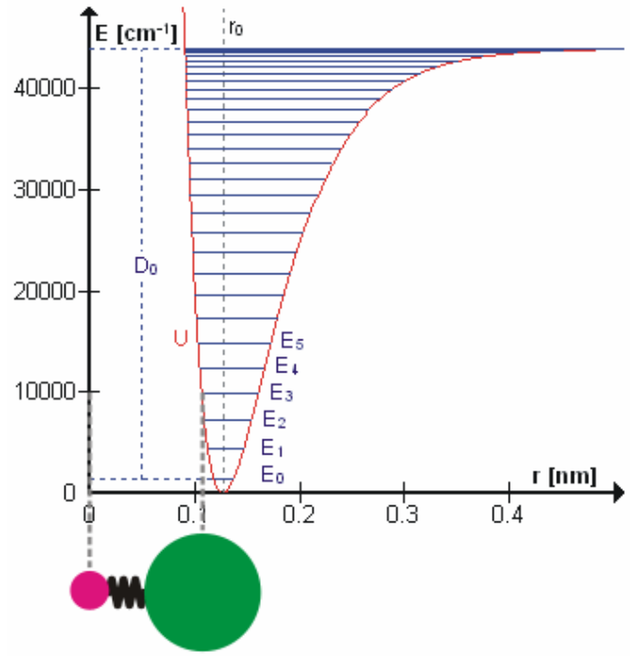

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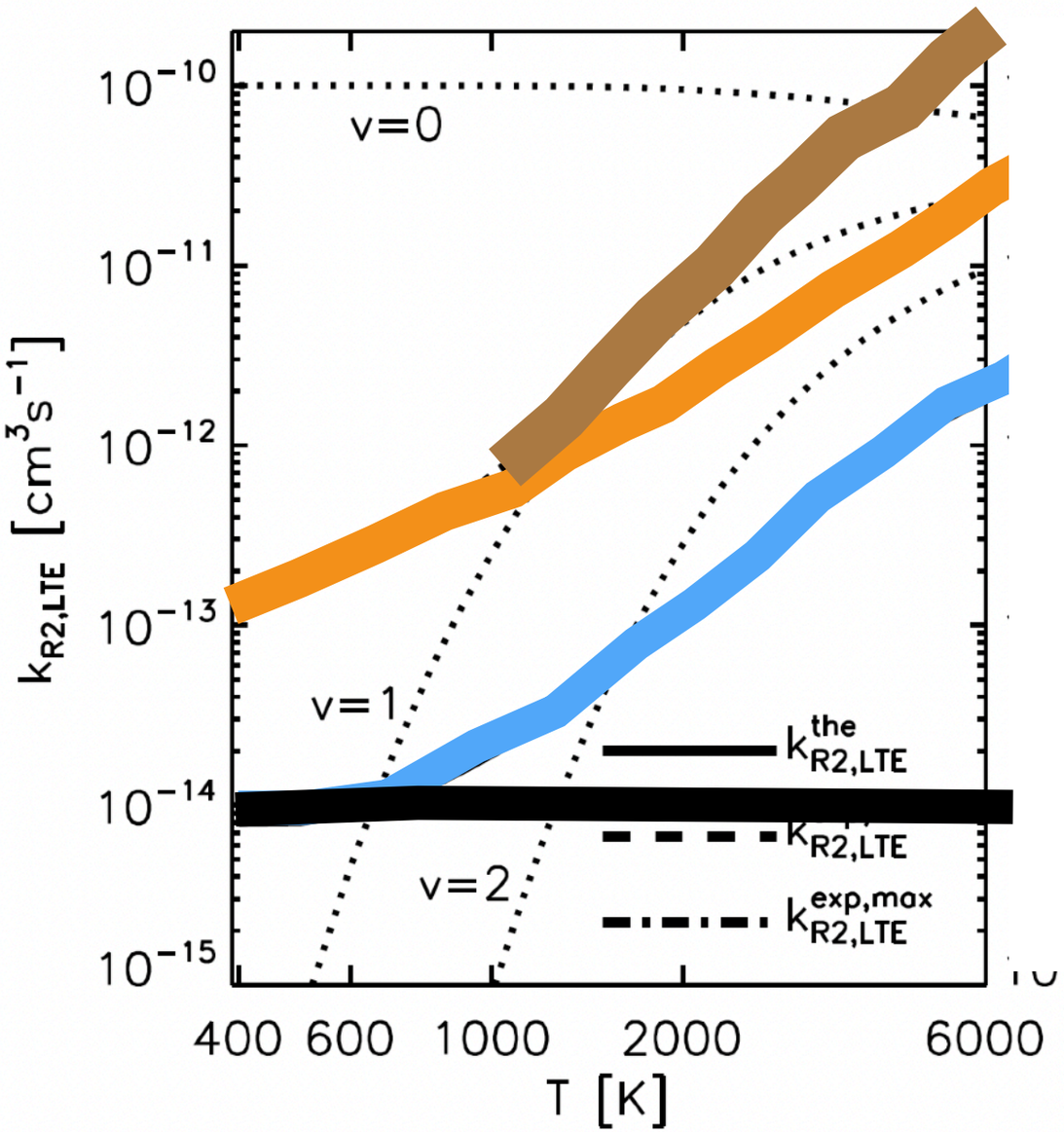


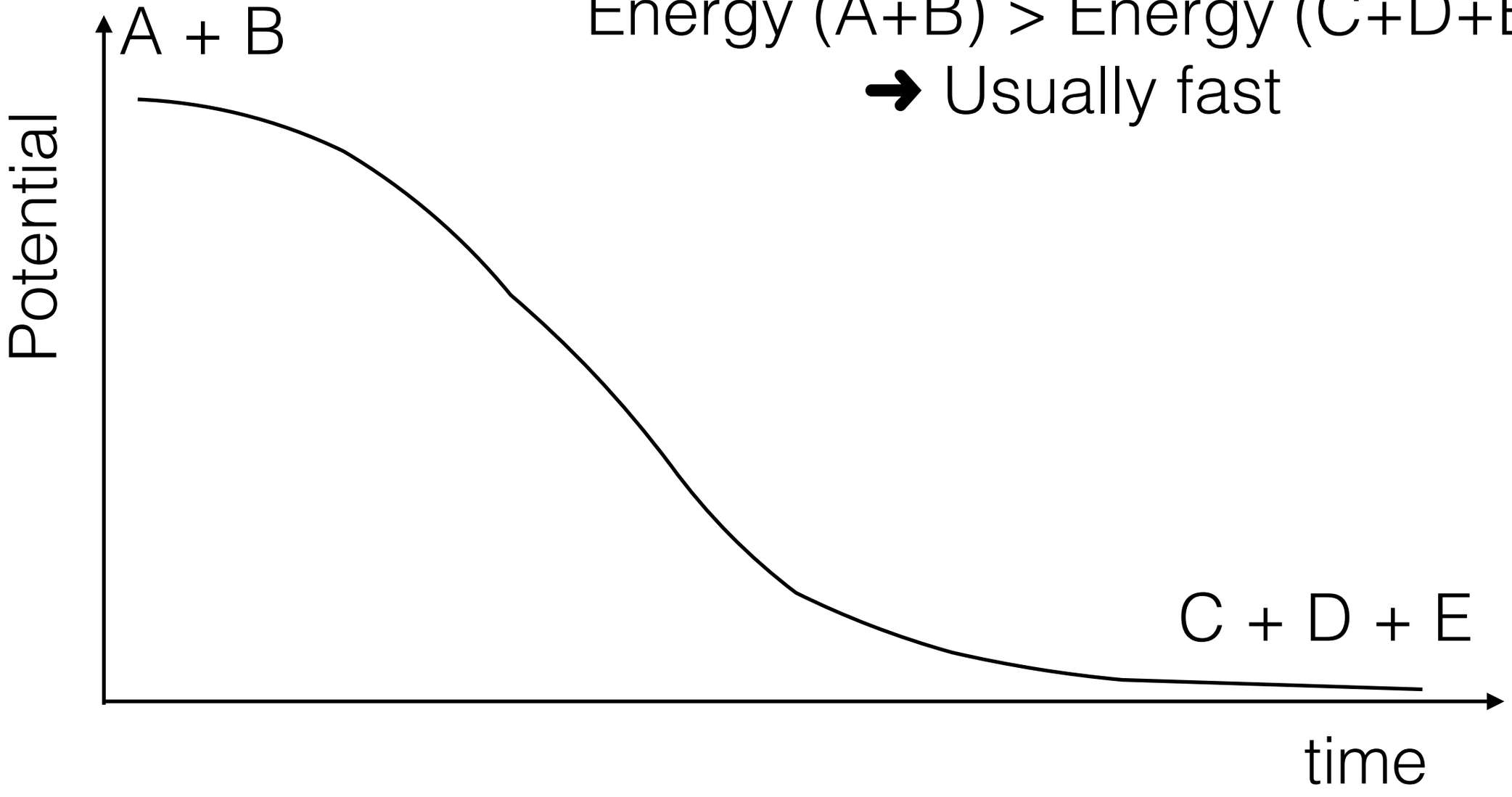
experimental, max
experimental, min
theory

Umist:
Astrochemistry comm'

A chemical reaction is a collision.
Outcome depends on interaction potential.

For exothermic reaction, A + B ➜ C + D + E:

Energy (A+B) > Energy (C+D+E)
➜ Usually fast



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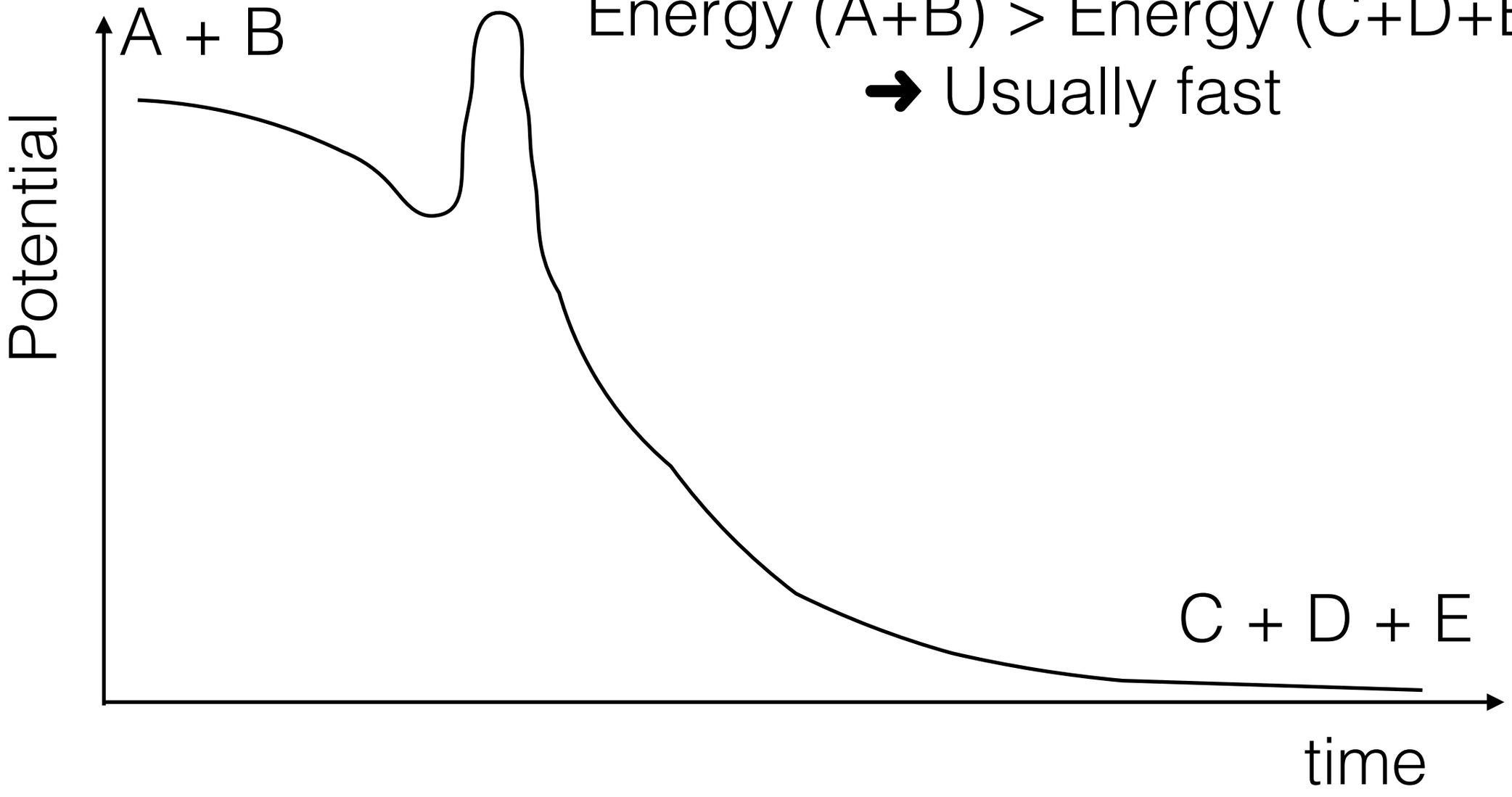

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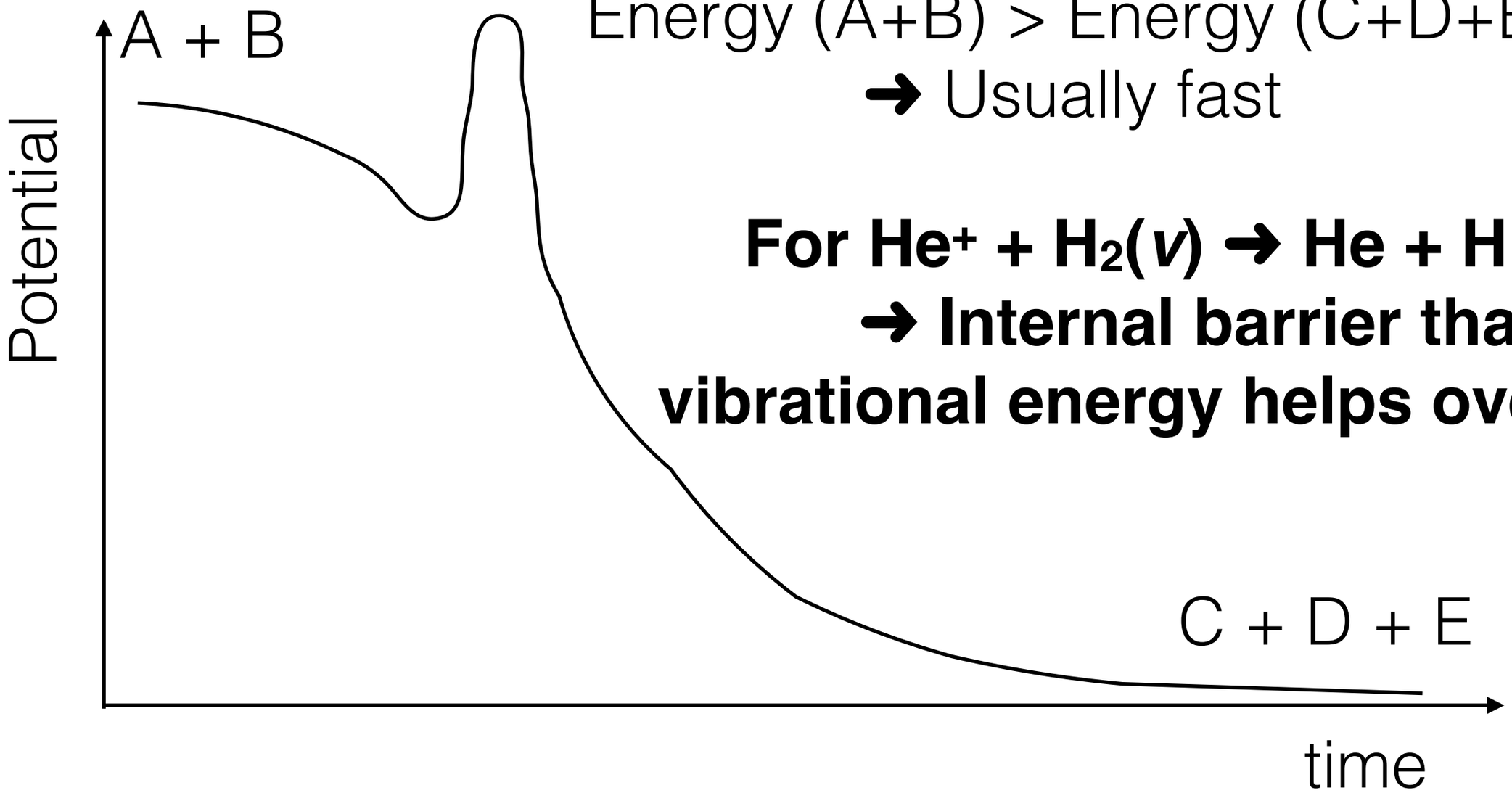

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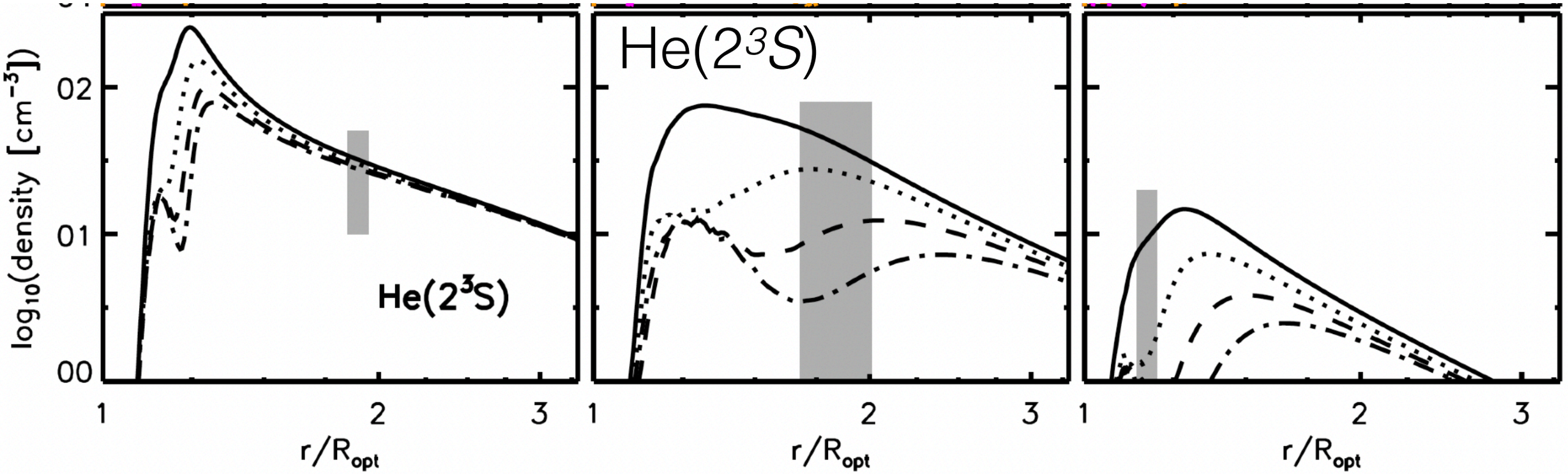
For $He^+ + H_2(v) \rightarrow He + H + H^+$
➜ Internal barrier that vibrational energy helps overcome

GM+2025, He(2^3S) densities predicted for the 4 proposed prescriptions of rate coefficient



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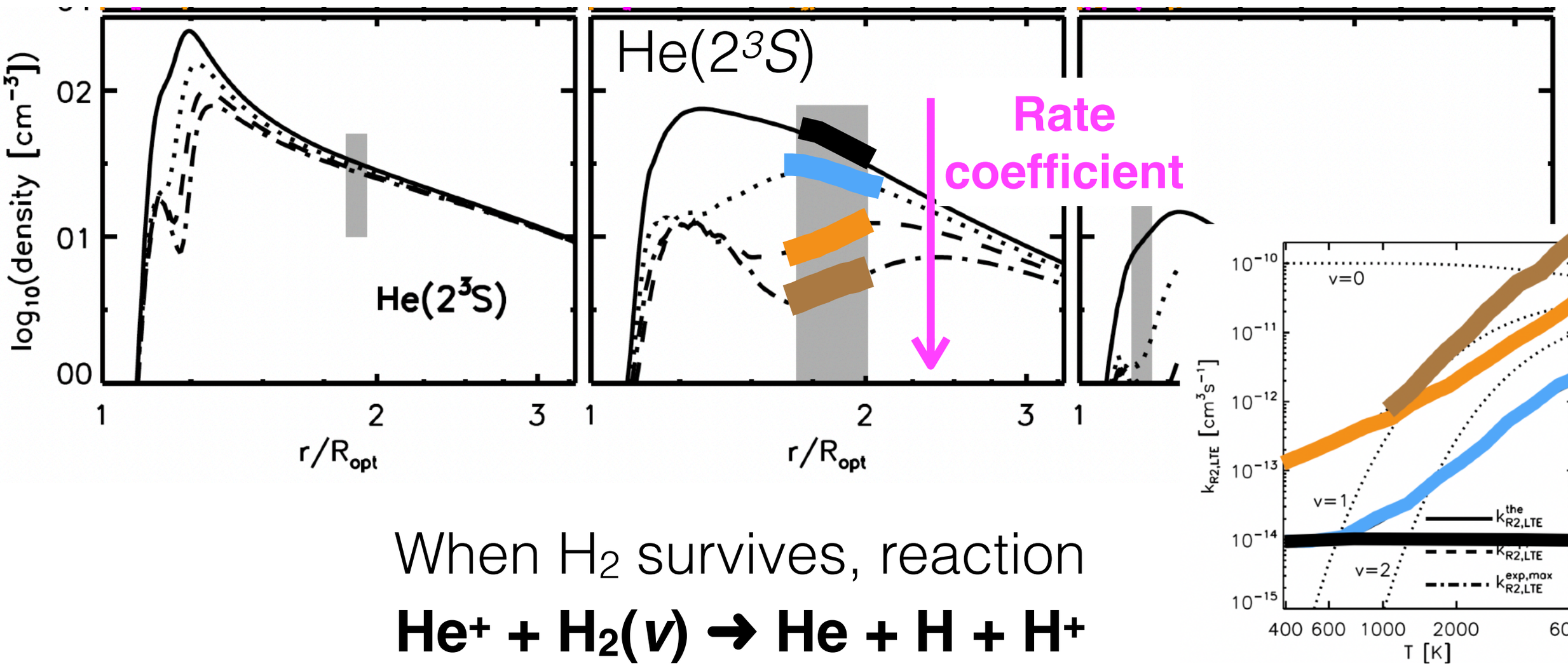

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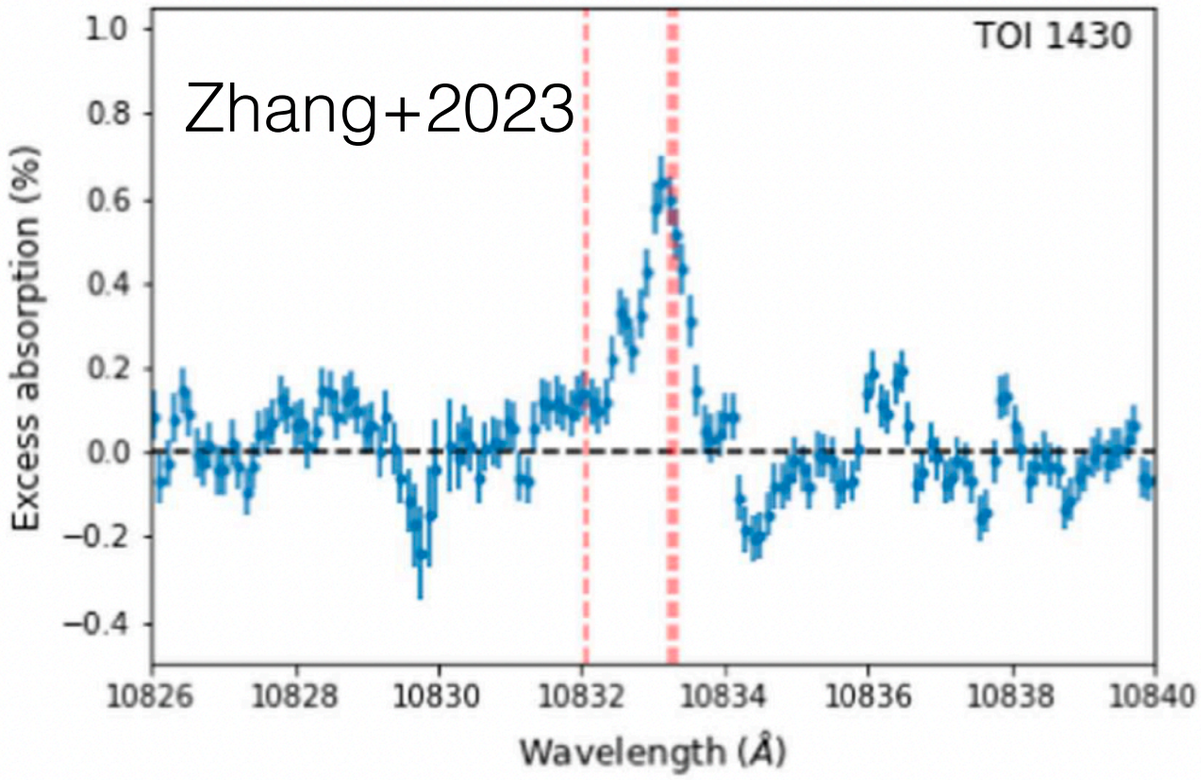

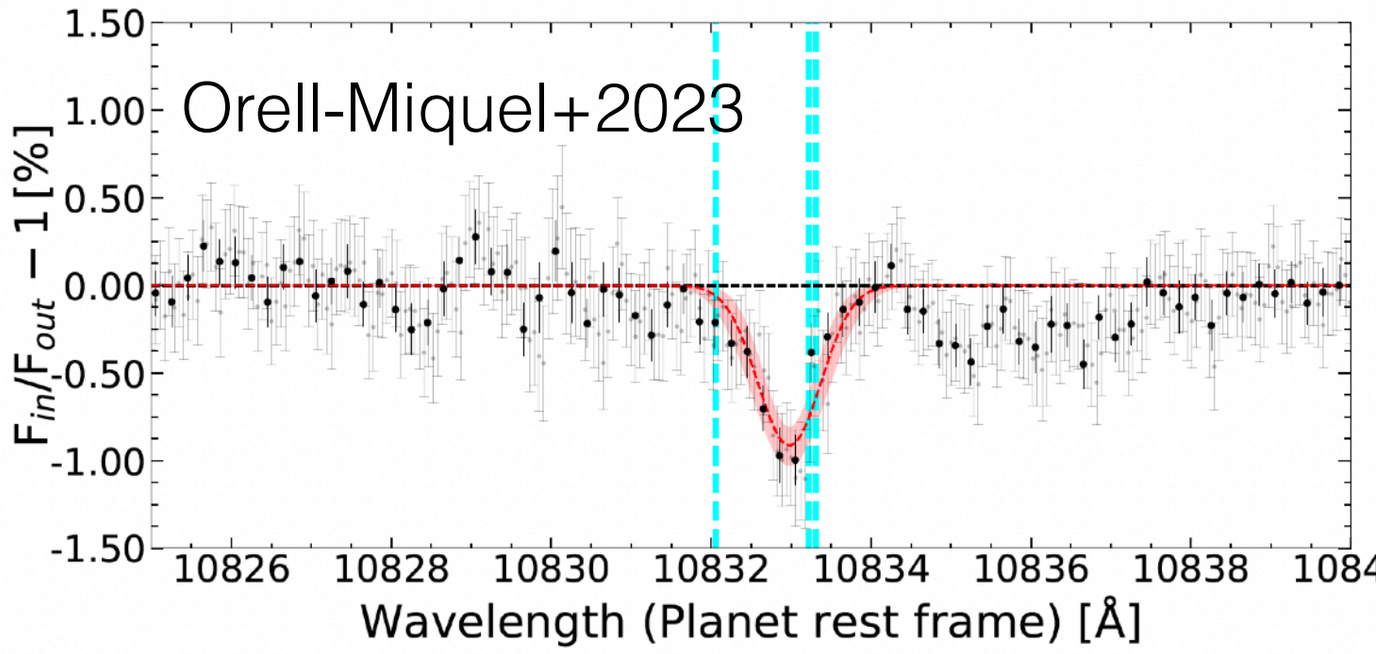

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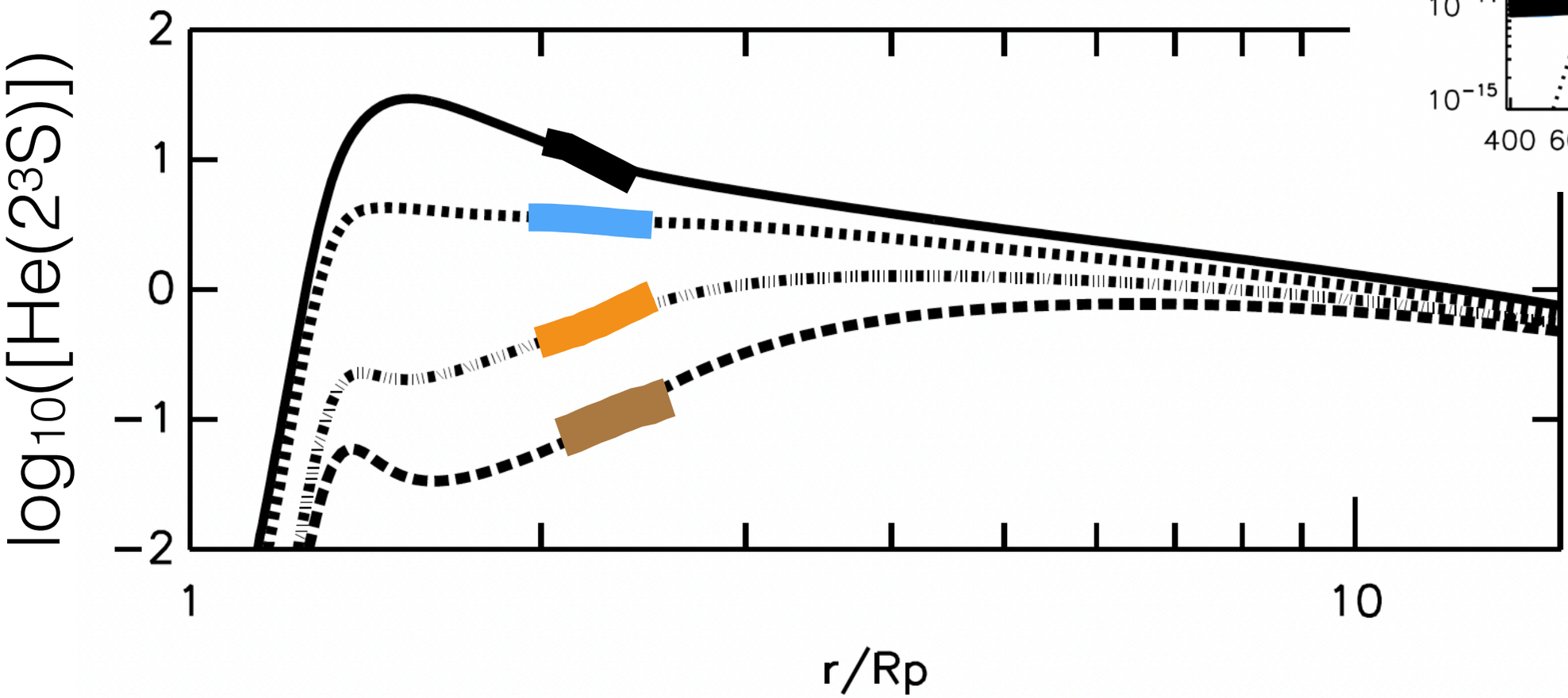

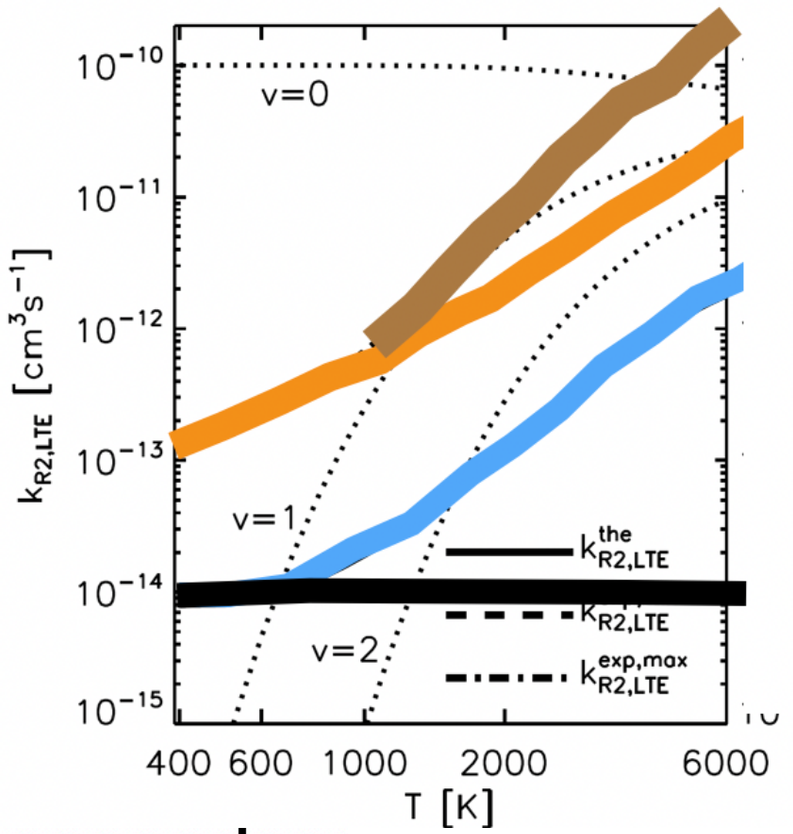

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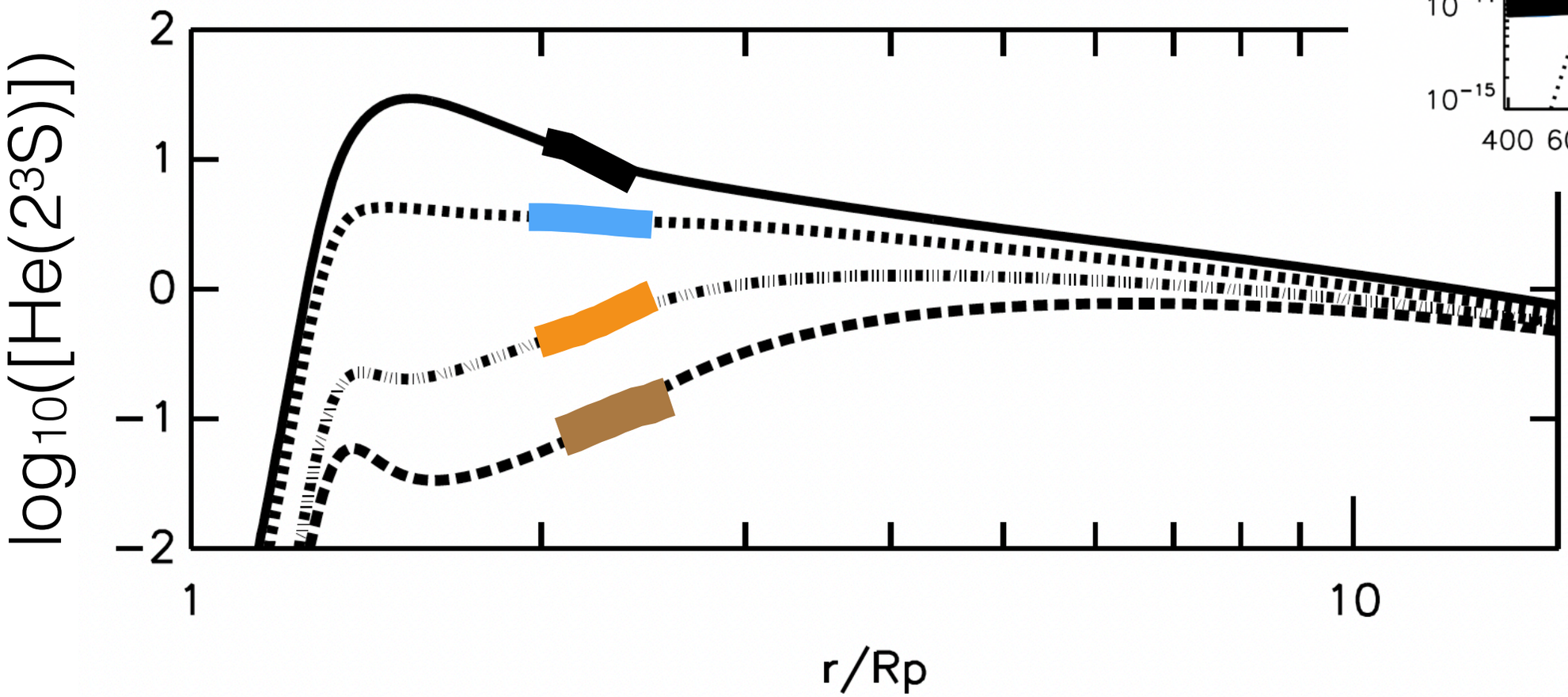
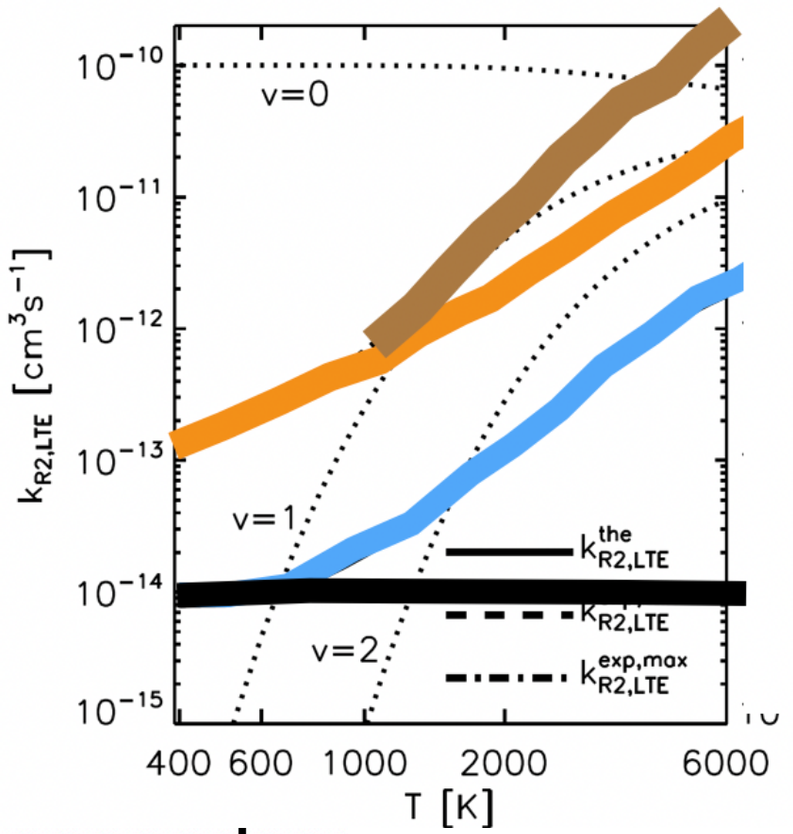
Model: Excess Absorption~0.37-0.6%
≤ 0.6-0.9% from meaurements





Recap

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This has implications on overall interpretation, in particular on retrieved He/H
(connected with formation, interior structure, etc…)

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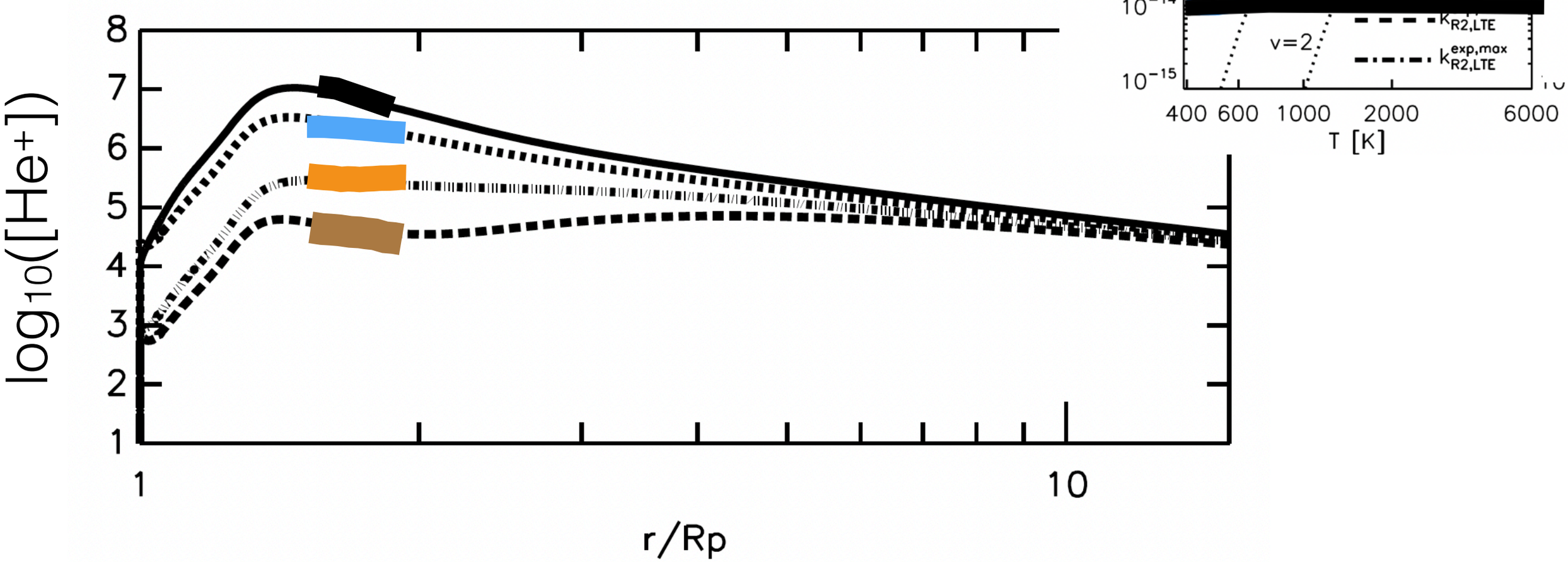

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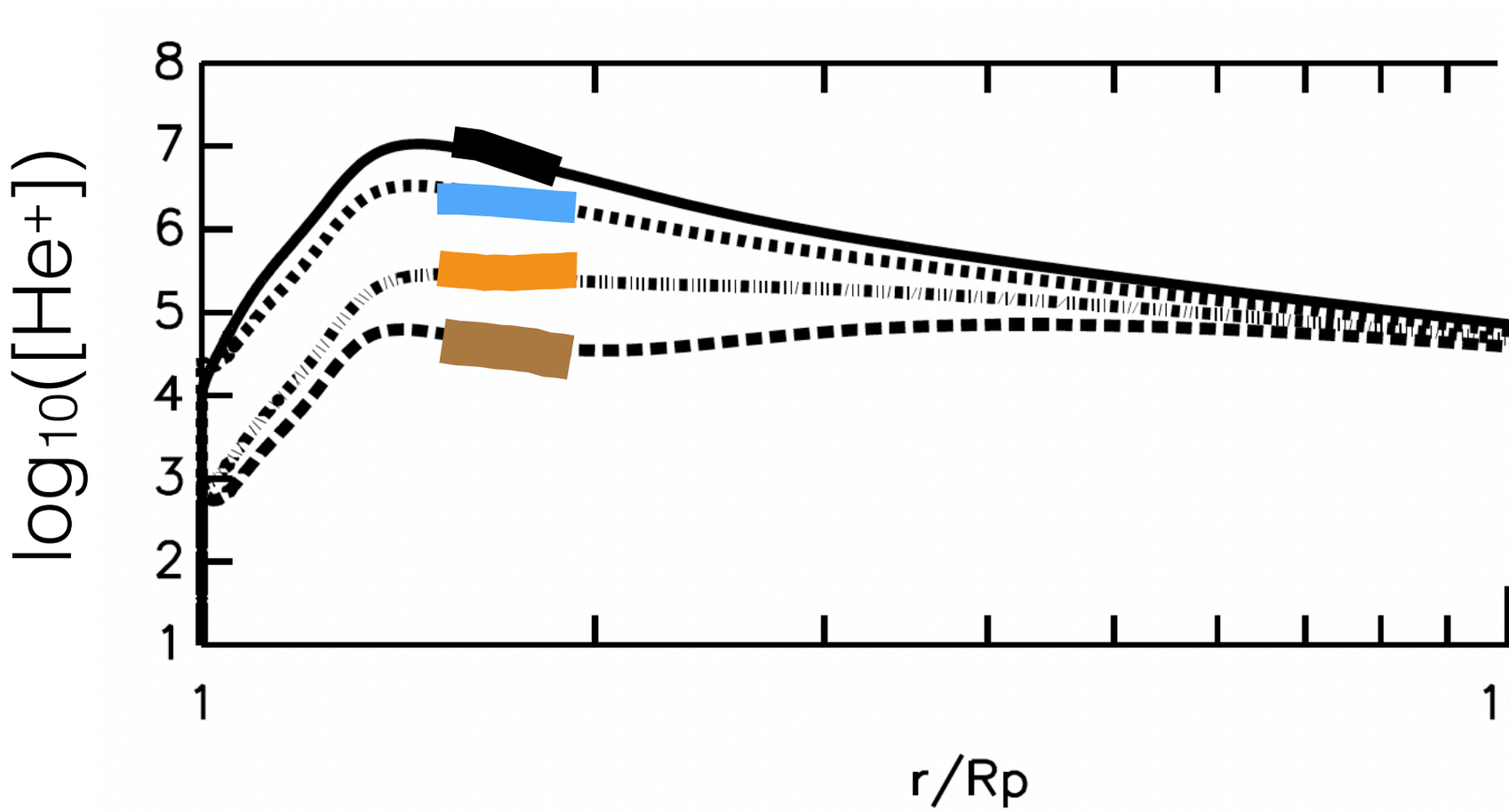

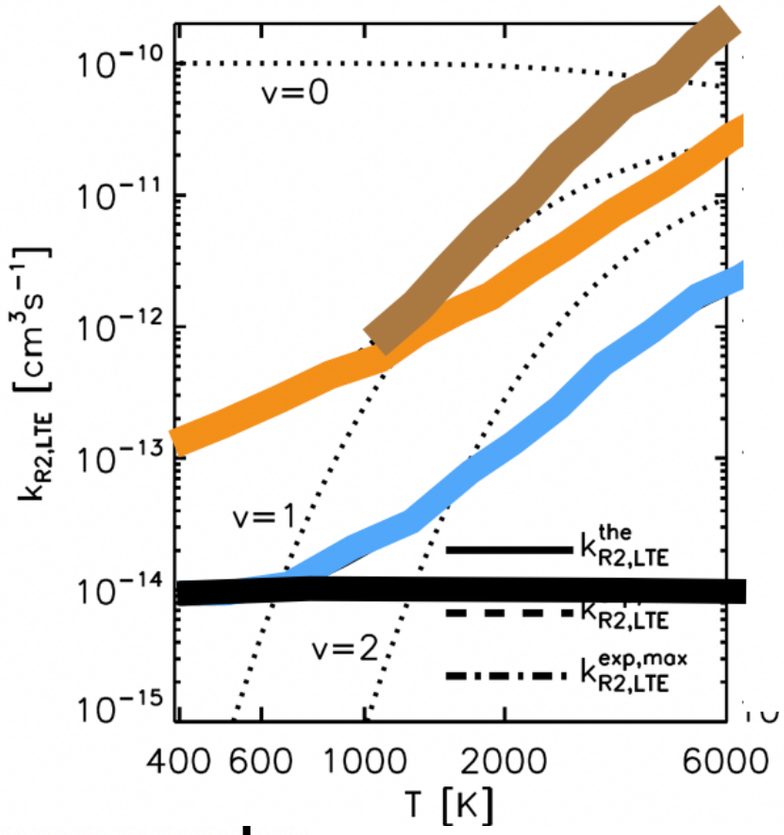

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