NON-EQUILIBRIUM ION-NEUTRAL CHEMISTRY BETWEEN BROWN DWARFS AND EXOPLANETS

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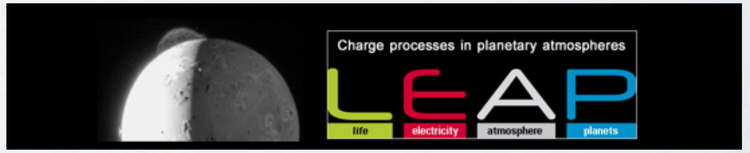


THE CH_4 - CO TRANSITION

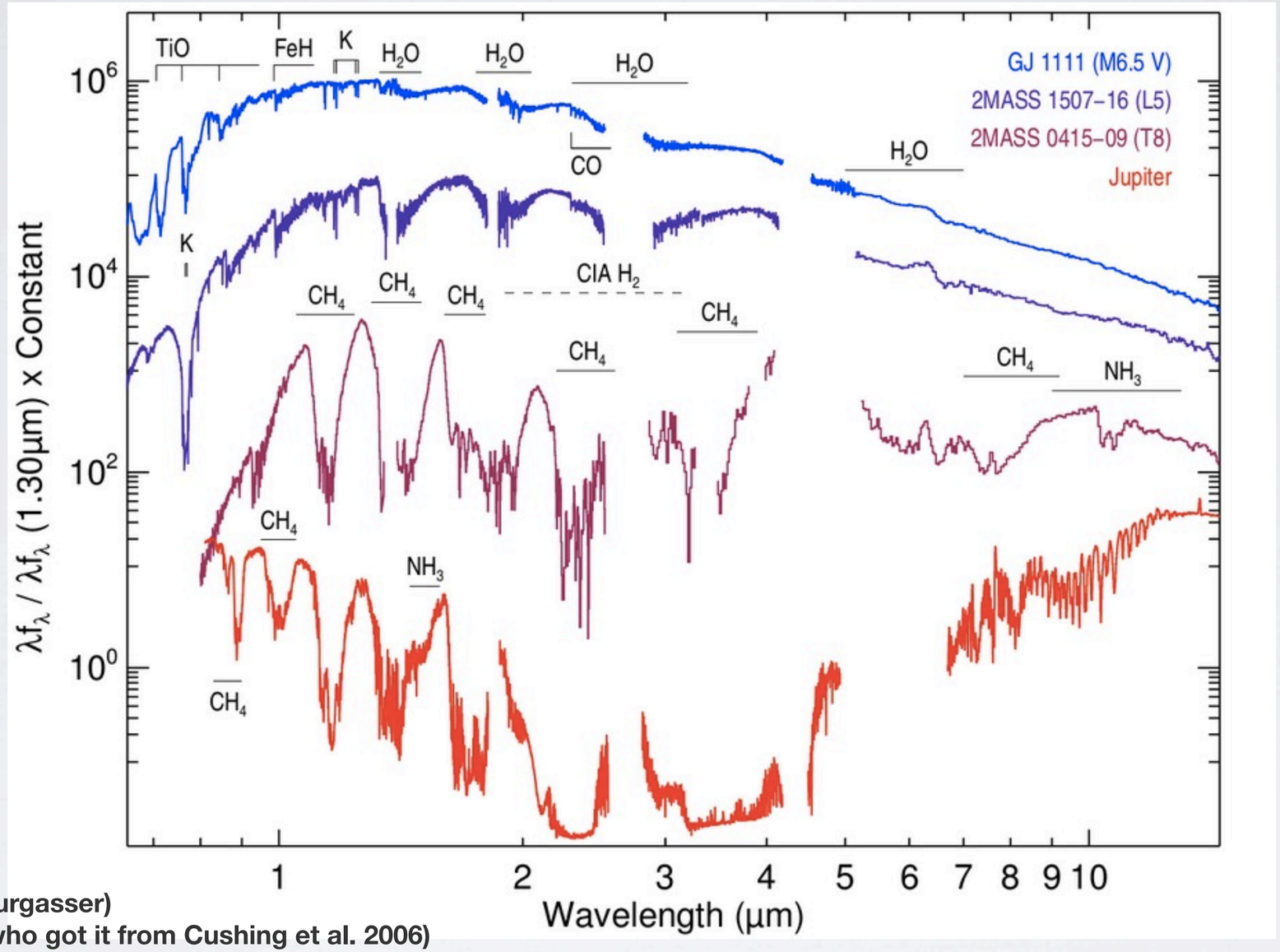
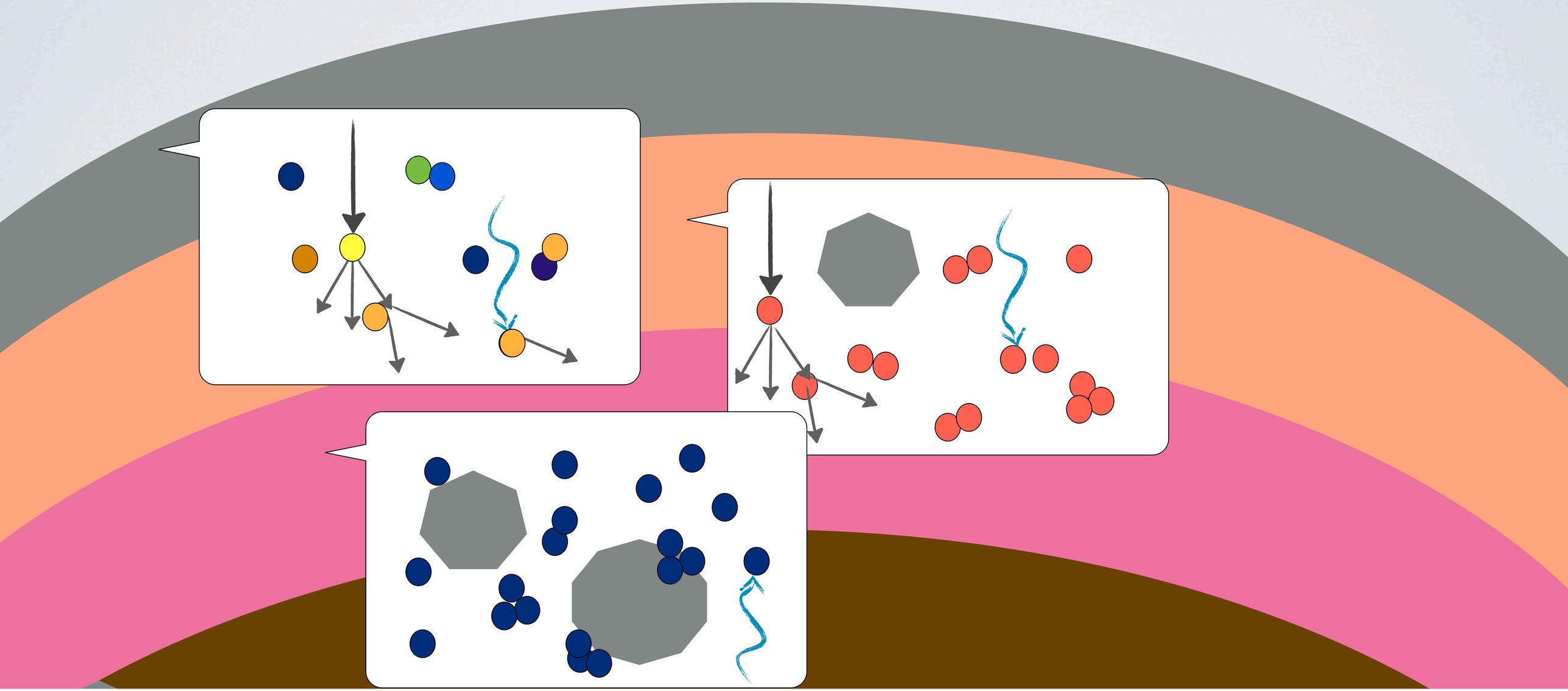


Figure from Exoclimes.com (Burgasser)
(from Marley & Leggett 2009, who got it from Cushing et al. 2006)

HOW TO MODEL SUBSTELLAR ATMOSPHERES: THE CHEMICAL KINETICS APPROACH



CHEMICAL KINETICS IS NECESSARY

- CO and CH_4 become vertically quenched. (Saumon et al. 2006)

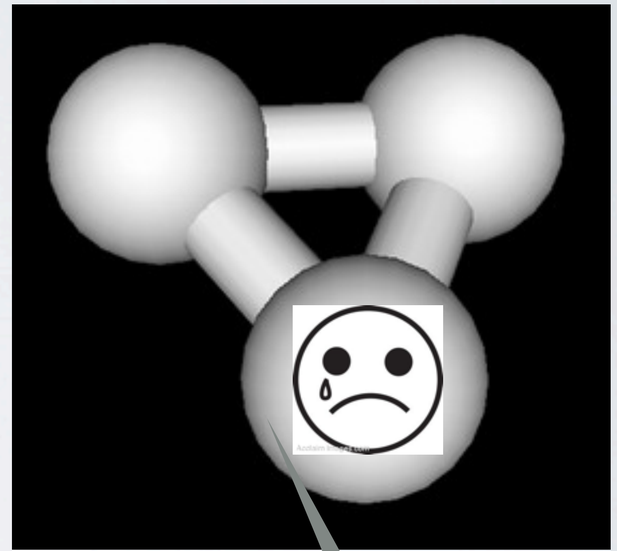
- Atomic species, C_2H_2 and HCN are enhanced by photodissociation chemistry. (Moses et al. 2011)

- Neither photodissociation nor vertical quenching can be treated with equilibrium or perturbation techniques.

- A chemical kinetics approach is necessary, either:

    - Using a robust rate network, accounting at least for all equilibrium formation and destruction pathways. (e.g. Venot et al. 2012, Moses et al. 2011)

    - In lieu of such techniques, dominant formation and destruction pathways can be used to estimate the effects of, e.g., chemical quenching (Bilger et al. 2013).



IONS AS A "PROBE" OF UPPER-ATMOSPHERIC COMPOSITION

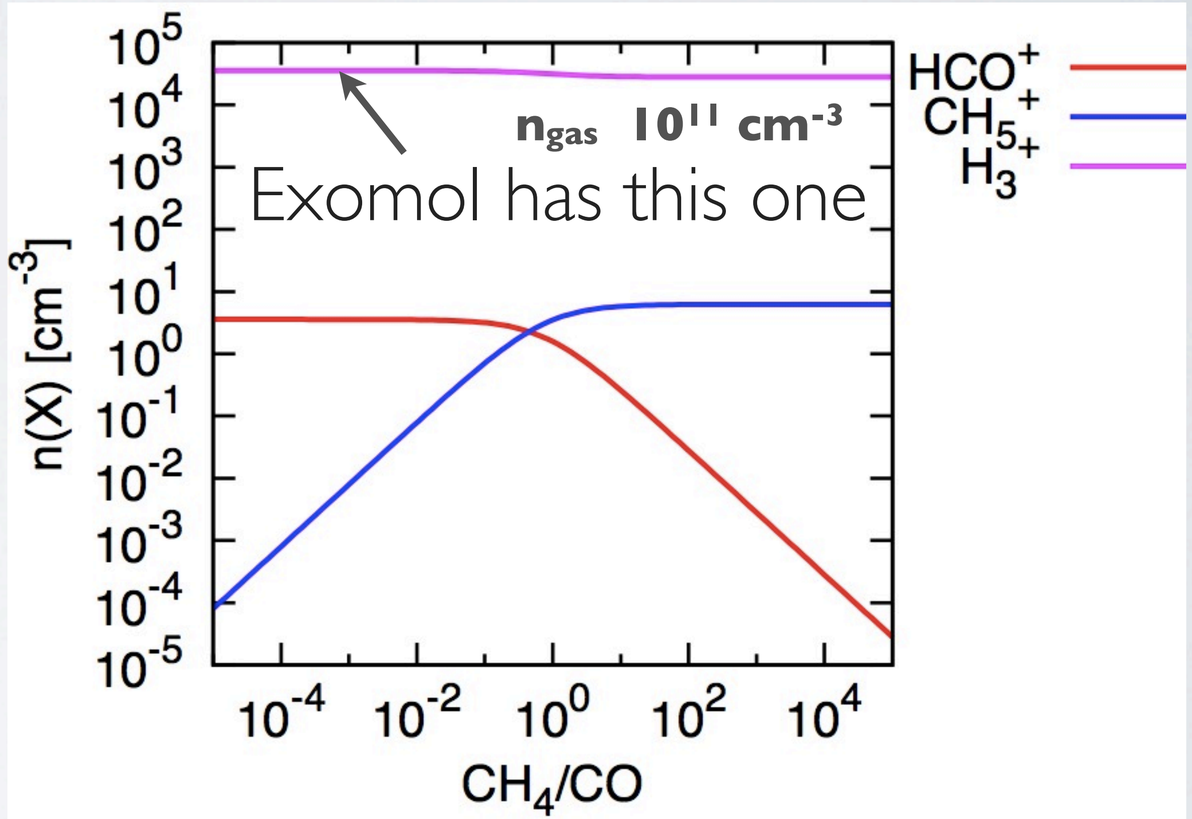
- H_3^+ is directly connected to the H_2 and the cosmic ray ionization rate. This makes it an excellent probe in its own right. (Harris et al. 2004)

- Recombination with its electron is difficult in such a weakly ionized plasma ($f_e = 10^{-7}$)

- H_3^+ destroyed in two dominant ways:

  - $H_3^+ + CO \longrightarrow HCO^+ + H_2$

  - $H_3^+ + CH_4 \longrightarrow CH_5^+ + H_2$



Model Substellar Atmosphere

+

Chemical Kinetics

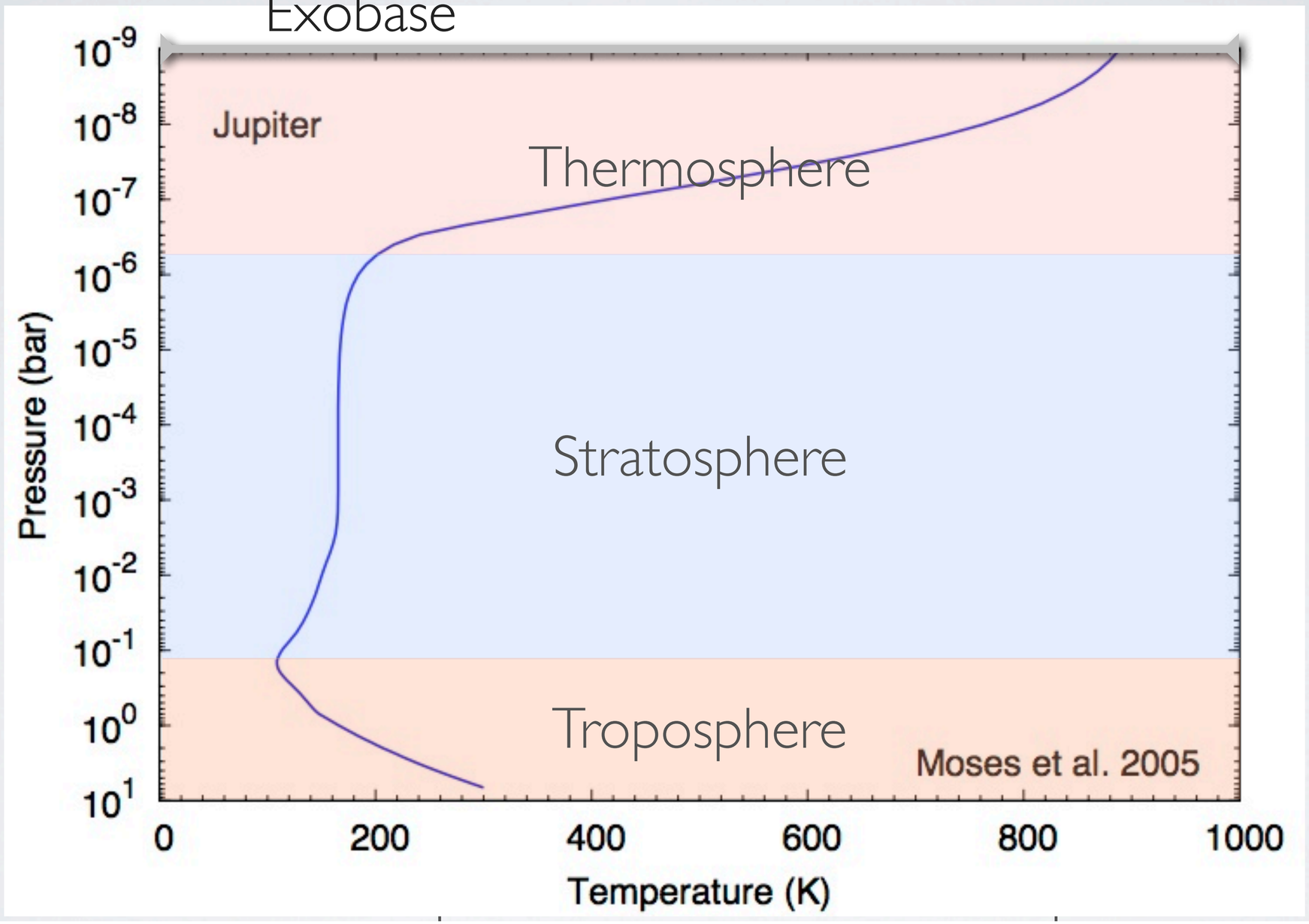
+

Ion-Neutral Chemistry

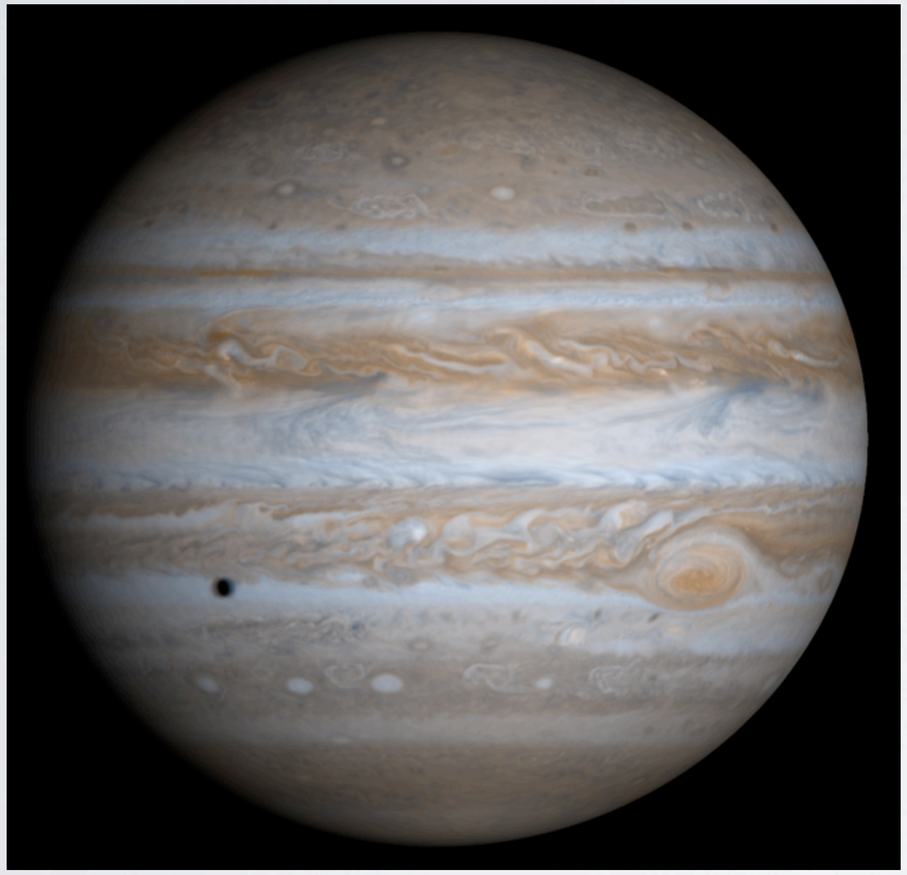
(No kinetics network for hydrogen-rich atmospheres accounts for ion-neutral chemistry!)

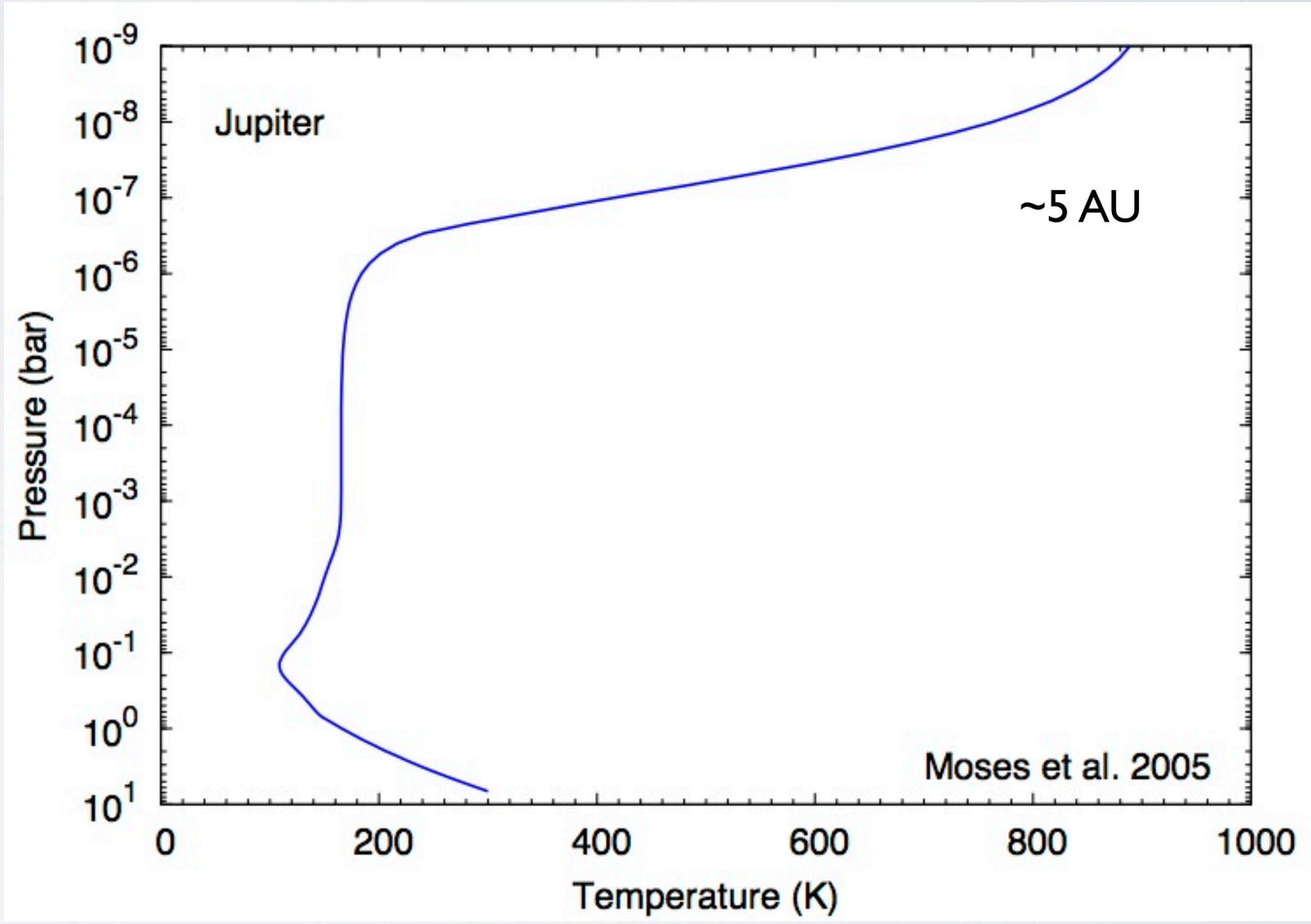
Mind the Gap - Brown Dwarfs and Exoplanets

PARTS OF A GIANT GAS PLANET'S ATMOSPHERE

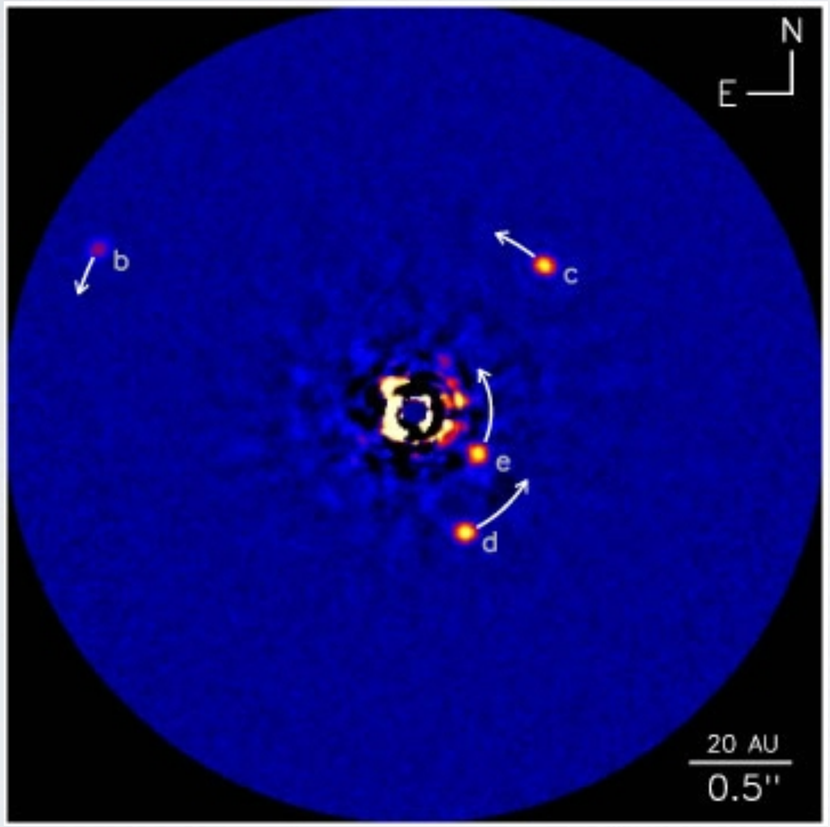


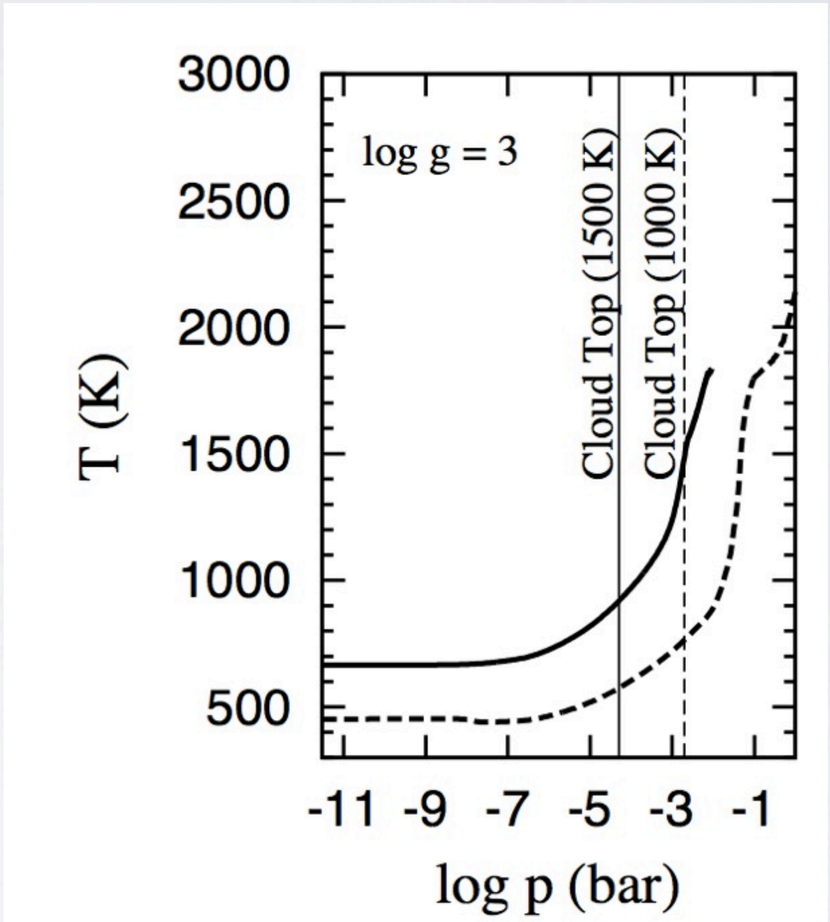
JUPITER-LIKE PLANET "BESPIN"





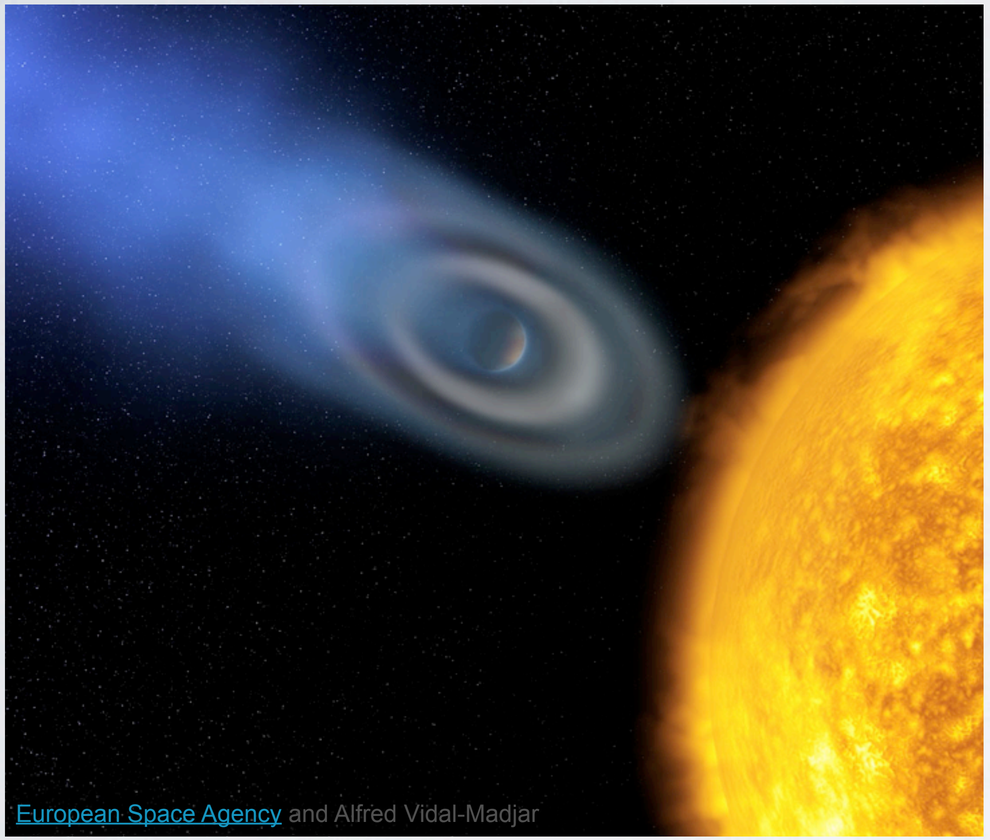
AN HR 8799 c-LIKE "PLANET": "HOTH"

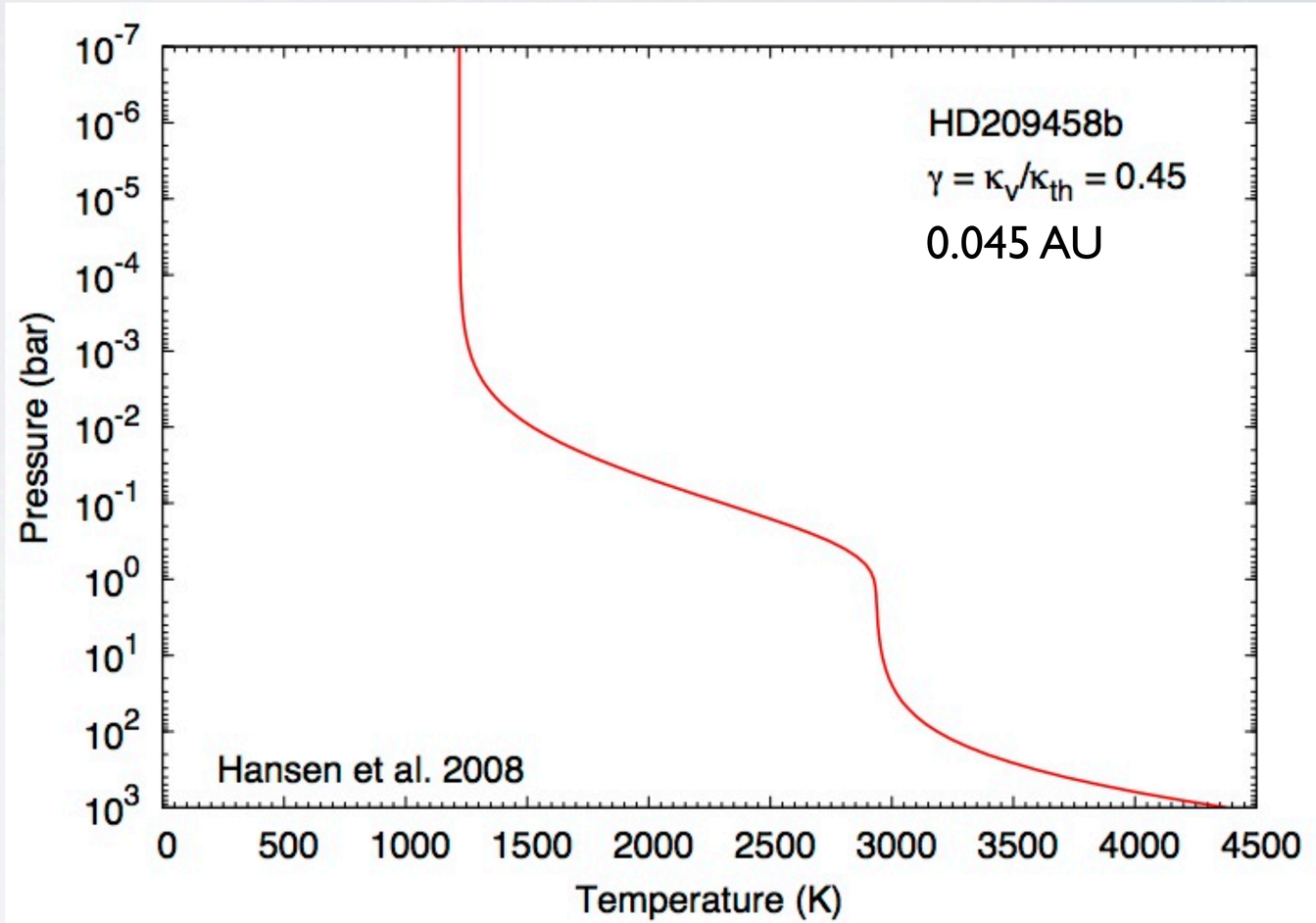




~40 AU

HD 209458 b-LIKE PLANET "OSIRIS"





OUR ION-NEUTRAL NON-EQUILIBRIUM NETWORK

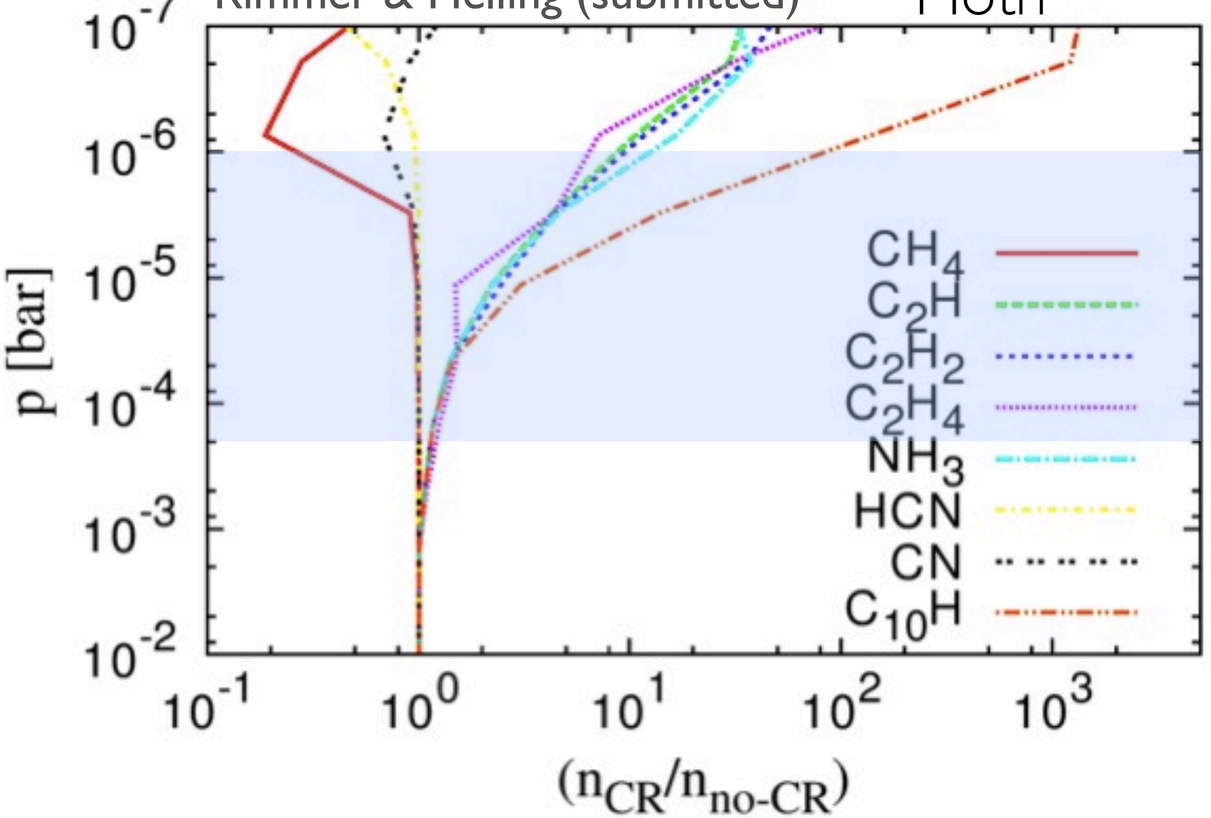
- Over 100 species
- Up to C2H6
- Includes Cations, some Anions
- Treats atmospheric mixing
- Cosmic rays via atmospheric transport model
- Analytic radiative transfer

- Over 2000 Reactions
- Reversible: Neutral-Neutral, Three Body, Ion-Neutral
- Combustion Reactions and Capture Reactions
- Non-Reversible: Photodissociation, Photoionization, Cosmic Ray Ionization

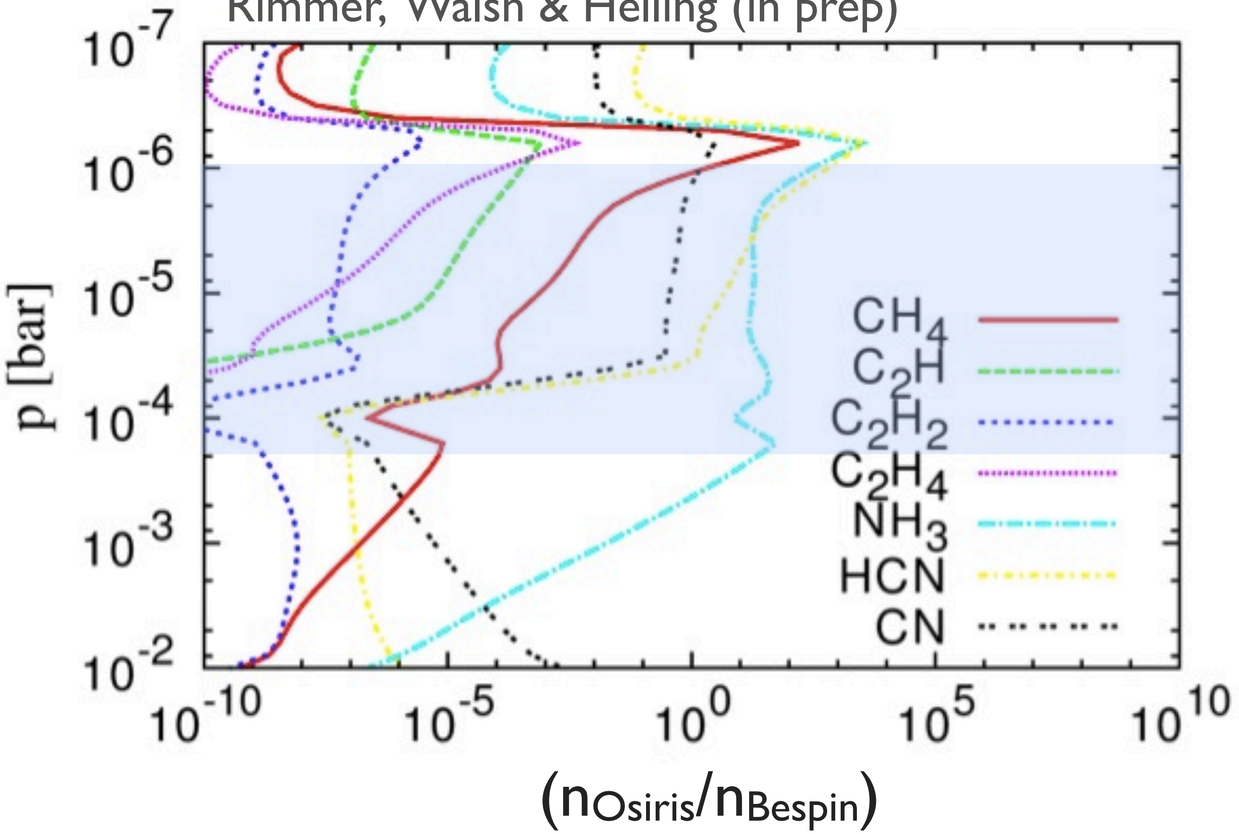
Mind the Gap - Brown Dwarfs and Exoplanets

RESULTS FOR THE HOT JUPITER COMPARED TO THE JUPITER-LIKE PLANET

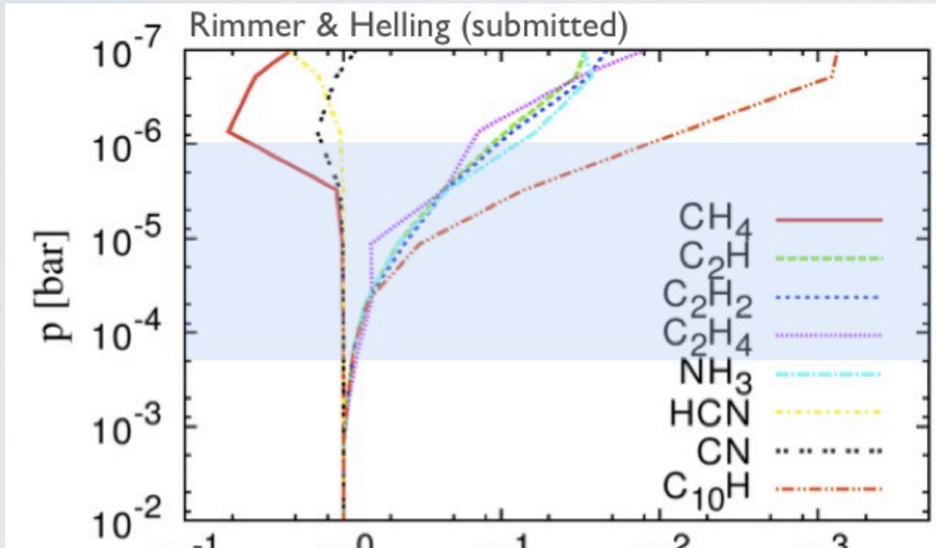
Rimmer & Helling (submitted) "Hoth"

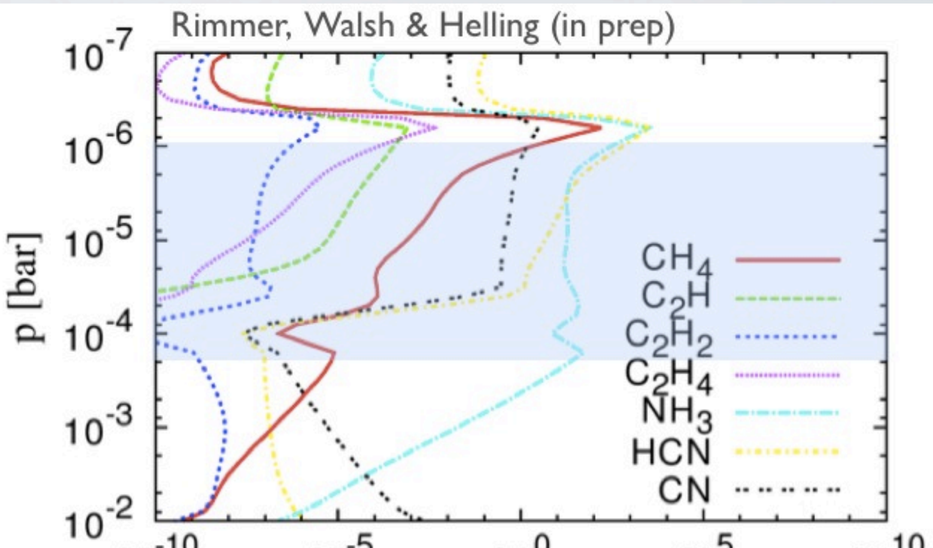


Rimmer, Walsh & Helling (in prep)



QUESTIONS


Rimmer & Helling (submitted)
p [bar]
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
CH_4
C_2H
C_2H_2
C_2H_4
NH_3
HCN
CN
$C_{10}H$
$(n_{CR}/n_{no\text{-}CR})$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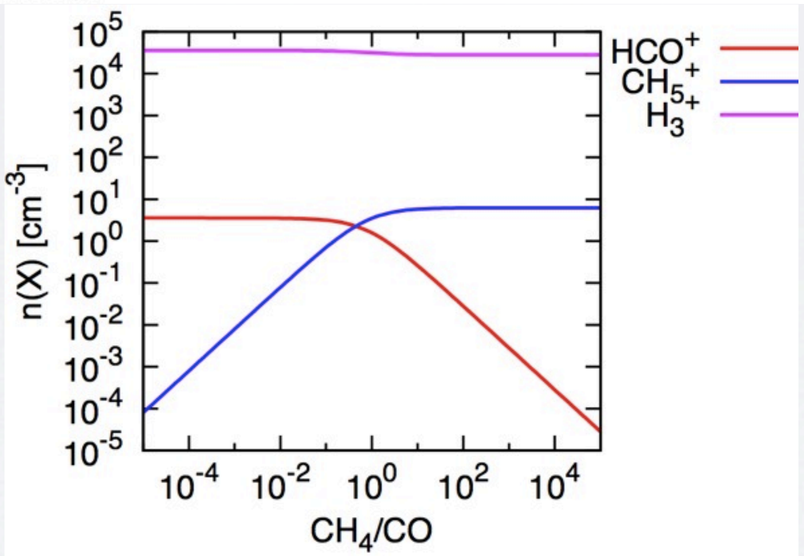
p [bar]
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-10}
10^{-5}
10^{0}
10^{5}
10^{10}
CH_4
C_2H
C_2H_2
C_2H_4
NH_3
HCN
CN
(n_{Osiris}/n_{Bespin})


n(X) [cm^{-3}]
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
CH_4/CO
HCO^+
CH_5^+
H_3^+