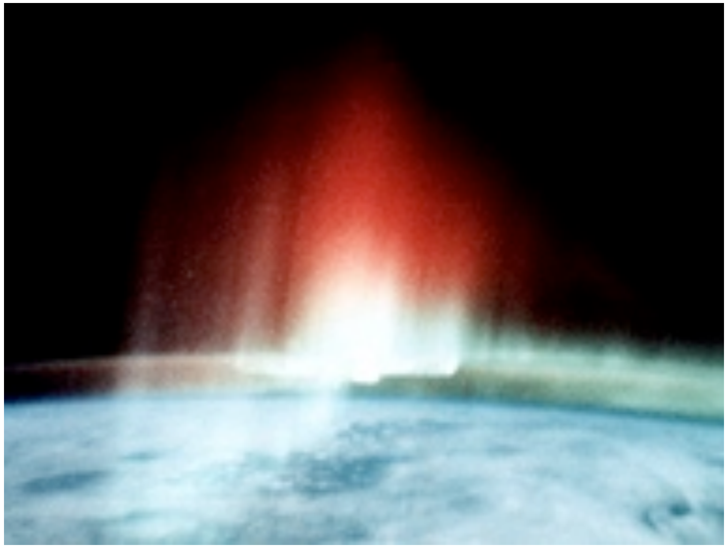
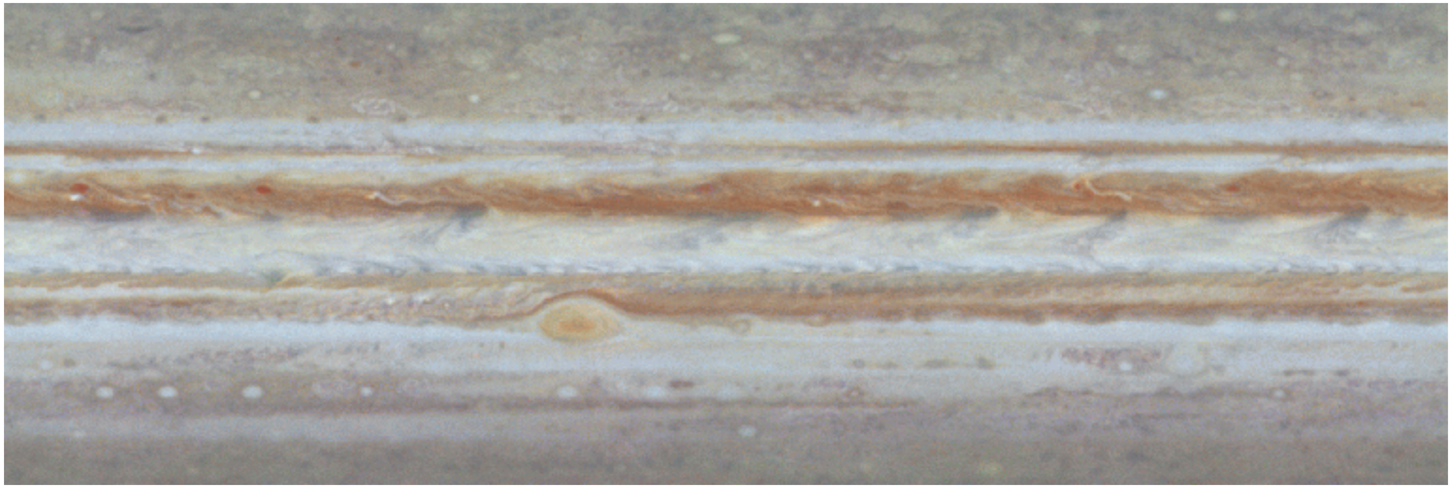
Planetary Atmospheres

Structure
Composition
Clouds
Photochemistry
Meteorology
Atmospheric Escape



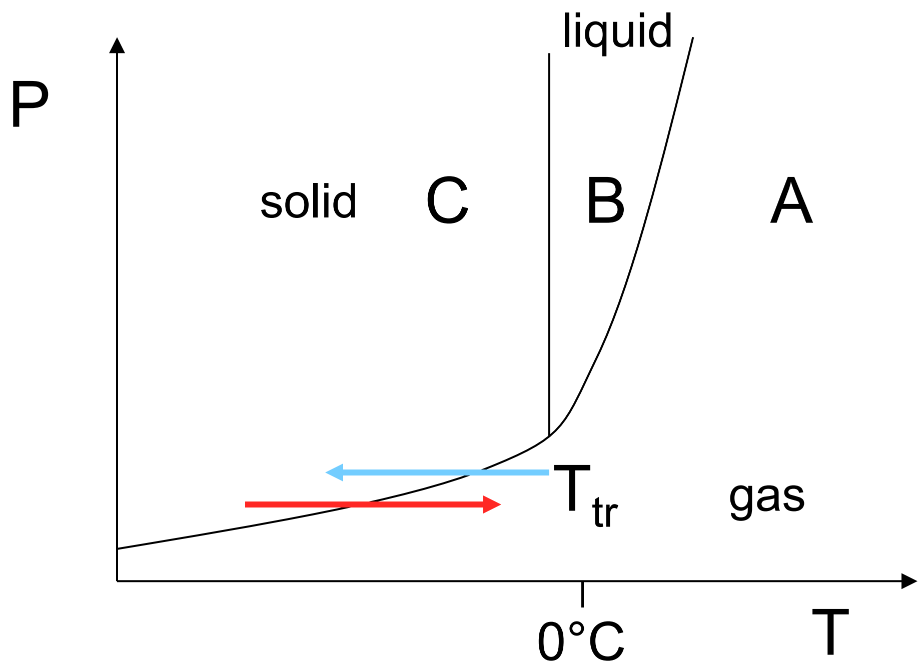


Cloud formation

Saturated Vapor Pressure: Maximum amount of water vapor partial pressure

Deposition

Sublimation



Cloud formation

Wet Adiabatic Lapse Rate:

$$P = C_L e^{-L_S/(R_{gas}T)}$$

Saturation Vapor Pressure

$$c_v dT = -P dV - L_S dw_S$$

L_s is *Specific* Latent Heat

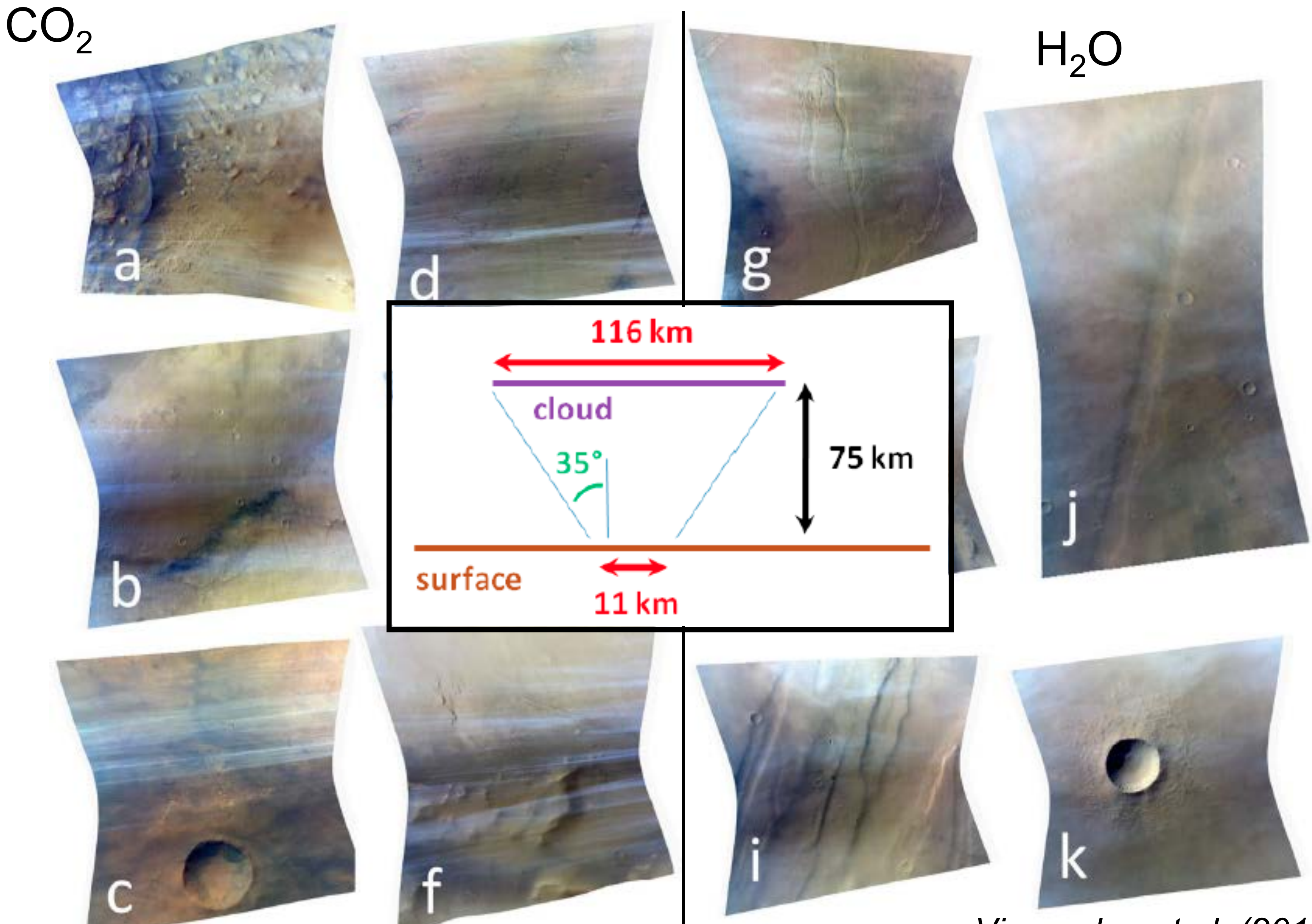
$$c_P dT = \frac{1}{\rho} dP - L_S dw_S$$

w_s is the mass of water vapor that condenses out per gram of air

$$\frac{dT}{dz} = -\frac{g_P}{c_P + L_S dw_S / dT}$$

= 5–6 K/km on Earth

Martian clouds



Vincendon et al. (2011)

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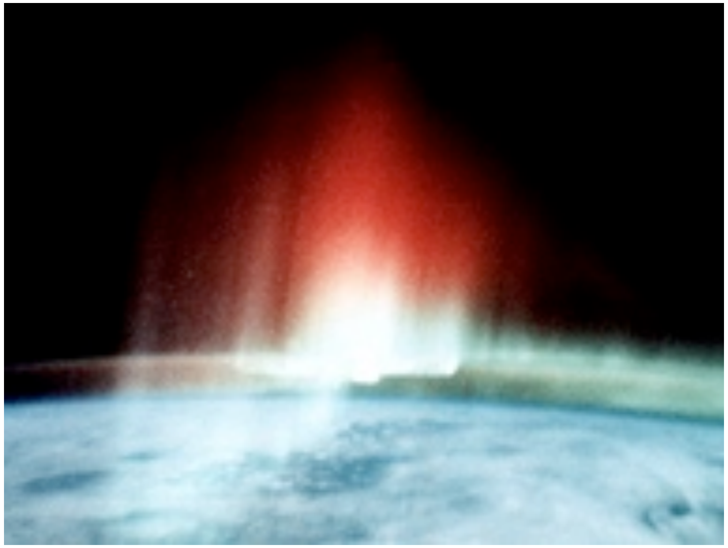
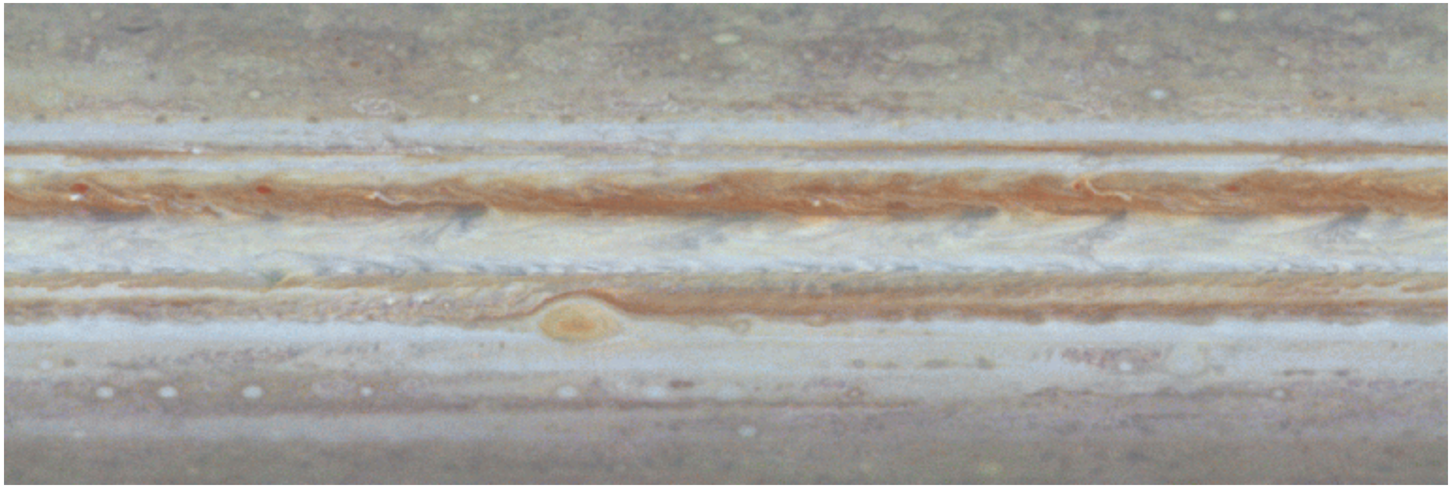




Photochemistry

We can characterize chemical reactions in the atmosphere in the following way:

1. Photolysis: Molecular breakup directly driven by solar radiation (also referred to as *photodissociation*)
2. Photoionization: Reactions that result in the ionization of atoms and molecules
3. Recombination: Direct/indirect reversing of the photolysis and photoionization reactions
4. Dissociative Recombination: Reversing the process of photoionization via breaking a chemical bond
5. Charge Exchange: Direct electron exchange between a close passing ion and neutral
6. Atom-Ion Interchange: Interaction between an ion and atom that results in compositional alteration of the ion.

Photolysis

Oxygen in the Earth atmosphere processed by photons:

(1) $$O_2 + h\nu \rightarrow O + O$$ for $\lambda < 175$nm

$$\frac{d[O]}{dt} = 2[O_2]J_1(z)$$ Production rate of O

Where $J_i(z)$ is the reaction rate for a reaction 'i' as a function of altitude, and [atom or molecule] indicates the number per unit volume

$$J_i(z) = \int \sigma_{x_\nu} \mathcal{F}_\nu e^{-\tau_\nu(z)/\mu_\theta} d\nu$$

Since the number of photons decreases exponentially with depth penetrated into the atmosphere, production of O increases with altitude even though $[O_2]$ increases as you approach the surface.

Recombination

Direct two body recombination reverses photolysis:

$$O + O \rightarrow O_2 + h\nu \qquad (2)$$

However, this reaction is slow, so three body processes dominate instead:

$$O + O + M \rightarrow O_2 + M \qquad (3)$$

$$O_2 + O + M \rightarrow O_3 + M \qquad (4)$$

Where the reaction rates can be written:

$$\frac{d[O_2]}{dt} = ?$$

$$\frac{d[O_2]}{dt} = [O]^2[M]k_{r3}$$

k_{ri} is the reaction rate dependent on the collision rate (thus T) of the molecules

Photoionization

Oxygen and Nitrogen in the Earth atmosphere ionized by photons:

$$O_2 + h\nu \rightarrow O_2^{+} + e^{-}$$

$$N_2 + h\nu \rightarrow N_2^{+} + e^{-}$$

$$O + h\nu \rightarrow O^{+} + e^{-}$$

However, these products are efficiently processed via charge exchange and atom-ion interchange to yield mostly NO^+ and O_2^+

$$N_2^{+} + O_2 \rightarrow N_2 + O_2^{+}$$

$$O^{+} + O_2 \rightarrow O_2^{+} + O$$

$$N_2^{+} + O \rightarrow NO^{+} + N$$

Ion Loss: Recombination

Dissociative Recombination:

$$O_2^+ + e^- \rightarrow O + O$$

$$NO^+ + e^- \rightarrow N + O$$

Radiative Recombination is much less efficient:

$$O^+ + e^- \rightarrow O + h\nu$$

Hence rapid processes like charge exchange and atom-ion interchange quickly replace the produced ions with dominant ions that can undergo dissociative recombination

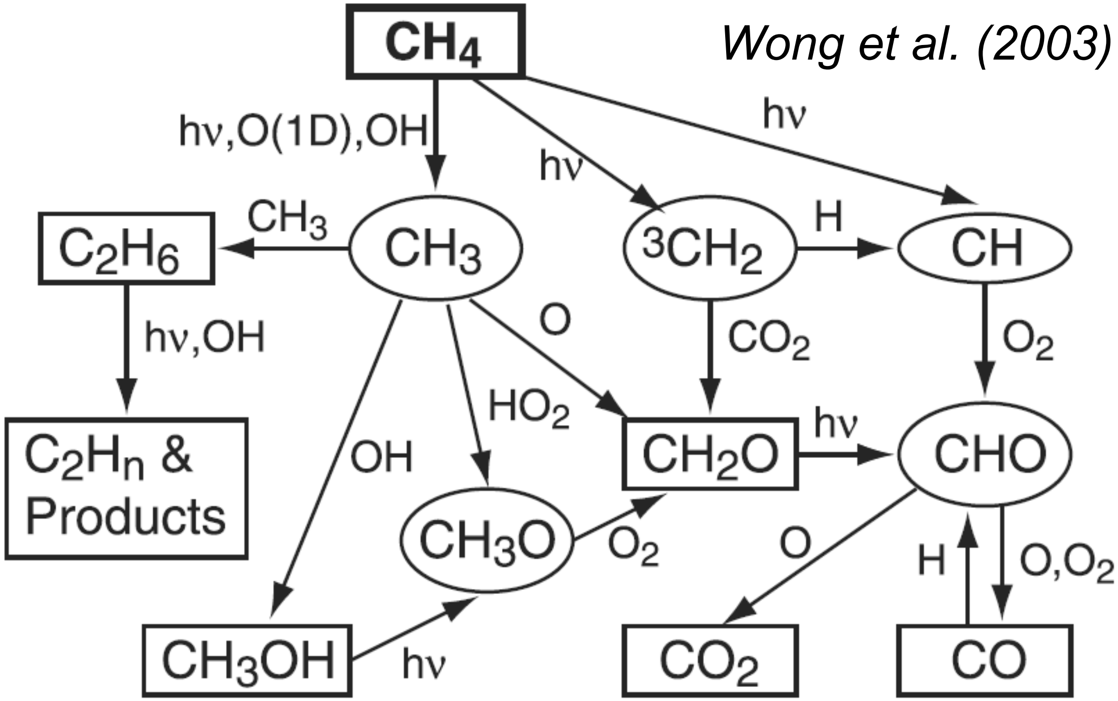
Methane on Mars

• Destroyed by photochemistry

➔ *300–600 yr lifetime*

…not fast enough??

Wong et al. (2003)



• Bar-Nun & Dimitrov (2006) argued that methane could also be produced photochemically

→ ***controversial***