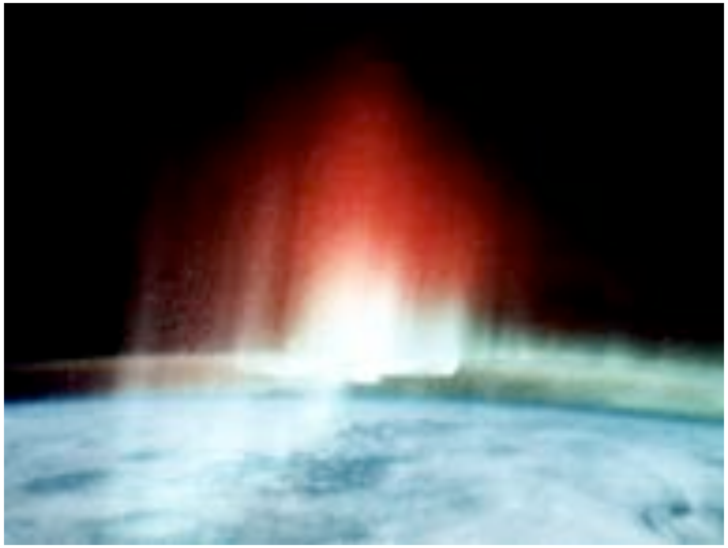
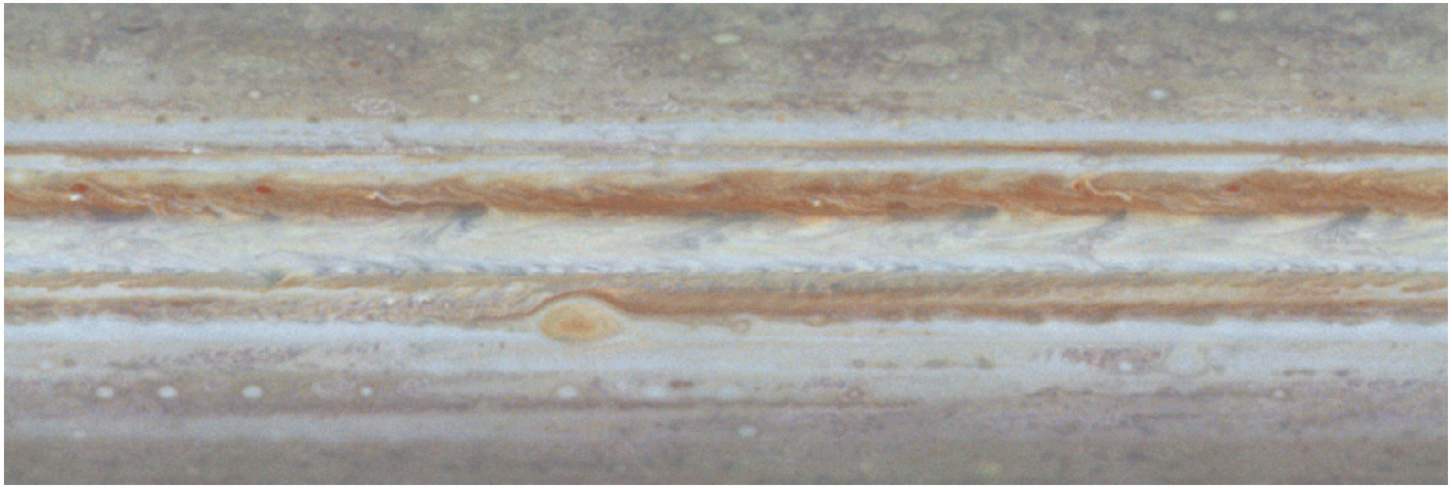
Planetary Atmospheres

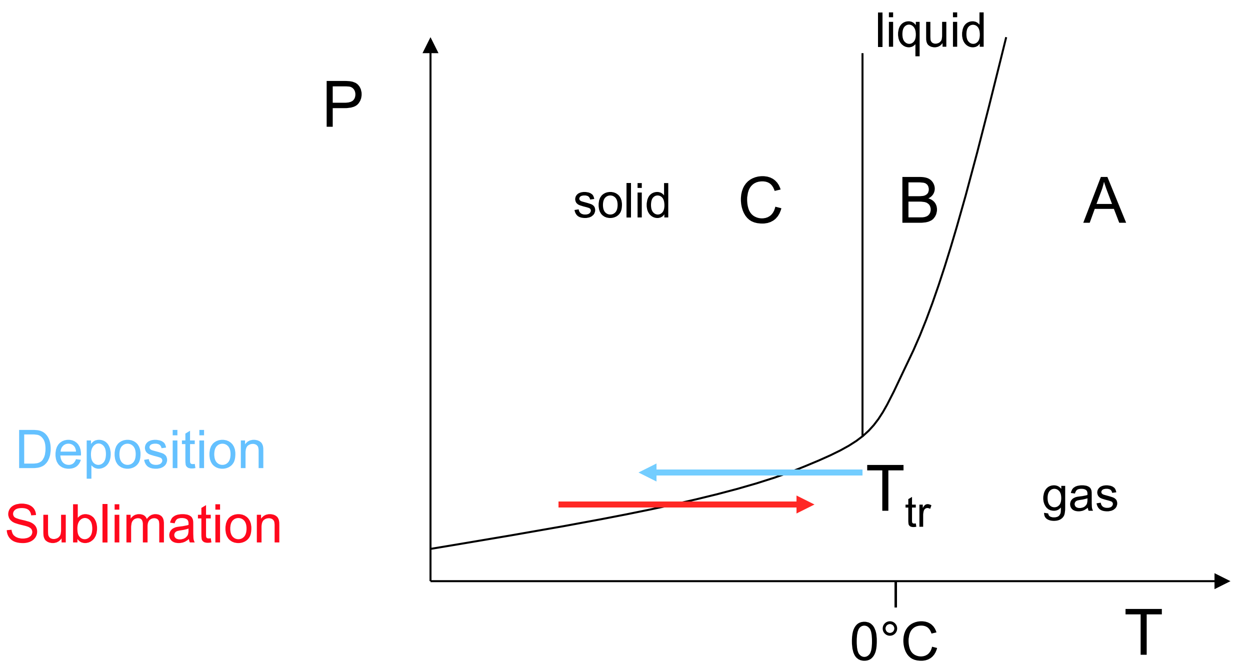
Structure
Composition
Clouds
Photochemistry
Meteorology
Atmospheric Escape





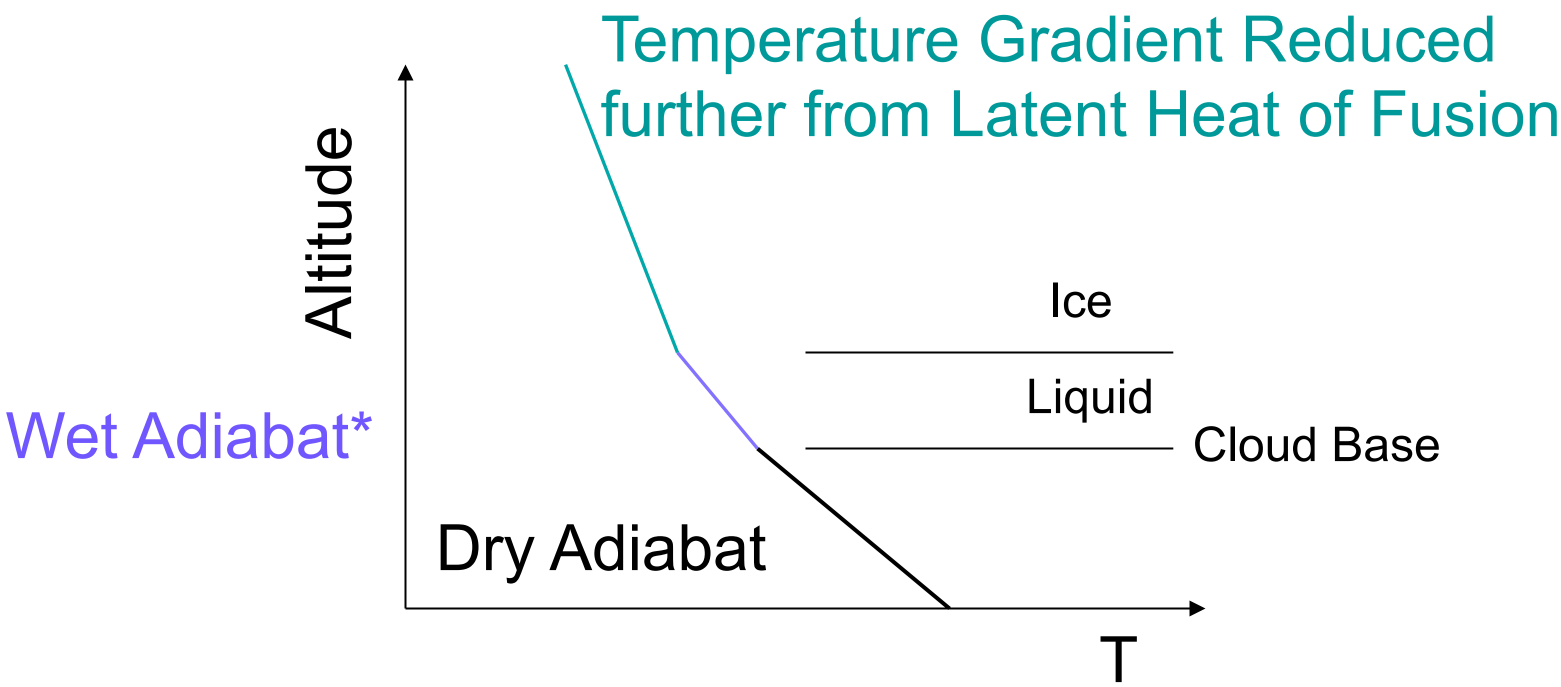
Cloud formation

Saturated Vapor Pressure: Maximum amount of water vapor partial pressure



Cloud formation

The phase change of water has an effect on the temperature structure of the atmosphere as well:



*Thermal gradient reduced due to Latent Heat of Condensation

Clouds

Clouds modify the surface/atmsopheric temperature of a planet in the following ways --

1. Decrease amount of incoming sunlight due to Albedo (reflectivity)
2. Heat immediate environment by absorbing solar radiation, thus changing the lapse rate
3. Blocking outgoing IR radiation can lead to green house warming near the surface
4. Reducing the lapse rate via latent heat release during cloud formation

Cloud formation

Wet Adiabatic Lapse Rate:

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

Saturation Vapor Pressure

$$c_v dT = -PdV - L_S dw_S$$

L_s is *Specific* Latent Heat

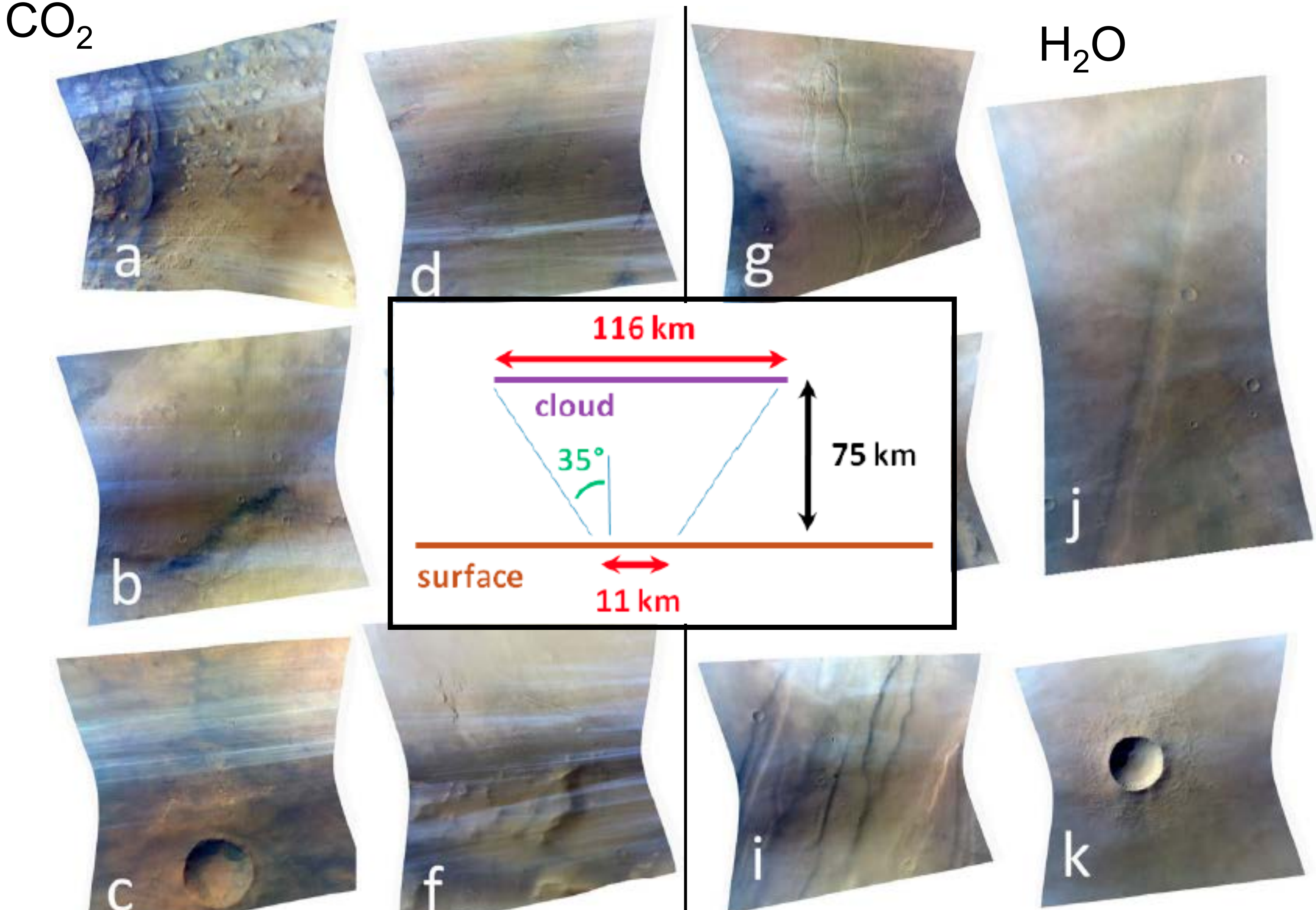
$$c_P dT = \frac{1}{\rho} dP - L_S dw_S$$

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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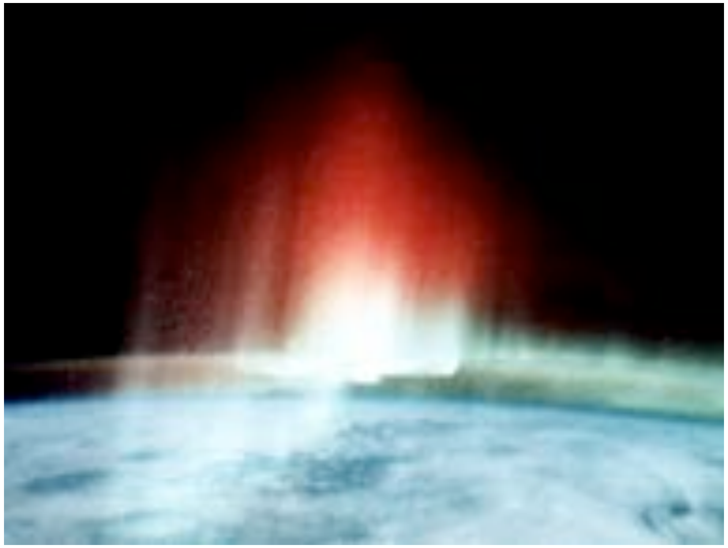
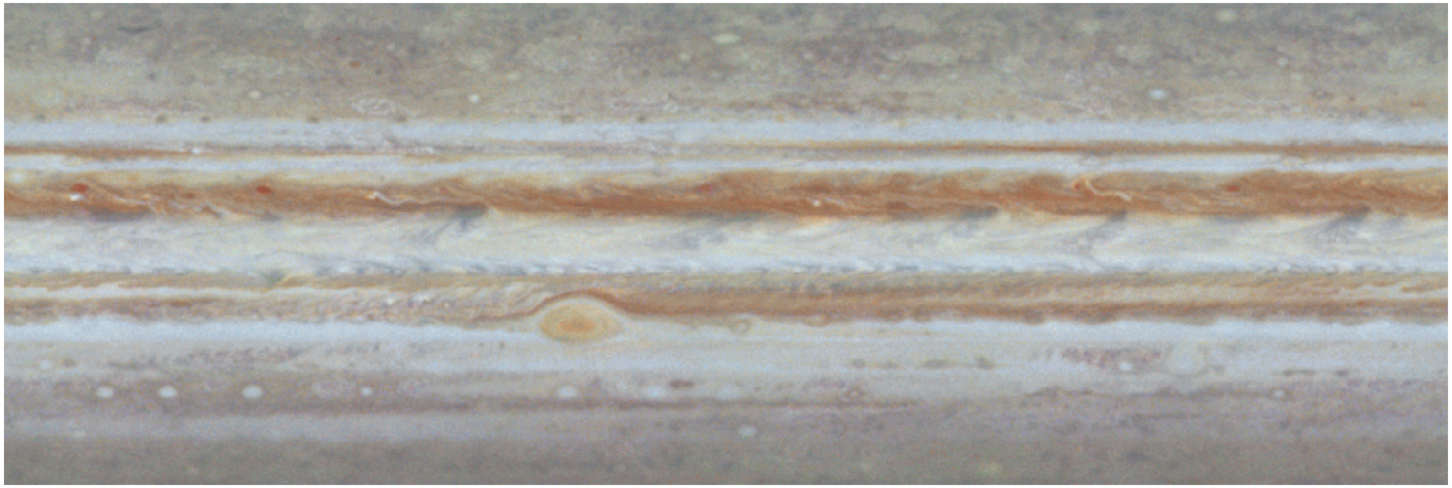




Photochemistry

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 λ < 175nm

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

$$\frac{d[O_2]}{dt} = [O]^2 k_{r2}$$

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

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

Photochemical Equilibrium

Assuming that the system is in photochemical equilibrium (I.e. no net building up or depleting of constituent atoms/ molecules), these reaction rates can be used to derive altitude distributions for each species.

$$k_{r2} \leq k_{gk} = \sigma_x \overline{\upsilon}_o \approx 2\text{x}10^{-10}\sqrt{\frac{T}{300}}$$

$$k_{r3} = \frac{2R}{\overline{\upsilon}_o} k_{r2}{}^2 \approx 10^{-12} k_{r2}{}^2$$

Assuming the gas-kinetic rate of collision, i.e. the upper limit of the reaction rate for direct recombination (where every collision 'sticks'), it's not immediately apparent why the three body production rate dominates at Earth's near-surface atmospheric pressure/density.

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:

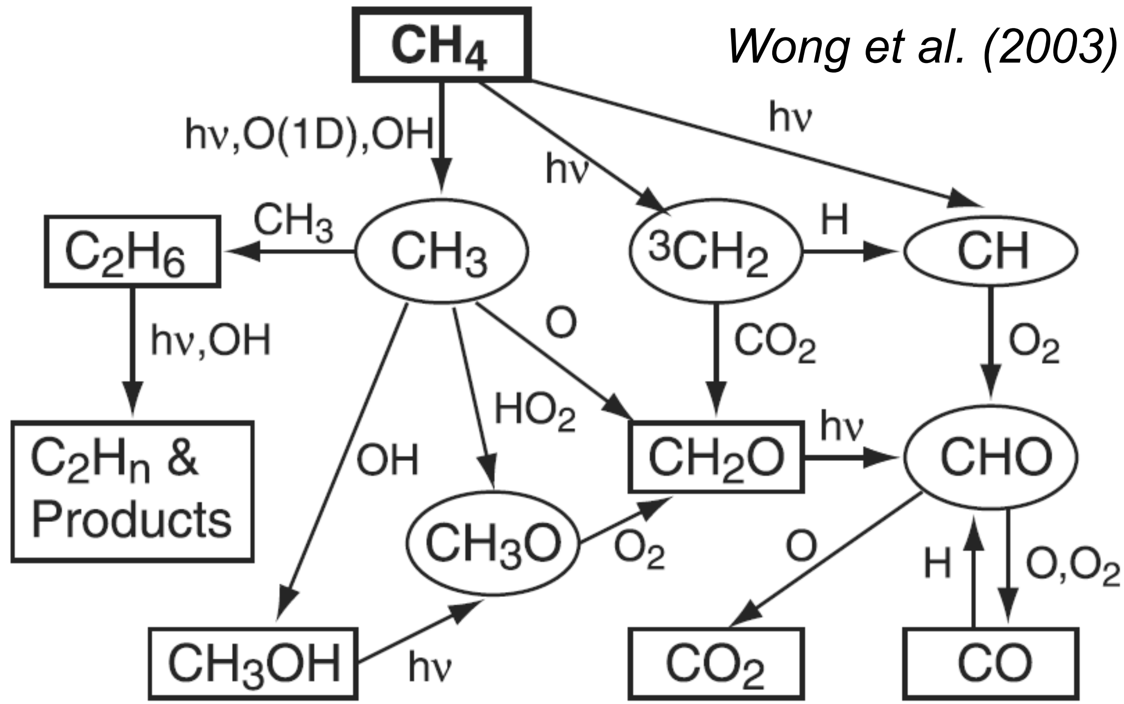
$$O^+ + e^- \rightarrow O + h\nu$$

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 production
  - → ***controversial***