Microwave Interactions with the Atmosphere

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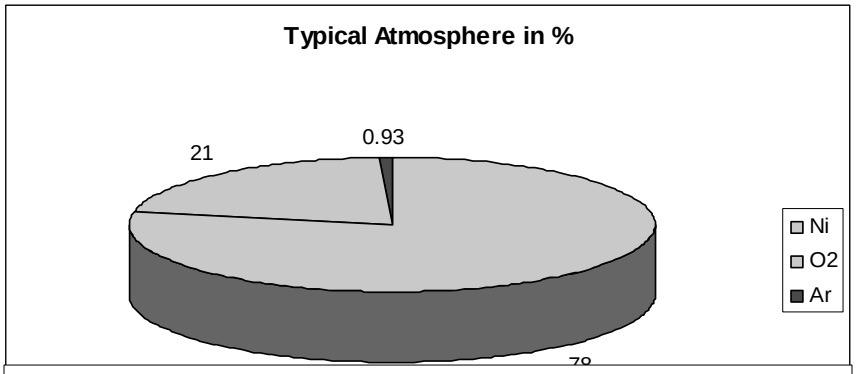
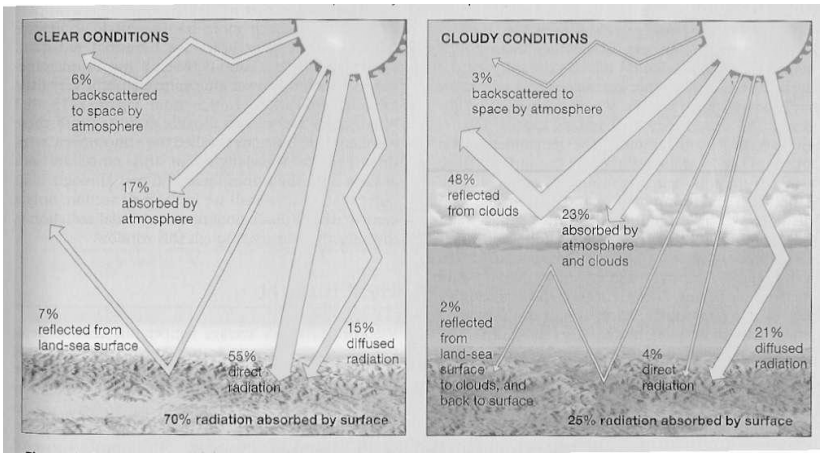
Atmosphere composition



Other components:

Carbon dioxide (CO_2), Neon (Ne), Helium (He), Methane (CH_4), Krypton (Kr), Hydrogen (H_2) and Water vapor (highly variable)

Atmospheric Constituents



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Introduction

- Up to now, we have assumed lossless atm.
- For *1 GHz< f< 15 GHz* ~lossless
- For higher frequencies, =>absorption bands

H_2O	O_2
•22.235 GHz	•50-70GHz
•183.3 GHz	•118.7GHz
•IR & visible	•IR & visible

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Outline

I. The atmosphere: composition, profile

II. Gases: many molecules

1. *Shapes*(*G, VVW, L*): below 100GHz, up to 300GHz

   e.g. H_2O , O_2

2. *Total Atmospheric*

   Absorption κ_g, opacity τ_θ, and atm-losses L_θ

3. T_B: Downwelling Emission by Atmosphere

   Sky Temp= cosmic + galaxy

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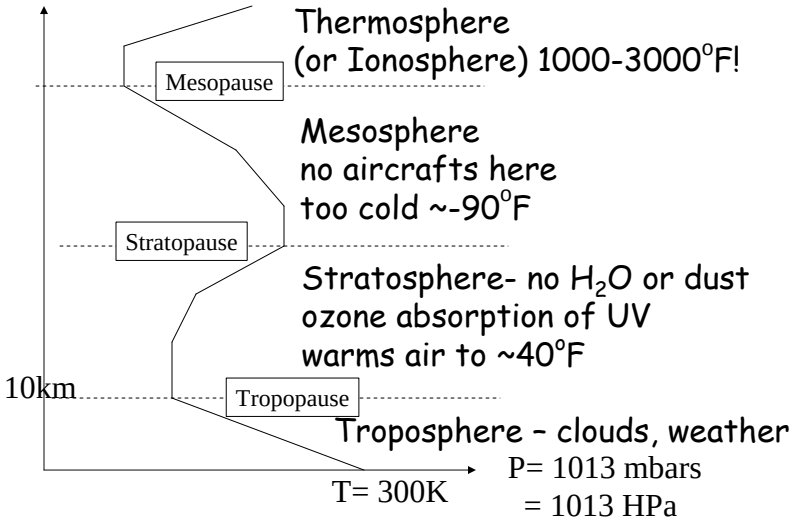
U.S. Standard Atmosphere



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Atmospheric Profiles

US Standard Atmosphere 1962

- Temperature

$$T(z)=\begin{cases} T_o - az & 0 \le z \le 11\,\text{km} \\ T_{(11)} & 11\,\text{km} \le z \le 20\,\text{km} \\ T_{(11)} + (z-20) & 20\text{km} \le z \le 32\ \text{km} \end{cases}$$

- Density

$$\rho_{air}(z) = 1.225 e^{-z/H_1}$$ where $H_1 = 9.5km$ density scale height

or $$\rho_{air}(z) = 1.225 e^{-z/7.3}[1 + 0.3\sin(z/7.3)]$$

- Pressure $P = nRT/V = \rho_{air} RT/M$ or $P_o e^{-z/H_3}$

where $H_3 = 7.7km$ Pressure scale height

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Water Vapor Profile

Depends on factors like weather, seasons, time of the day. It's a function of air temperature.

•Cold air can't hold water

•Hot air can support higher humidities.(*P* dependence)

$\rho_v(z) = \rho_o e^{-z/H_4}$ $[g/m^3]$

where ρ_o *averages 7.72 in mid latitudes and the total mass of water vapor in a column of unit cross section is*

$$M_v = \int_0^\infty \rho_v(z)\,dz = \rho_o H_4$$

where H_4 = between $2 - 2.5km$ water - vapor scale height

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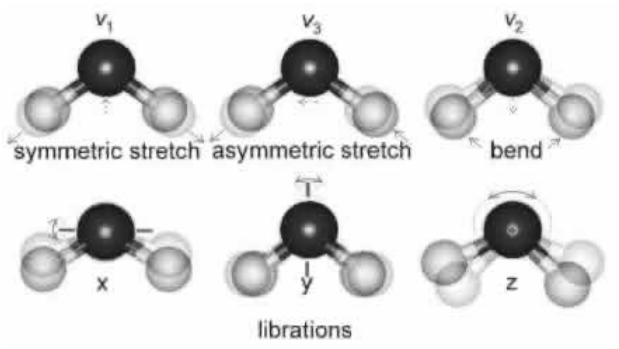

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EM interaction with Molecules

- **Total internal energy state for a molecule**
  - electronic energy corresponding to atomic level
  - vibration of atoms about their equilibrium position
  - rotation of atoms about center of molecule
  - $\mathcal{E} = \mathcal{E}_e + \mathcal{E}_v + \mathcal{E}_r$
- **Bohr condition** $f_{ml} = (\mathcal{E}_m - \mathcal{E}_l)/h$
- **Values for energy differences for**
  - *electronic*: *2* to *10* eV
  - *vibrational-rotational*: *0.1* to *2* eV
  - *pure rotational*: 10^{-4} to 5×10^{-2} eV (microwaves)

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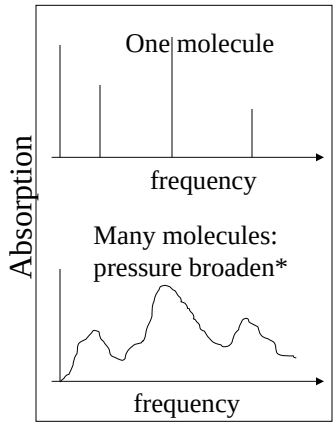
Line Shapes



$$\kappa_a(f, f_{lm}) = \frac{4\pi f}{c} S_{lm} F(f, f_{lm})$$

where,
- S_{lm} is the line strength
- $F(f,f_{lm})$ is the line shape

LINE SHAPES
- Lorentz
- Gross
- Van-Vleck-Weisskopt

*caused by collision between molecules

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Line shapes

- Lorentz $$F_L(f, f_{lm}) = \frac{1}{\pi} \frac{\gamma}{(f - f_{lm})^2 + \gamma^2}$$
- Gross $$F_G(f, f_{lm}) = \frac{1}{\pi} \frac{4 f f_{lm}}{(f_{lm}^2 - f^2)^2 + 4 f^2 \gamma^2}$$
- Van-Vleck-Weisskopt

$$F_{vw}(f, f_{lm}) = \frac{1}{\pi} \left(\frac{f}{f_{lm}} \right)^2 \frac{\gamma}{(f_{lm} - f)^2 + \gamma^2} + \frac{\gamma}{(f_{lm} + f)^2 + \gamma^2}$$

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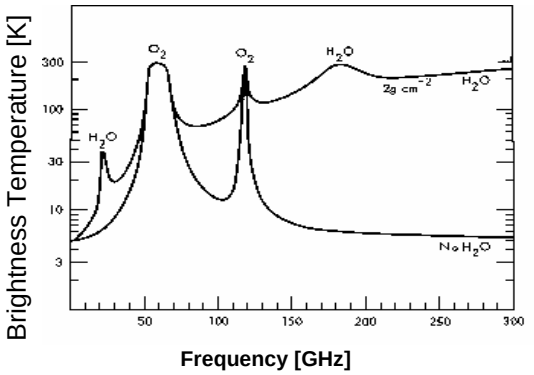
Absorption Bands

- Mainly water and oxygen for microwaves



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Total Atmospheric

- Absorption κ_g,

$$\kappa_g = \kappa_{H_2O} + \kappa_{O_2}$$

- Opacity τ_θ,

$$\tau_\theta = \int_0^\infty \kappa_e(z)\sec\theta dz = \sec\theta\ \tau_o$$

- Loss factor L_θ

$$L_\theta = e^{\tau_o \sec\theta} = e^{\int_0^\infty \kappa_g(z)\sec\theta dz}$$

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Atmospheric Emission

- For clear atmosphere

$$T_{DN} = \sec\theta \int_0^{\infty} \kappa_a(z')T(z')e^{-\tau(0,z')\sec\theta}dz'$$

where $\tau(0,z') = \int_0^{\infty} \kappa_a(z)dz$

Also there is some background radiation

$$T_{extra} = T_{cosmic} + T_{gallactic}$$

T_{cos}=2.7K from the Big Bang and T_{gal}~0 above 5GHz

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Relative Humidity

Air Temperature	Vapor air can hold	Actual Vapor in the air [gr per kg dry air]	Relative humidity
86°F	27.6	10.83	39%
77°F	20.4	10.83	53%
68°F	14.9	10.83	72%
59°F	10.8	10.83	100%

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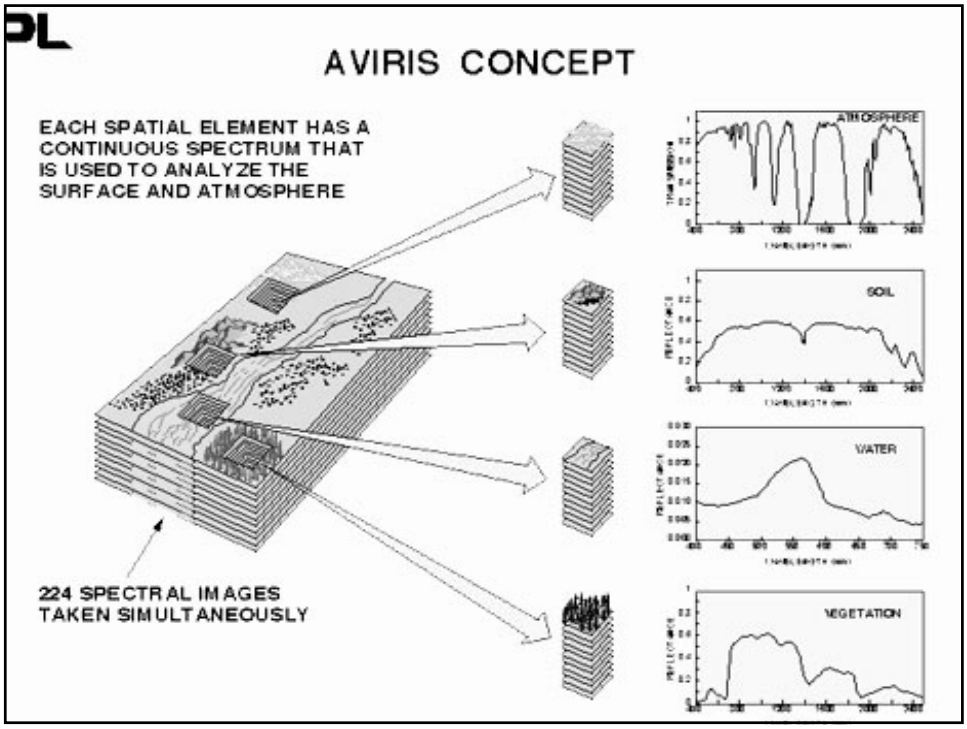
AVIRIS CONCEPT
EACH SPATIAL ELEMENT HAS A CONTINUOUS SPECTRUM THAT IS USED TO ANALYZE THE SURFACE AND ATMOSPHERE
224 SPECTRAL IMAGES TAKEN SIMULTANEOUSLY
ATMOSPHERE
SOIL
WATER
VEGETATION