Topic 2 – Measuring the Solar System

2.1. Orbit – Distance

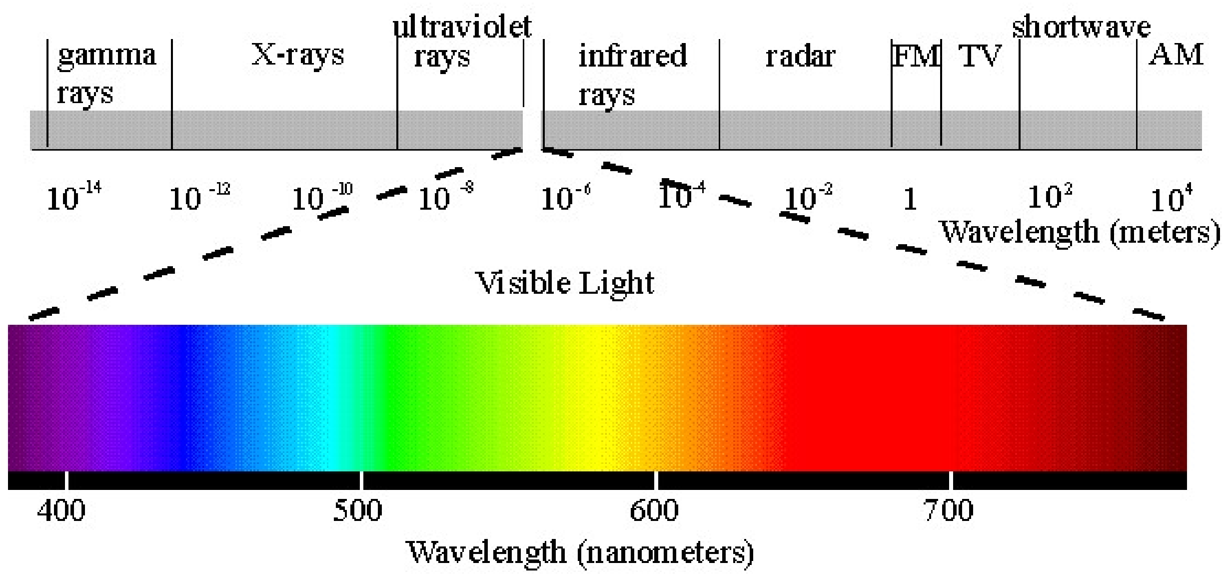
2.2. Mass – Size – Shape

2.3. Mapping – Surfaces and atmospheres

2.4. Mapping – Ages

2.3. Mapping surfaces and atmospheres

Electromagnetic spectrum



Parameters of interest:

energy absorbed/transmitted/reflected

$$\boxed{E = h\upsilon = \Delta E}$$

molecular/atomic level transitions

$$\boxed{\lambda = \frac{c}{\upsilon}}$$

wavelengths/frequencies

Planets will radiate energy, depending on their temperature

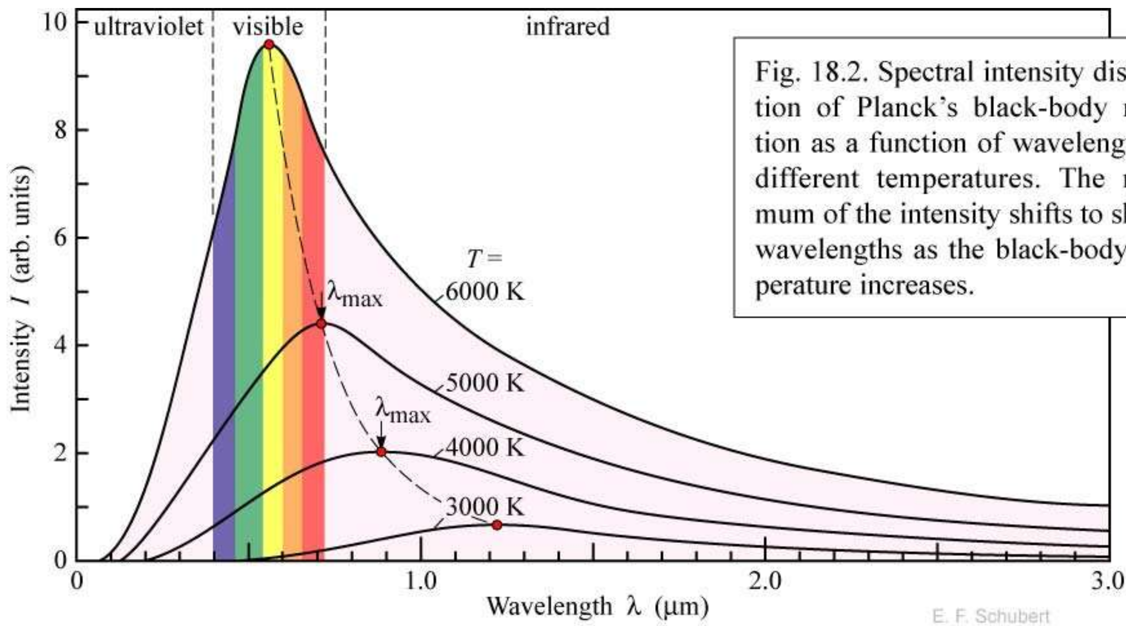


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

Planck's law for black-body radiation at temperature T

$$\boxed{B(\upsilon) = \frac{2h\upsilon^3}{c^2} \times \frac{1}{e^{\frac{h\upsilon}{kT}} - 1} \Leftrightarrow B(\lambda) = \frac{2hc^2}{\lambda^5} \times \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}}$$

Integrating over entire spectrum (Stefan-Boltzmann's law):

$$\boxed{\int_0^{+\infty} B(\upsilon)\,d\nu = \int_0^{+\infty} B(\lambda)\,d\lambda = \sigma T^4}$$

where $\sigma = 5.671 \times 10^{-8}$ W m^{-2} K^{-4} is Stefan's constant

Simple relation between black-body temperature and maximum emitted at frequency ν_{Max}:

$$\boxed{\frac{T}{\nu_{Max}} = 0.5099\ \mathrm{cm \cdot K}}$$ (Wien's law)

For wavelengths, B(λ) maximum for: $\boxed{\lambda_{Max} \times T = 2898\ \mu\mathrm{m \cdot K}}$

one eqn to remember

The colder an object, the higher the wavelength emitted.

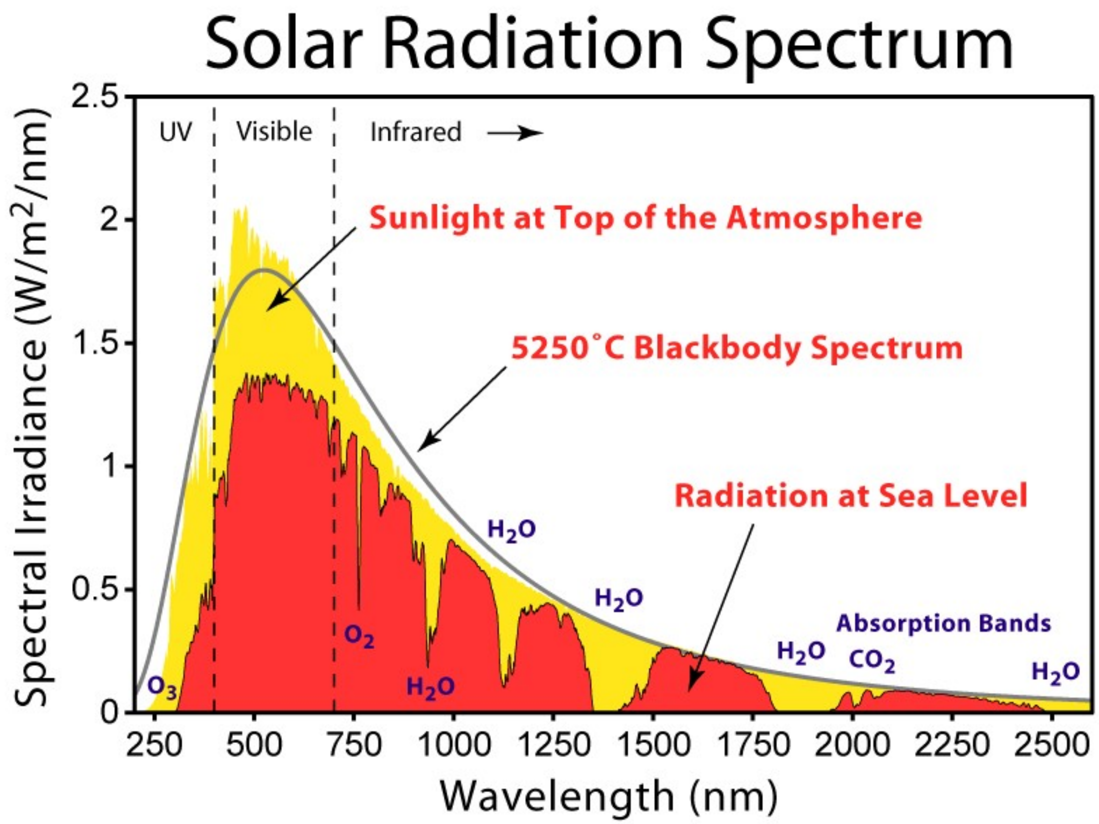
In the Solar System, planets emit between ~ 9 μm (Mercury) and ~110 μm (Pluto).

Intrinsic thermal radiation of planets is therefore negligible in the optical domain (0.4-0.8 μm)

We can still see planets with the naked eye/telescope. Why?

Radiation from the Sun is reflected according to planet's composition.

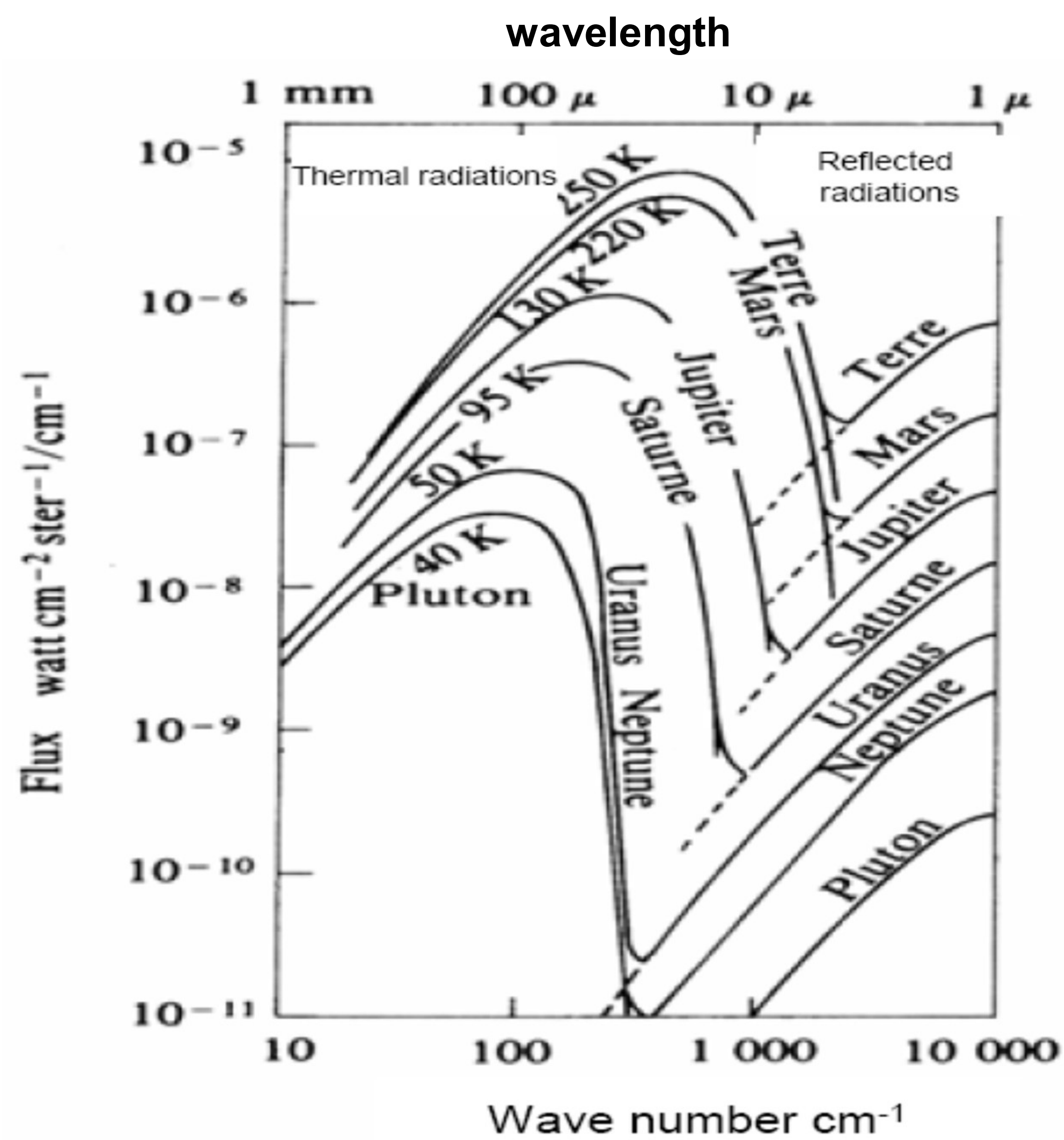
This means the surface (if visible at particular wavelength) and the atmosphere



Earth measurements

It varies with amount of solar radiation (closer or further from Sun)
(e.g. comets: increasing in brightness as closer to Sun)

It varies with atmospheric processes (e.g. white cloud vs. black rock)



Th. Encrenaz, Space Science Review, 1984.

can b smaller

Albedo = ratio of radiation reflected (~ 0.5 for icy satellite, ~ 0.01 for asteroid)

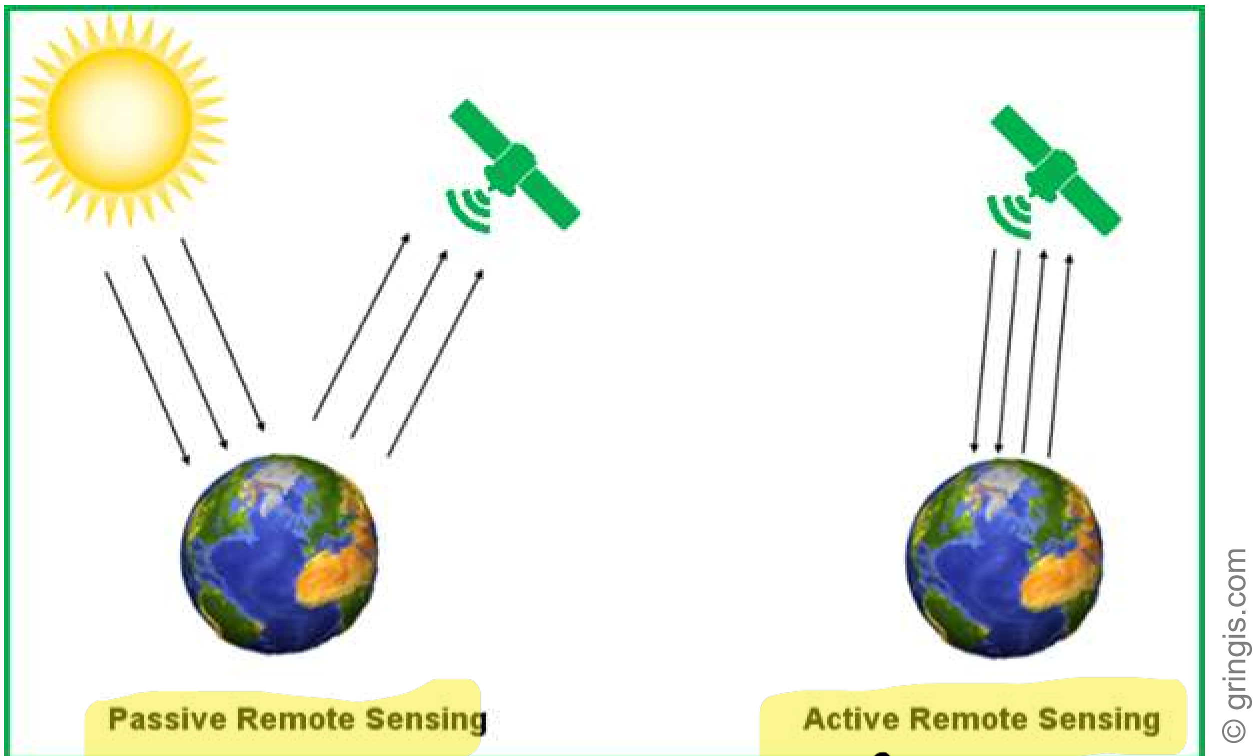
1 Albedo = perfectly reflected (mirror)

0.5 Albedo = icy surface

to see

EM radiation: natural (e.g. Sun) or artificial (e.g. radar)

Role of atmosphere: need for different wavelengths (different depths?)



V might be able to see some bodies better at certain wavelengths

need more power

Passive remote sensing most common in planetary exploration
Active sensing: constrained by power budget (space probe or from Earth)

2.3. Mapping surfaces and atmospheres

Planetary atmospheres can obscure views of the surface

UV u see more of the surface

… at least at some wavelengths (different atmospheric components)

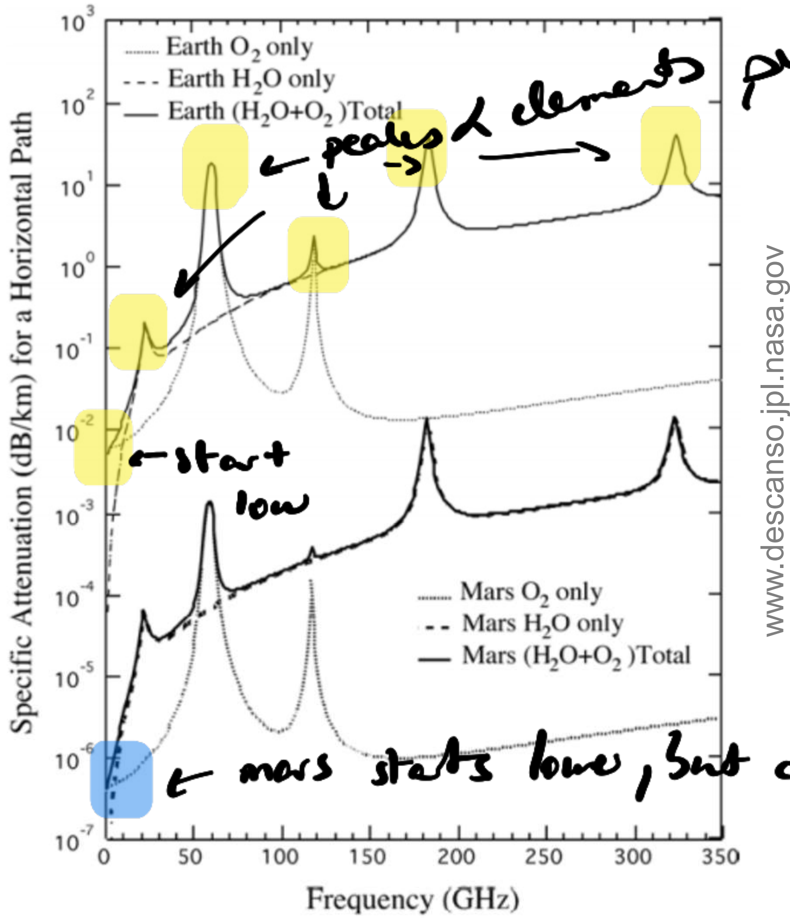
diff λ = diff components

© NASA

If the atmosphere is too thick, we can only measure its own rotation period.

We need to account for the attenuation at different wavelengths

Varies with location and varies with time



← peaks & elements present

← start low

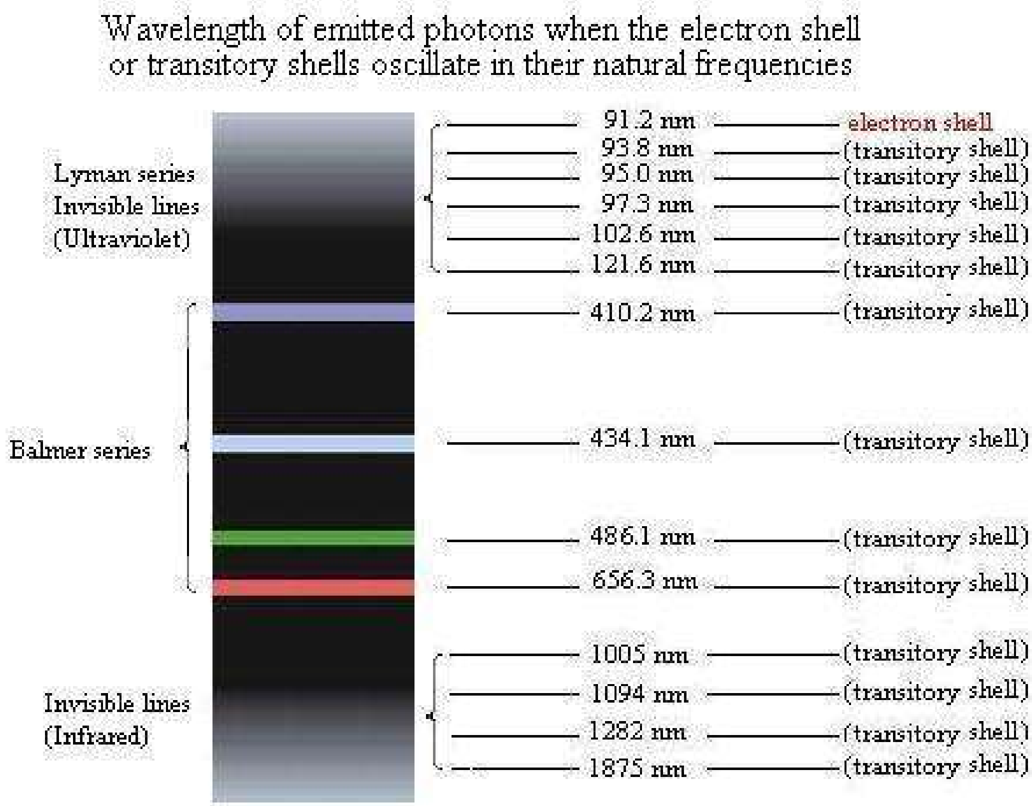
← mars starts lower, but also shows peaks & present elements

gives indicat° about present materials

Figure 4-5. Gaseous Specific Absorption Attenuation by Water Vapor, Oxygen, and Both at the Surface of Earth and Mars. The upper three thin lines are for attenuation at Earth, while the lower three thick lines are for Mars.

Radiation affected by transition/recombination processes:

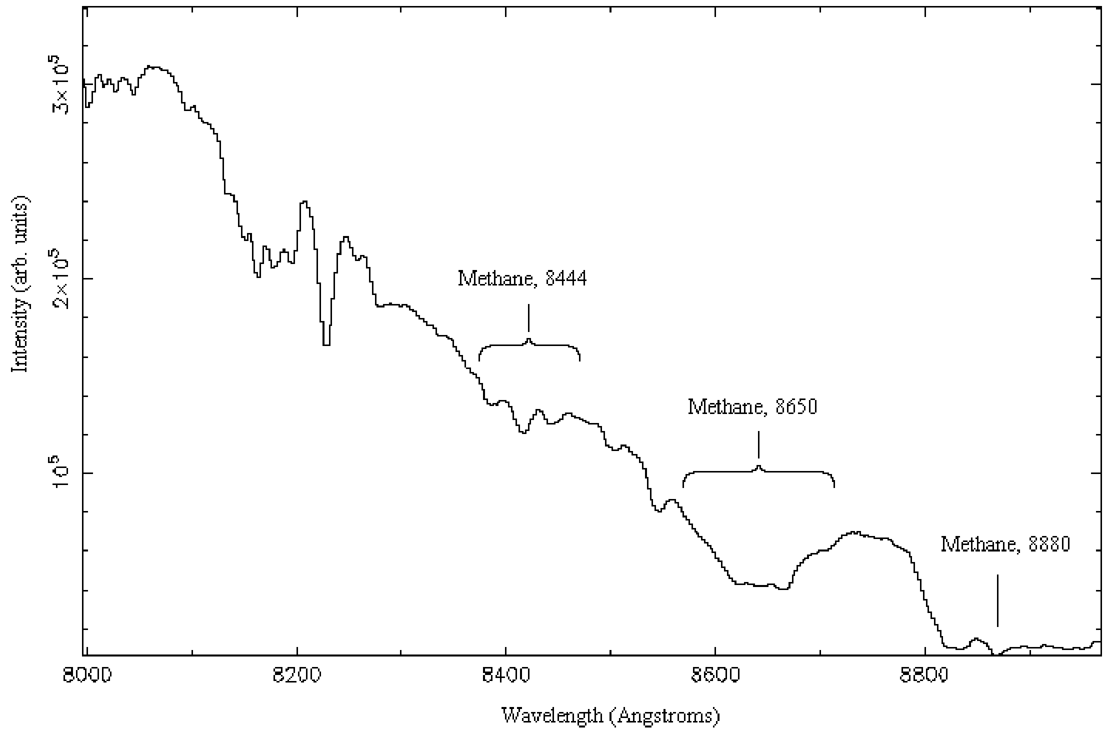
Higher temperature ⇒ higher energy ⇒ higher levels ⇒ different transitions



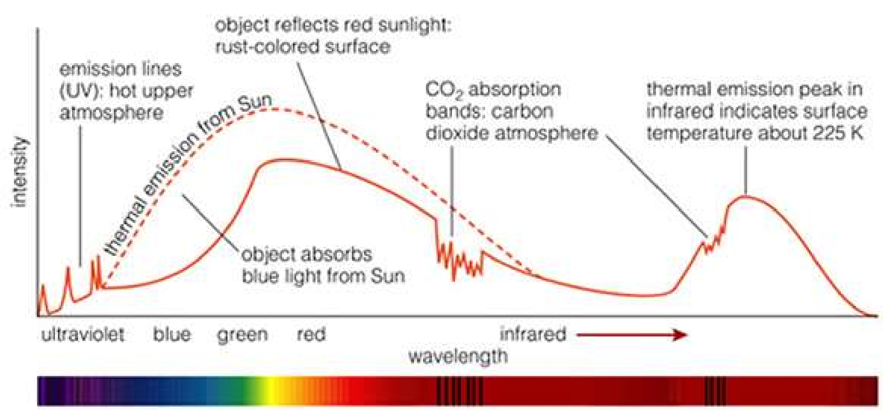
(Year 1 labs: Balmer series of Hydrogen)

Complete spectra give indication of planetary surface and/or atmosphere composition

Jupiter



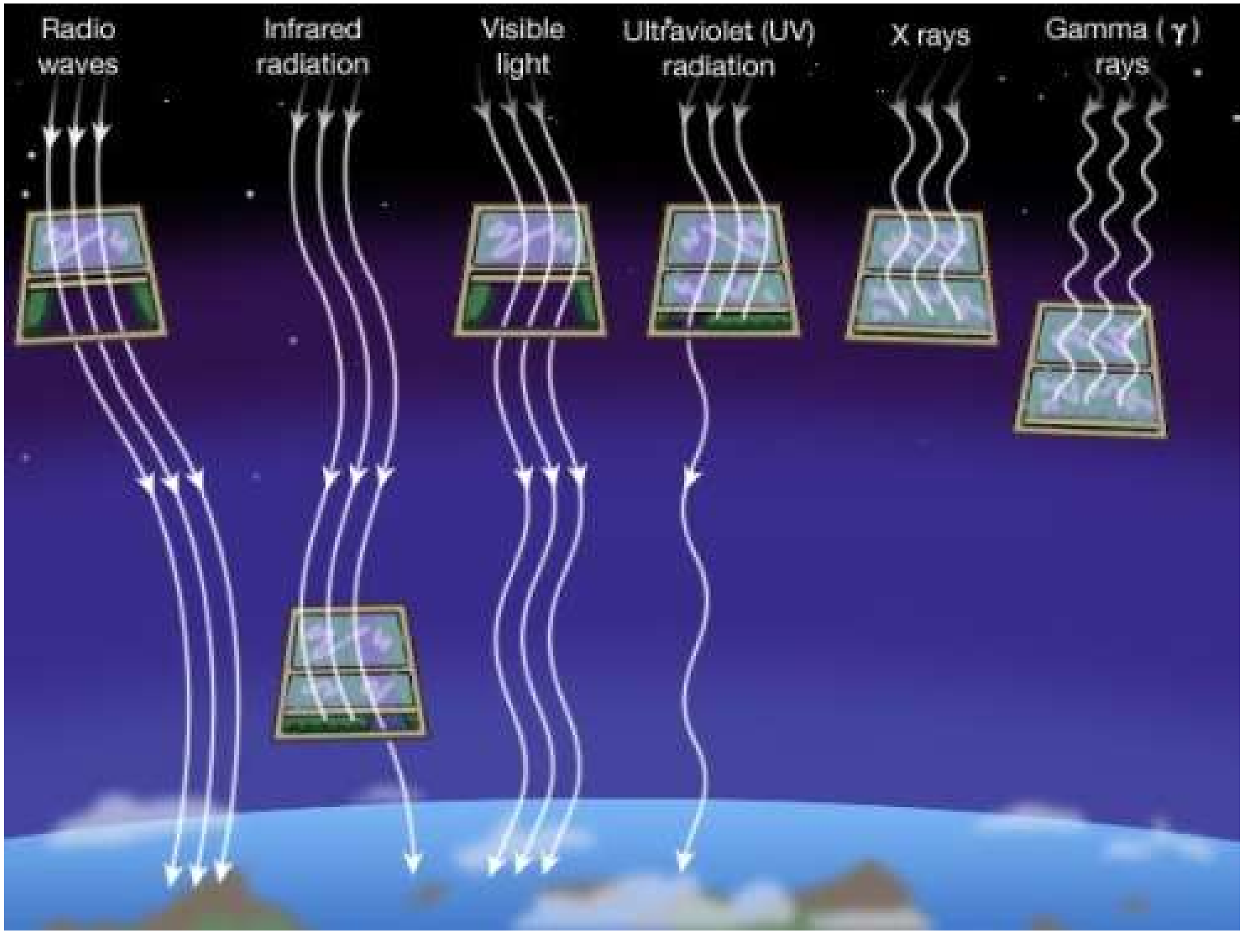
Mars



Rotation rate

Determined from visual or radar (Doppler) observations

Uses different wavelengths for different depths



Measuring the Solar System

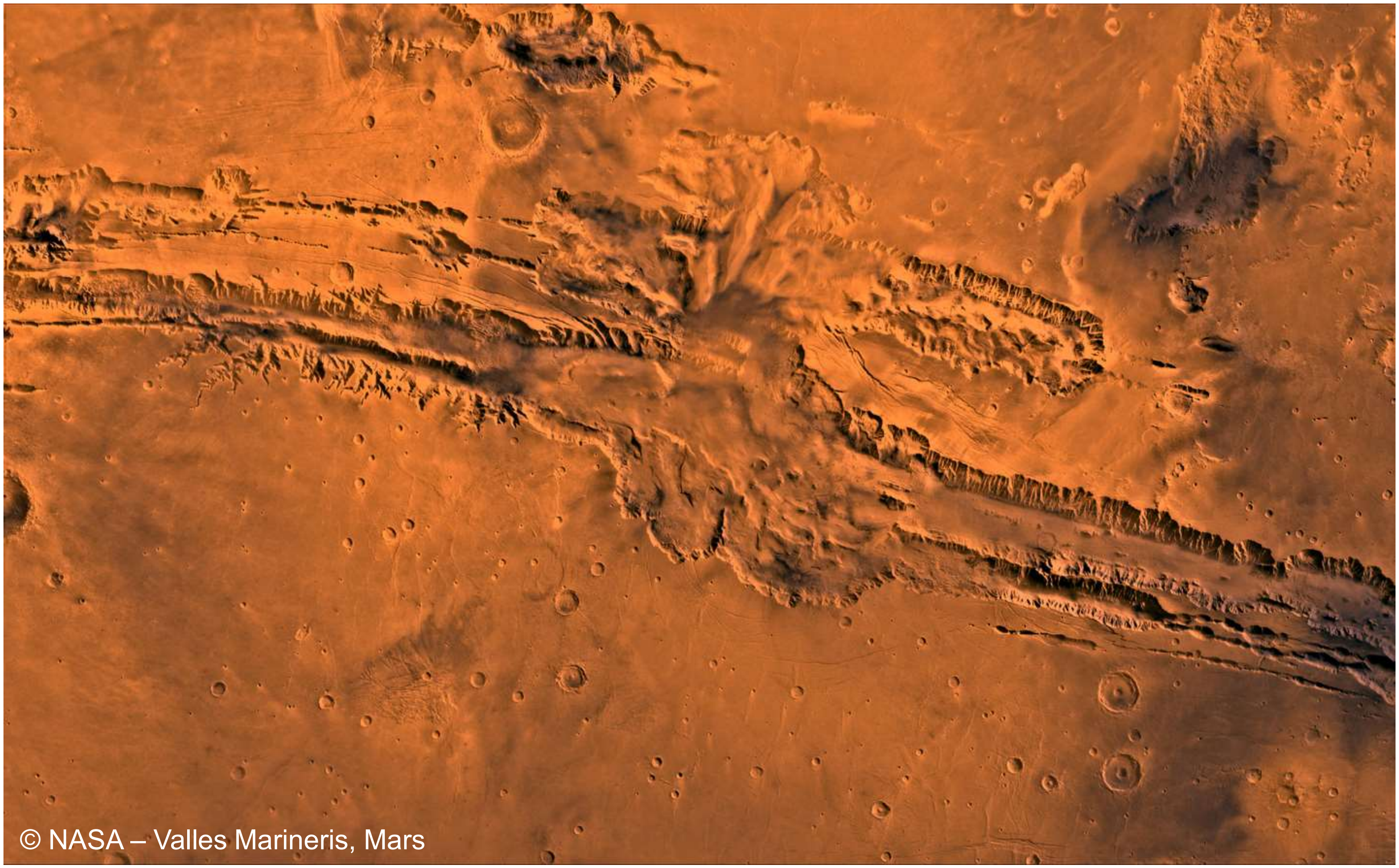
√ **2.1. Orbit – Distance**

√ **2.2. Mass – Size - Shape**

√ **2.3. Mapping – Surfaces and atmospheres**

2.4. Mapping – Evolution

2.3. Mapping - Planetary evolution



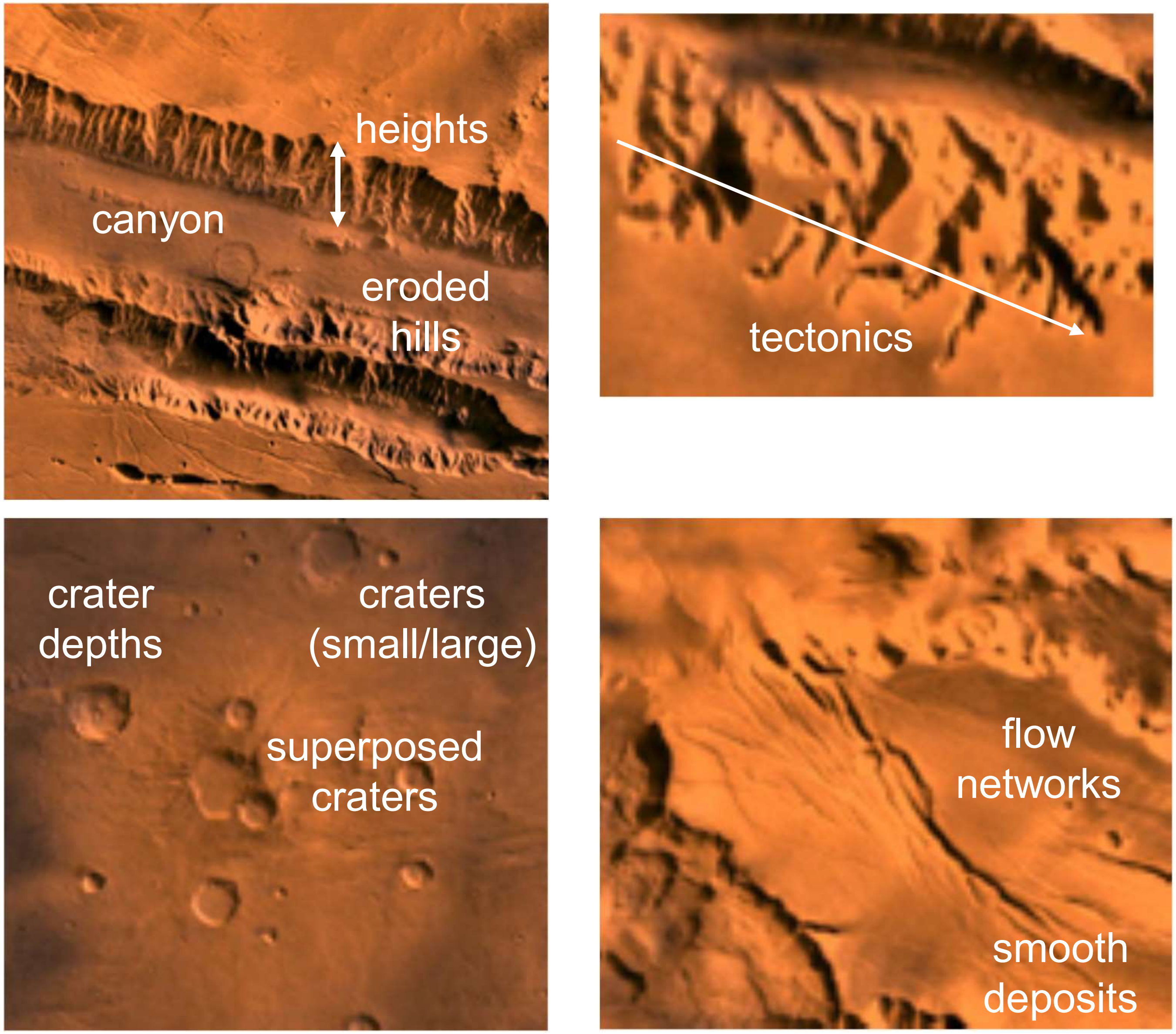
© NASA – Valles Marineris, Mars

What can this image of the surface tell us?

~ grand canion

techtoniq plaques

Mapping of surface units



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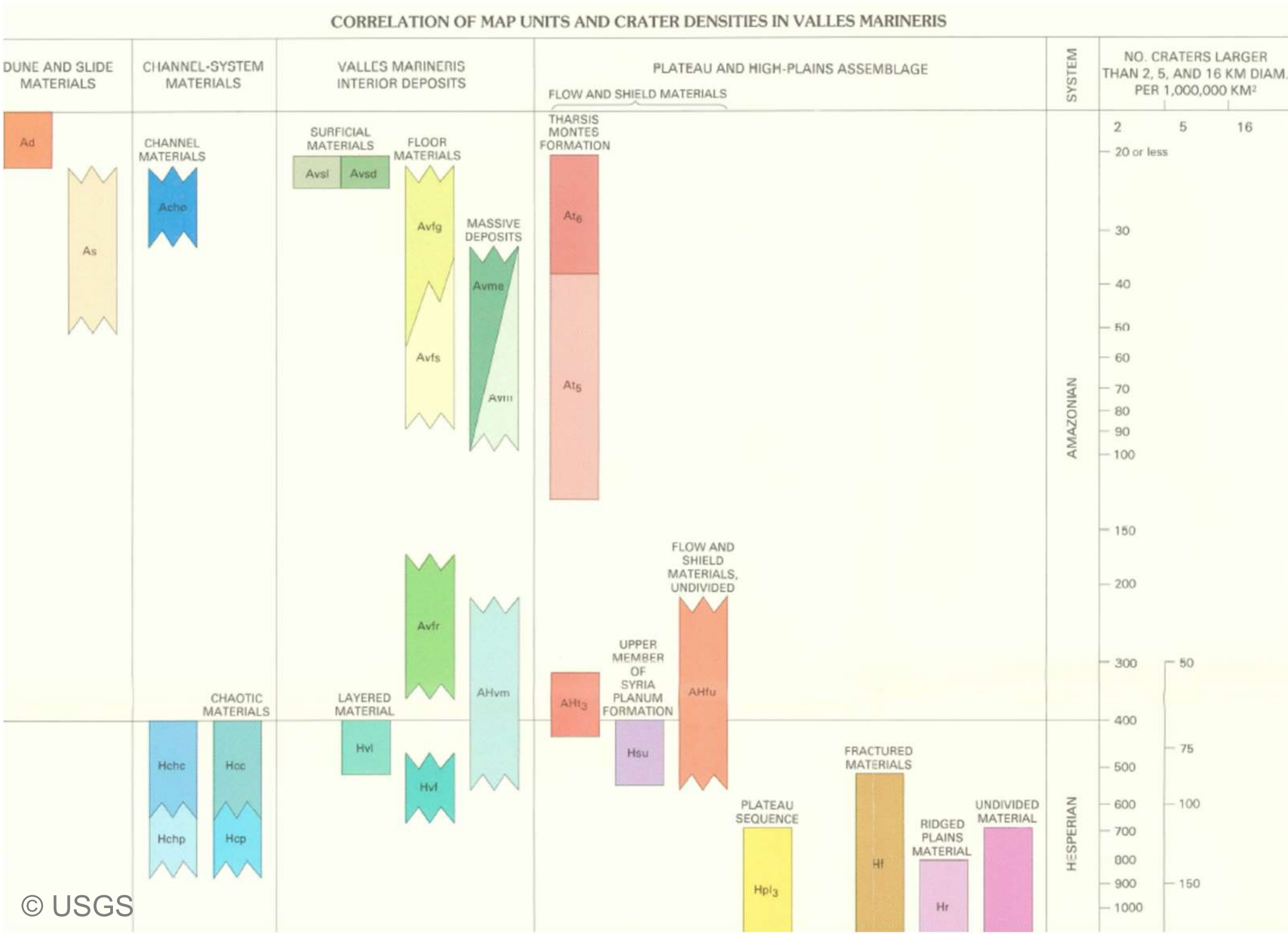
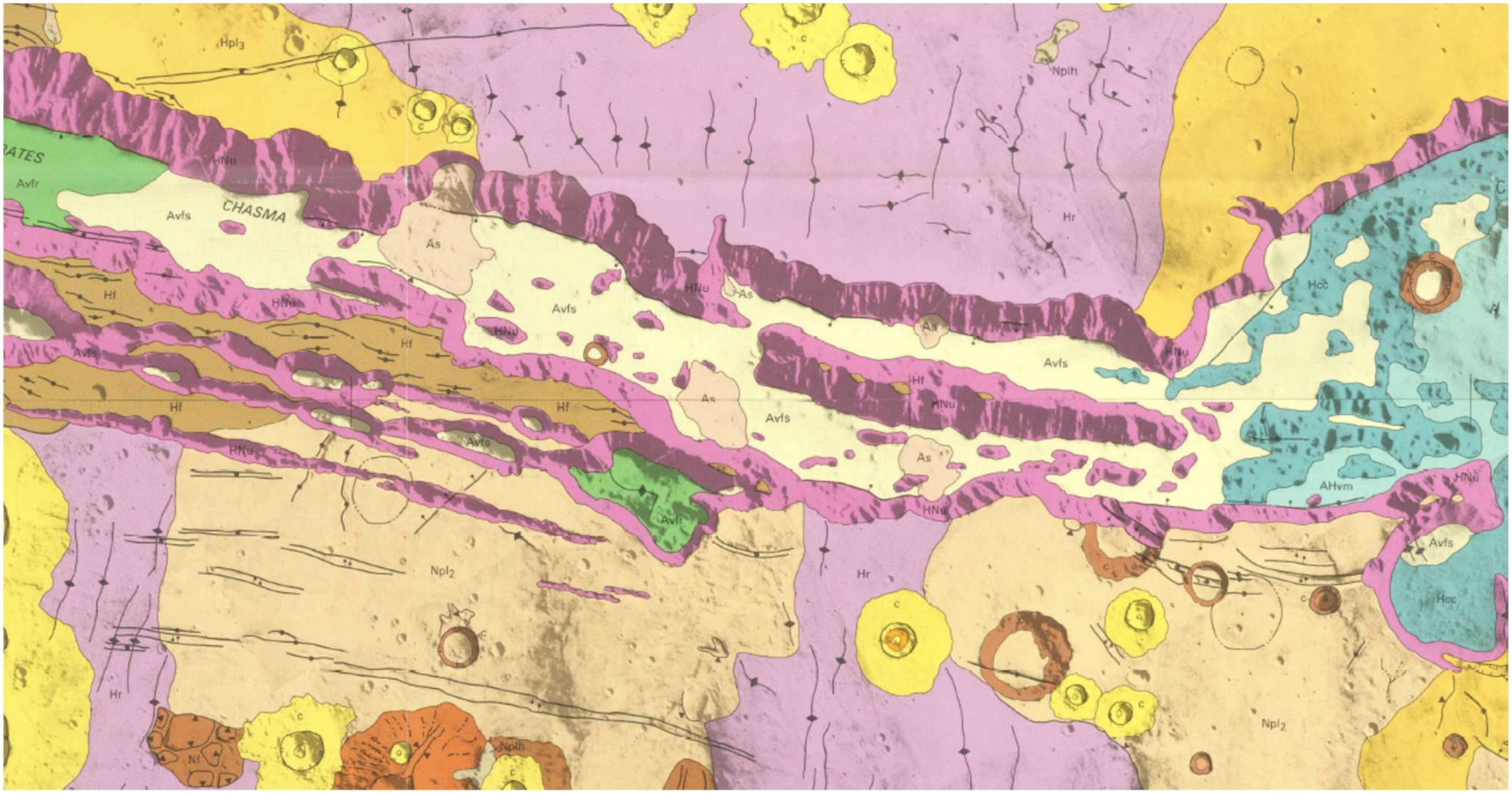
Relative mapping of surface units



Flow networks are used to delineate different geological episodes

Densities and superposition of craters are used to infer relative dates

Relative mapping of surface units



Geological complexity shows different stages of evolution

But in what order? We can assess this with crater densities and superposition of features. But it is still very subjective/relative.

Absolute dating

Atmospheric composition: isotopic ratios give estimate of ages and replenishment rates:

$$\boxed{N = N_0\, e^{-\lambda t}}$$

(PH20016 *Particles, Nuclei and Stars*)

N: fraction of isotopes (from starting number N_0)

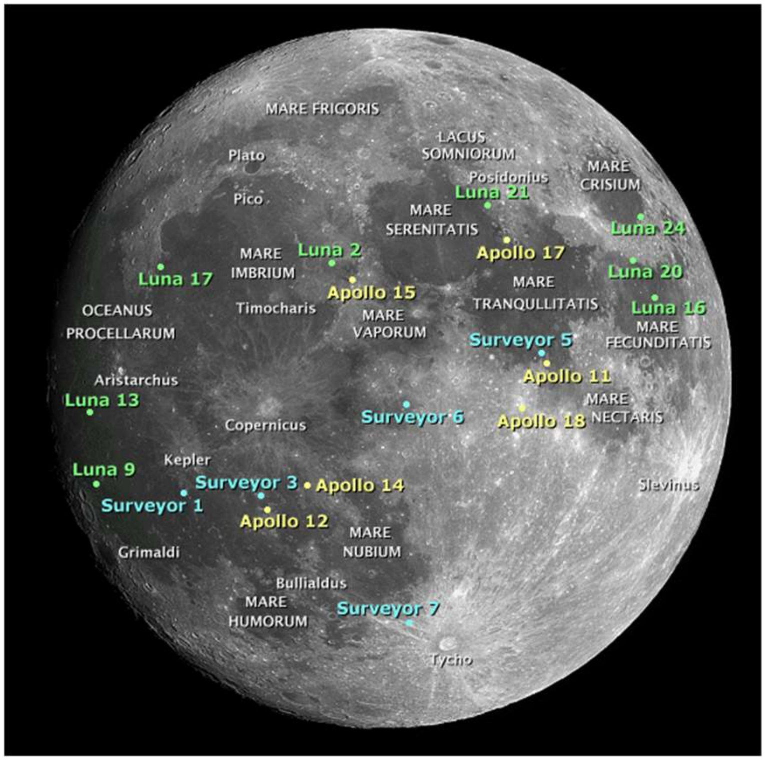
Typical elements: ^{244}Pu, ^{129}I,^{12} C, ^{7}N, ^{17}O/^{18}O, ^{89}Sr, ^{39}Ar/ ^{40}Ar
Can also be used *in situ*

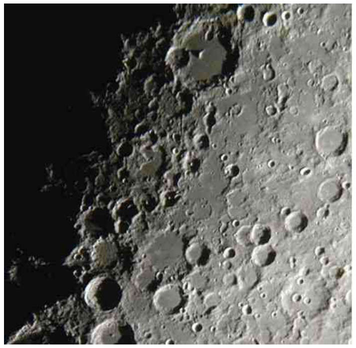
Long-term dating: (^{40}K, ^{40}Ar), (^{87}Rb, ^{87}Sr) and (^{238}U, ^{238}Pb)
with respective decay constants 5.8×10^{-11} yr^{-1}, 1.4×10^{-11} yr^{-1}, 1.5×10^{-11} yr^{-1}

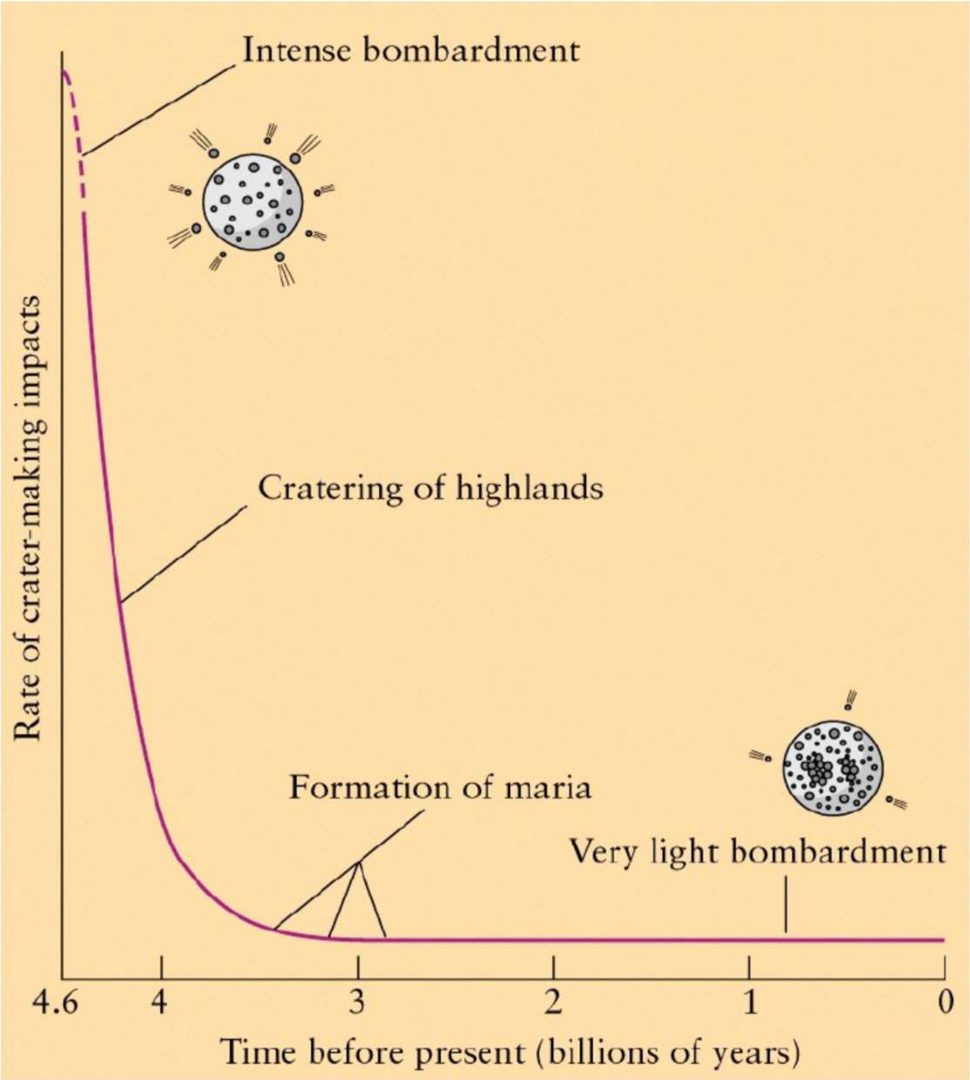
Yields Solar System age of 4.55×10^{9} years (from meteorites)

Has been used on Earth (extensively) and on Moon (at landing sites)

Used to calibrate relative dating from impact cratering (from Moon/Earth meaurements)







Measuring the Solar System

√ **2.1. Orbit – Distance**

√ **2.2. Mass – Size - Shape**

√ **2.3. Rotation of surface/atmosphere**

√ **2.4. Mapping – Ages**