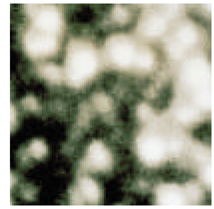
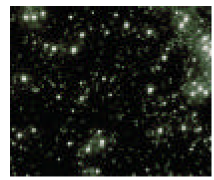
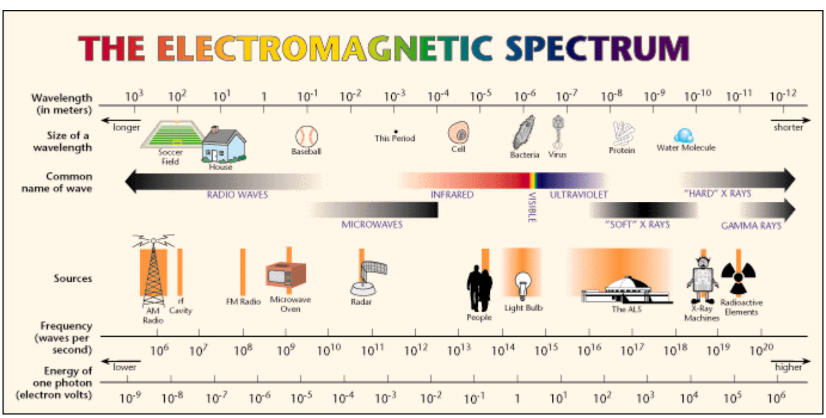
Effects of Earth's Atmosphere on Astronomical Observations

1. Limited wavelength ranges
   （有限的波段）
2. Extinction (消光)
3. Refraction（折射）
4. Curvature （曲率）
5. Atmospheric turbulences
   （大氣擾動）







http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html

1. Limited wavelength ranges

Transparent relatively in optical and radio (and some infrared) ➔ atmospheric “windows”

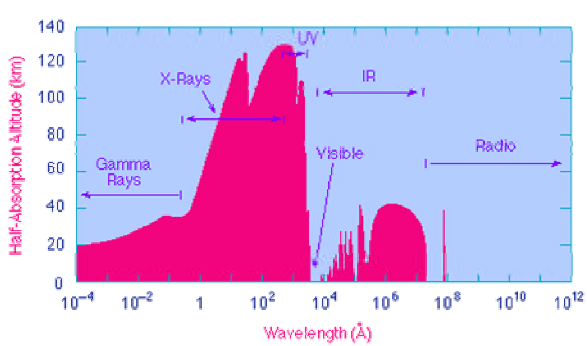
Optical window: 300 nm to 1.4 μm

- O_3 (ozone) H=25 km
- H_2O, CO_2 …

Radio window : 8 mm to ~15 m → Reflection in ionosphere H~100 km

Plasma frequency

Atmospheric Windows



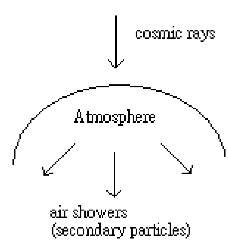
http://csep10.phys.utk.edu/astr162/lect/light/windows.html

Q：波長越短應該吸收越多 但為何γ射線吸收少？

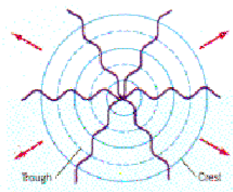
大氣吸收的機制：

— **電子躍遷** (electronic transition)
— **分子振動** (vibration; stretching)
— **分子彎擺** (bending)
— **分子轉動** (rotation)

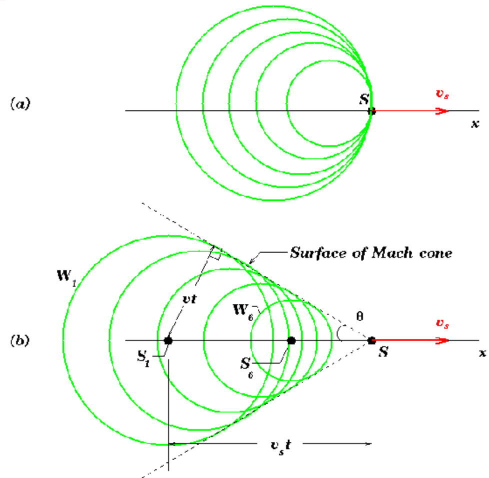
- In addition to photons, the atmosphere also stops energetic charged particles → **cosmic rays** (mainly p^+, e^-) from space; $E \sim 10^{10}$-10^{20} eV
- Atmosphere ≈ 1 m of lead
- High-speed particles, if v ↑↑ ➔ $v > c/n$ (=light speed in the medium, n: refractive index) → **? erenkov radiation**



Cerenkov radiation



A source emits spherical wavefronts



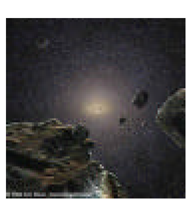
http://dept.physics.upenn.edu/balloon/cerenkov_radiation.html

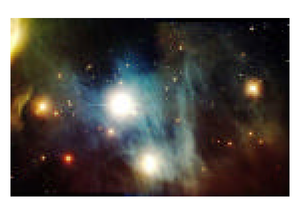
- Even beyond earth’s atmosphere, there is absorption

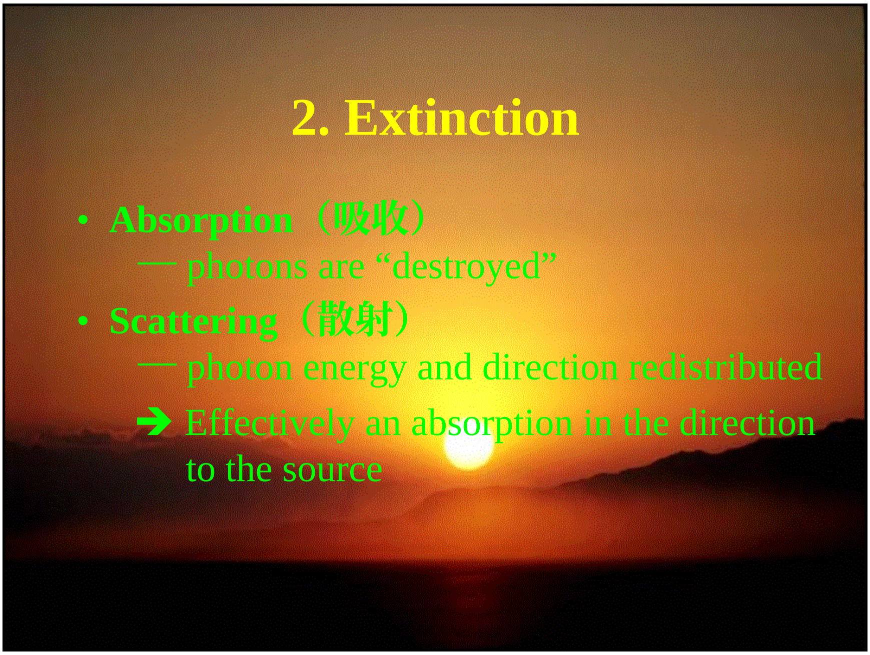
→ [dust + gas] in the solar system, in the interstellar medium（星際物質）, and circumstellar medium（環星物質）

Dust → strong absorption in visual and UV

Gas → strong absorption in EUV and soft X-ray







Q：如何知道某顆星有多亮？

觀測　但，觀測什麼呢？

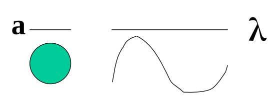
來自天體的電磁波 → 星際消光
→ 大氣消光 → 望遠鏡收集
→ 偵測器感應 → "讀數" (count)

把這個讀數和「標準星」的讀數相比 → 亮度

例如某顆星的讀數為 1000.0，**而利用相同儀器某標準星（視星等為**9.0**等）讀數為** 500.0，**那麼** …

Q: Why is the sky blue？

Scattering ….



Size of particles ˜ a

1. 2 π a << λ (radio) Þ **scattering ? λ**

   $I_{scattering}$ µ λ^{-4} **(Rayleigh scattering)**

   ∴ **Blue** sky

2. **2 π a >> λ Þ scattering ≠ λ**

   ∴ **Gray** sky in a cloudy day!

3. **2 π a ˜ λ (dust, optical) Þ $I_{scattering}$** µ λ^{-1}

   ⇒ Interstellar reddening (紅化)

3. Refraction

Apparent Altitude	Angle of Refraction
0	35’21”
1	24’25”
3	14’24”
10	05’18”
30	01’41”
60	00’34”
90	00’00”

- Sun/moon at zenith distance = 90 ° (refraction ~ 35’), but their sizes ~ 30’, so when we seen center at horizon, they in fact are below the horizon

4. Curvature

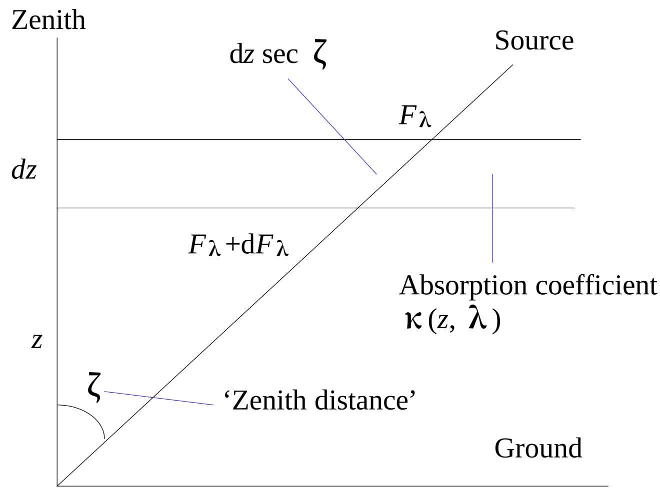
Curvature and refraction can be ignored if zenith distance ≦ 45 °

If we ignore curvature and refraction,

→ Atmosphere = a series of plane parallel layers, with thickness dz at height z.

$$dF_l = -kF_l \cdot \sec z \, |dz|$$

where $\kappa = \kappa(z, \lambda)$ is the absorption coefficient



忽略大氣折射與曲率，來自天體的光線穿過系列平行大氣層，強度不斷減弱

If F_0 = flux outside atmosphere, then integrating z, we obtain flux at ground level (z=0)

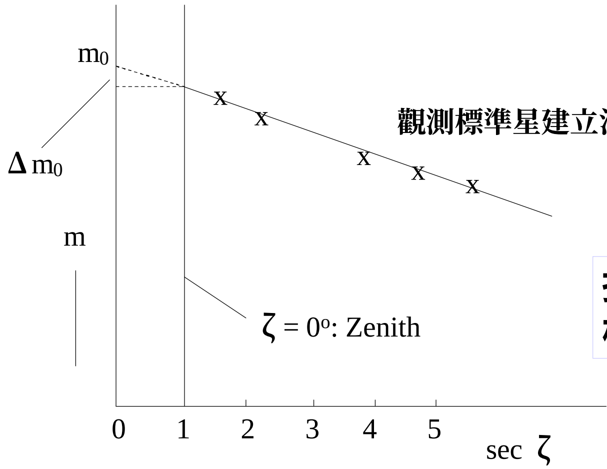
$$\Rightarrow F_l(z) = F_0 \exp[-\sec z \int_0^\infty k(z,l)dz]$$

At the zenith (ζ =0)

$$F_l(0) = F_0 \exp[-\int_0^\infty k(z,l)dz]$$

$$\Rightarrow \log F_l(z) = \log F_0 + \sec z \cdot \log \frac{F_l(0)}{F_0}$$

Since $m_l = -2.5 \log F_l + const$



據以修正目標星星等

視星等與 sec ζ 的關係,
並外差到大氣以外的數值

$$m_l = m_0 + \Delta m_0 \cdot \sec z$$

m_λ: observed from ground
m_0 : would have observed outside atmosphere
Δm_0 : absorption in terms of magnitude at zenith

(cf. $y = b + ax$)

So, m_0 and Δm_0 can be estimated by measuring m_λ(observable) at different ζ (known).

For ζ ≧60 ° , refraction and curvature have to be considered

Define similarly, $m_l = m_0 + \Delta m_0 \cdot M(z)$

where M(ζ) is the **air mass** = absorption (length) along the curved light-path

For small ζ , *M* (ζ) ˜ sec ζ

亦即若天頂角小, sec ζ **約就是大氣質量**

Otherwise → determine empirically

⇒ look-up table

But air is not static

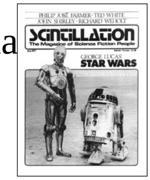
➔ Try to observe as close to zenith as possible

Apparent zenith distance (degrees)	Air mass
40	01.30
50	01.55
60	02.00
70	02.90
75	03.82
80	05.60
85	10.40
87	15.36
88	19.79

5. Atmospheric Turbulences

大氣擾動 → 有如在游泳池底看世界

Cause the stellar image to

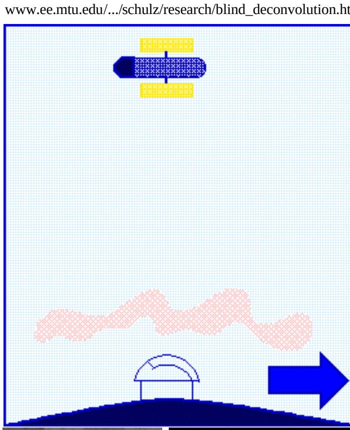


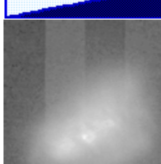
- blink (**scintillation**) — variation of air ma along line of sight **一閃一閃亮晶晶**
- move around (‘**seeing**’) — variation of refractive index along line of sight **晃來晃去看不清**

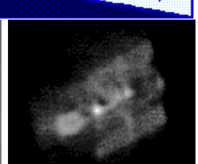
“seeing” (**視相寧靜度**) → a point source, after long exposures, is smeared into a ‘seeing’ disk

Typically, seeing (disk) ~ a few arcsec across

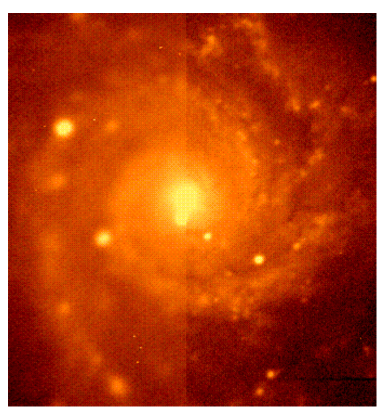
www.ee.mtu.edu/.../schulz/research/blind_deconvolution.html




Distorted image


Restored image of HST

Effects of Astronomical Seeing --- M74 (NGC 628)



http://www.astr.ua.edu/gifimages/m74seeing.html

- Extended sources are not affected as much (∵ averaged out)
e.g. Planets $\theta \sim 10''$–$30''$ would appear 'steady' but stars (point sources) 'twinkle'.

Usually optical telescopes are seeing-limited

- At radio λ_s, with very small-scale turbulences, seeing/scintillation are not important

Radio telescopes are diffraction-limited
i.e., limited by the optics, rather than by atmosphere

Radio λ_s are affected by interplanetary and ISM scintillation

To overcome rapid scintillation

⇒ Fast (high-time-resolution) observations

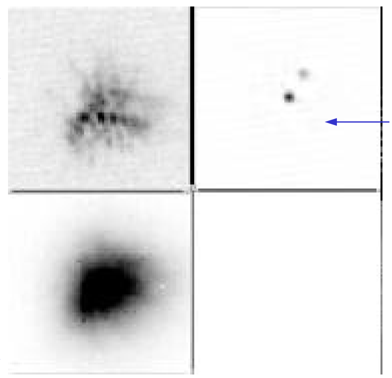
Radio λ_s ⇒ Hewish in 1960s tried to study IS scintillation

⇒ Discovered pulsars

Optical λ_s ⇒ 'speckle' imaging

Speckle Imaging（散斑成像）

連續快速(0.1 s) 曝光，把大氣擾動「凍結」



經過影像處理斑點干涉影像（左圖），發現這是顆雙星

一般長期(40 s) 曝光，大氣擾動造成星點影像模糊

Movie

http://www.ciw.edu/alycia/speckle.html