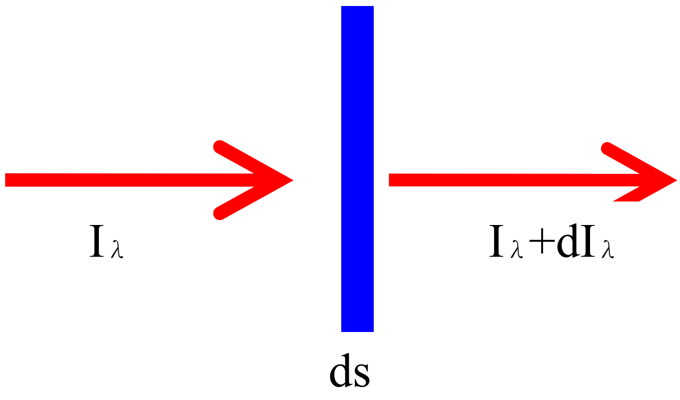
Chapter 0 – What are Stellar Atmospheres?

0-1 Stellar atmospheres

- Stars have temperature ~3000K to 40000k
- Stars must be in gaseous phase.
- How do we get information from stars? ➔ Mostly from the *radiation* (exception: *astroseismology*). .
- Astronomers define *the atmosphere as those layers of the star from which we get the radiation.*
- The photons from deeper layers are absorbed once or many times and the final emitted by the atoms on outer layer.
- The ‘photosphere’ is the visible disk, whilst the `atmosphere’ also includes coronae and winds.
- *The energy transport mechanism of the atmosphere is radiation*.
- Stellar atmospheres are primarily characterized by two parameters: (T_{eff}, log *g*).
    - Effective temperature (in K), is defined by $L=4\pi R^2 \sigma T_{eff}^4$ related to *ionization*.
    - Surface gravity (cm/s^2), $g = GM/R^2$, related to *pressure*.
    - Taking the Sun as example: T_{eff}=5777K, log g=4.44

0-2 How thick is the atmosphere?

Infinitesimal thickness



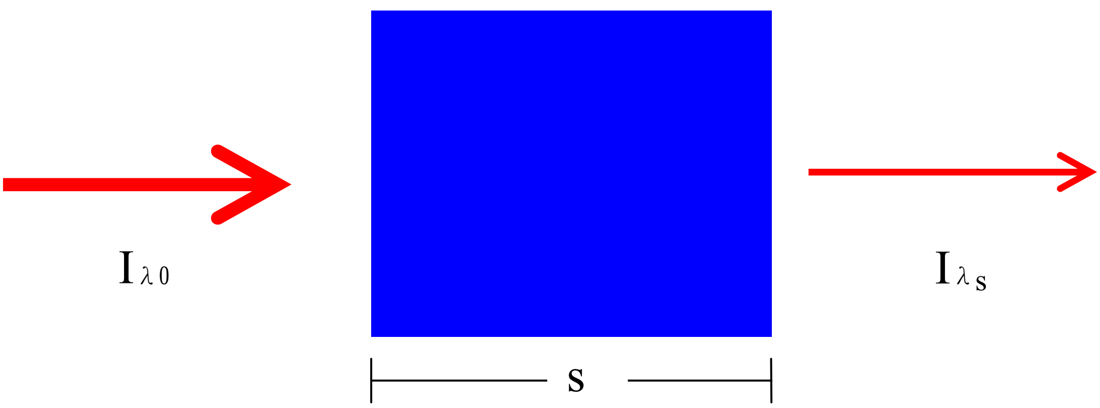
A certain ratio of radiation is absorbed by the thin layer

$$\frac{dI_\lambda}{I_\lambda} = -\rho\kappa_\lambda ds$$

or

$$\rho\kappa_\lambda = -\frac{1}{I_\lambda}\frac{dI_\lambda}{ds}$$

- Minus sign here means the absorption.
- κ_λ : absorption coefficient or opacity, ρ : mass density
- κ_λ :
  - Depends on nature of the absorber (composition etc.) and also the wavelength (frequency) but not on state of absorber (density)
  - The coefficient can be measured in lab, or
  - By the atomic theory



$$\frac{dI_\lambda}{I_\lambda} = -\rho\kappa_\lambda ds$$

$$\int_{I_{\lambda 0}}^{I_{\lambda s}} \frac{dI_\lambda}{I_\lambda} = -\int_0^s \rho\kappa_\lambda ds'$$

$$\ln I_\lambda \Big|_{I_{\lambda 0}}^{I_{\lambda s}} = -\int_0^s \rho\kappa_\lambda ds'$$

$$\ln \frac{I_{\lambda s}}{I_{\lambda 0}} = -\int_0^s \rho\kappa_\lambda ds'$$

$$I_{\lambda s} = I_{\lambda 0} \exp\left(-\int_0^s \rho\kappa_\lambda ds'\right)$$

$$\tau_\lambda \equiv \int_0^s \rho\kappa_\lambda ds'$$

τ_λ: optical depth

$$I_{\lambda s} = I_{\lambda 0} e^{-\tau_\lambda}$$

s: physical depth

- Note:
  - τ_λ is a function of wavelength λ and the physical length
  - ρ, κ_λ is a function of wavelength λ and position
  - Optical thick: large τ_λ, optical thin: small τ_λ
  - Geometric thick: large s, geometric thin: small s
  - Geometric thick is not equivalent to optical thick and vice versa.

- Question: where dose the absorbed energy go?

- Thickness of the atmosphere of stars
  - ~100 km for the Sun, ~1000km for the hottest main-sequence stars
  - Taking the Sun as example,

  τ =10 at depth 500km, $I/I_0 = e^{-10} = 4.54\times10^{-5}$

  Sun's radius ~$7\times10^{10}\,cm$

  Thickness of Sun's atmosphere: $\sim 5\times10^{7}\,cm$

  Ratio: $\frac{5\times10^7}{7\times10^{10}} = \frac{5}{700} \sim 7\times10^{-3}$

  Compare with an apple of radius of 5 cm

  $5\times7\times10^{-3} = 3.5\times10^{-2}\,cm = 0.35mm$

  Thiner than the skin of an apple.

- Question: how do we infer the interior and the deep layers of a star from the radiation of its very thin atmosphere?