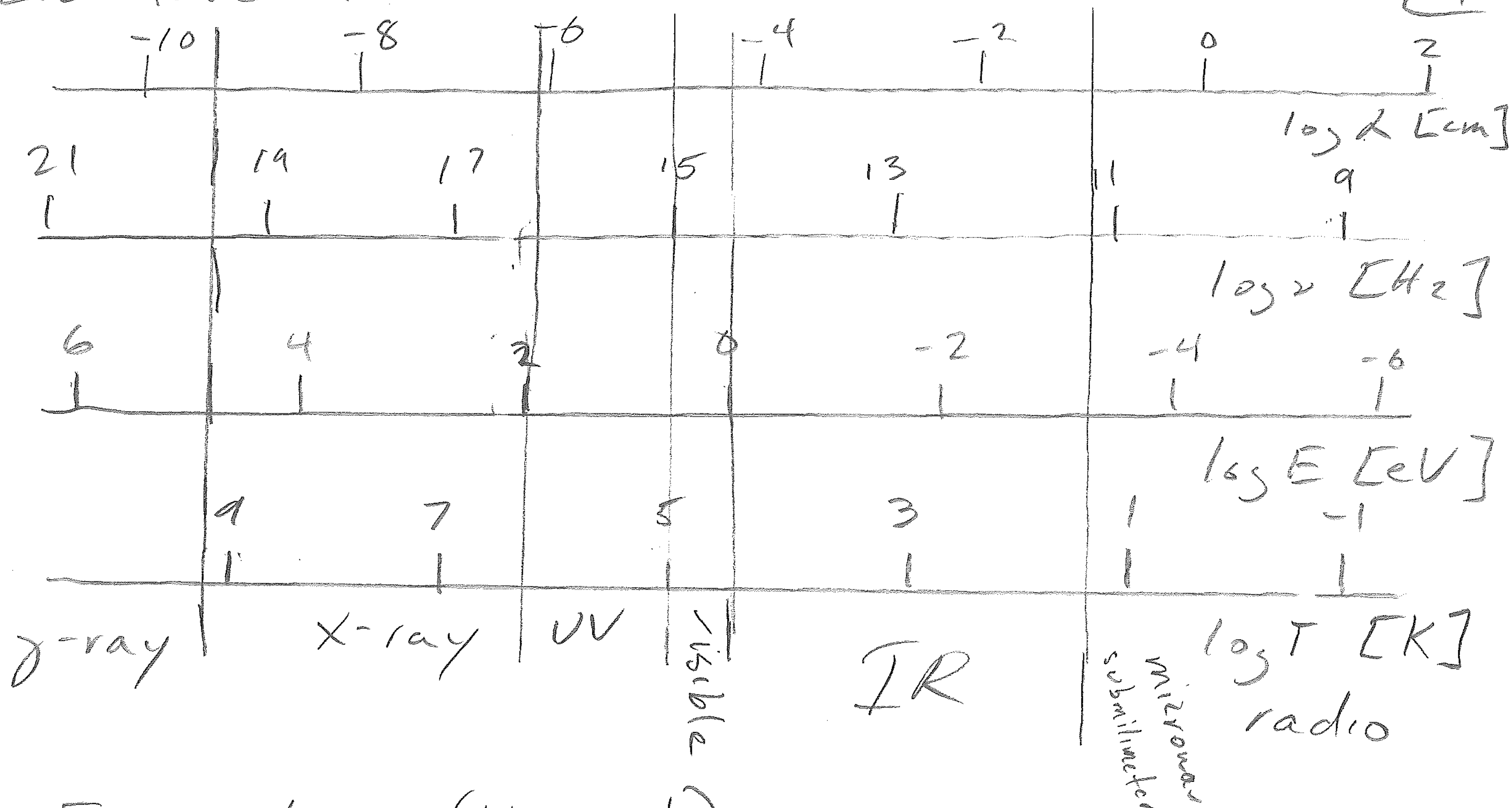
Lecture 1 Reading Assignment RL 1.1-1.4 L1



Examples (thermal)

Stars $10^3 - 10^5$ K IR - visible, UV

Dust 10 K radio/IR

CMB 3 K

atomic lines (allowed) 10-1000 eV, UV, X-ray

galaxy cluster $T = 10^7$ K X-ray

accretion disk $\approx 10 M_\odot$ BH 10^7 K

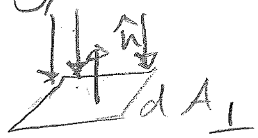
Some emission (actually a lot in astronomy) is non-thermal, meaning it cannot be characterized by a temperature. Such processes depend on electron energies, B-fields, photon backgrounds etc. As we will describe.

Approximations

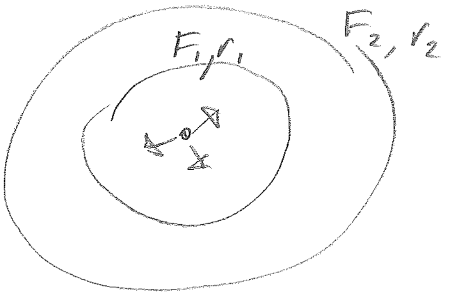
- The radiation field is classical
  (except thermal radiation)
  - holds when lots of photons in state $\left(n \gg \frac{1}{\lambda^3}\right)$
  - even though we often detect photons using their [discrete] particle nature, the spectrum / intensity once enough photons are gathered approaches classical expectation.
- Electrons can be treated as classical particles
  (except for in atoms)
  - Valid when $\lambda_{light} \gg \lambda_{debroglie} = \frac{h}{p}$
    so it doesn't matter that particle is wave-like
- Geometric optics [i.e light travels in straight lines]
  - Subtle will talk about it
  - Used in almost all astro calculations
  - not geometric optics = seeing, scintillation, star-shades, diffraction limit, certain occultation

Energy flux

Energy through surface related to



flux: $dE = F\,dt\,dA_\perp$



Point source

$$F_1 \times 4\pi r_1^2 = F_2 \times 4\pi r_2^2$$

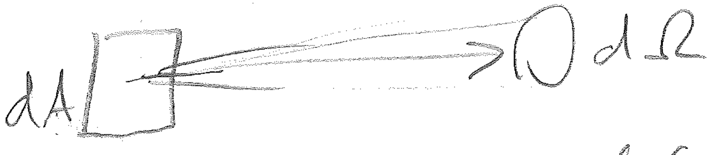
$$\Rightarrow \quad F_1 = F_2 \left(\frac{r_2}{r_1}\right)^2$$

$$= \frac{\text{constant}}{r^2}$$

Dillution!!

Intensity

Flux is all rays passing through a given area. Let's consider energy along individual rays.



(dA is normal)

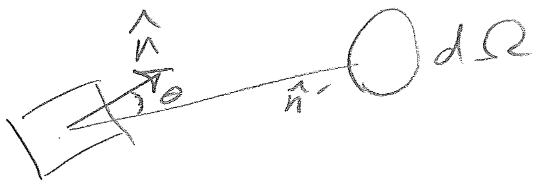
Specific intensity is defined as

$$dE = I_\nu \, dA \, dt \, d\Omega \, d\nu$$

$$[I_\nu] = E L^{-2} T^{-1} \Omega^{-1} \text{ frequency}^{-1}$$

in c.g.s. $\text{erg s}^{-1}\,\text{cm}^{-2}\,\text{sr}^{-1}\,\text{Hz}^{-1}$

Net flux



Fractional flux from $d\Omega$:

$$dF_\nu = I_\nu \cos\theta \, d\Omega$$

where $\cos\theta = \hat{n} \cdot \hat{n}'$

(Flux is same through \ as | for ⇇)

The total flux from all solid angles is

$$F_\nu = \int d\Omega \frac{dF_\nu}{d\Omega} = \int d\Omega \, I_\nu \cos\theta$$

For isotropic radiation, net flux is zero.

Momentum flux

$$p = \frac{E}{c}\hat{n}' \text{ for radiation}$$

$$p_{\hat{n}} = \frac{E}{c}\cos\theta \qquad \text{where again } \cos\theta = \hat{n}\cdot\hat{n}'$$

$$\Rightarrow \quad p_\nu = \frac{1}{c}\int d\Omega \cdot I_\nu \cos^2\theta$$

The extra $\cos\theta$ is to get component of momentum $\perp$ to dA

Constancy of specific intensity along rays

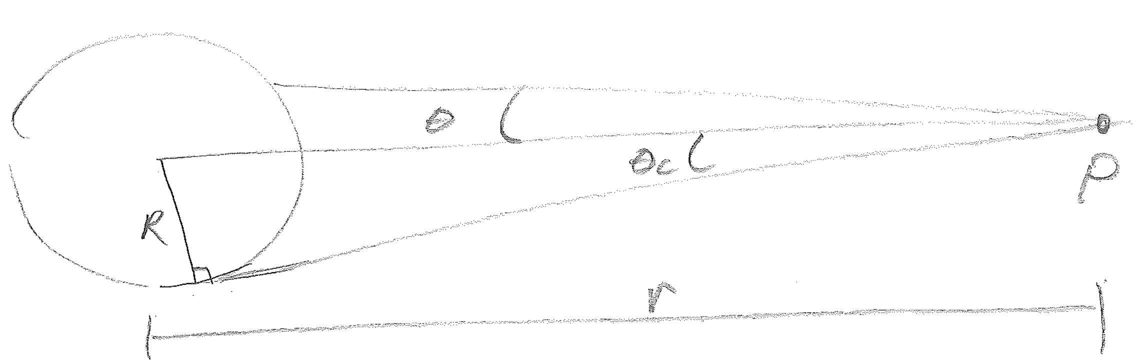
Specific intensity is number of photons going in certain direction. While a bundle of directions spreads out, a single direction does not suffer this dillution. Thus, intensity is conserved along rays (in absence of absorption)

[There is an exception: cosmological redshift causes $I_\nu \propto (1+z)^3$]

Intensity is the same as surface brightness.

Many nebulae are very large on the sky. Orion is $1° \times 1°$ for example, easily resolved by the eye. Even if we put Orion 10x closer away, it would be no easier to see its diffuse emission because SB is conserved. [The reason we cannot see it is that our eyes don't gather enough photons to detect such SBs]

Inverse square law from intensity



Consider a sphere of uniform surface brightness B [i.e. all rays leaving sphere have same intensity]

The flux at P is

$$F = \int d\Omega \cos\theta \, B$$

$$= B \int_0^{2\pi} d\phi \int_{\cos\theta_c}^{1} d\cos\theta \cos\theta$$

$$= B \times 2\pi \times \tfrac{1}{2}\left[1 - \cos^2\theta_c\right]$$

$$= \pi B \sin^2\theta_c$$

$$\text{\&} \quad \theta_c = \sin^{-1}\left(\frac{R}{r}\right)$$

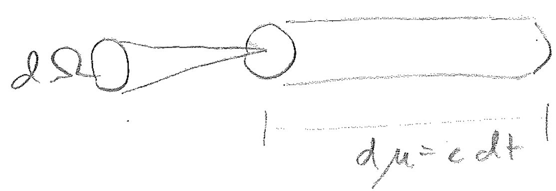
$$= \boxed{\pi B \left(\frac{R^2}{r^2}\right)}$$ inverse sq. law!!

At surface $(r = R)$

$\boxed{F = \pi B.}$ We will use this a lot!

Radiative energy density

Define u_ν as energy density per unit volume per unit frequency



$$dV = dA\, c\, dt$$

$$dE = u_\nu(\Omega)\, dA\, c\, dt\, d\Omega\, d\nu$$

$$= I_\nu\, dA\, dt\, d\nu\, d\Omega$$

$$\Rightarrow \quad u_\nu(\Omega) = \frac{I_\nu}{c}$$

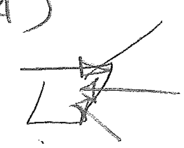
$$u_\nu = \int d\Omega\, u_\nu(\Omega) = \frac{1}{c}\int d\Omega\, I_\nu$$

$$= \frac{4\pi}{c} J_\nu \qquad J_\nu = \frac{1}{4\pi}\int d\Omega\, I_\nu$$

$$u = \int d\nu\, u = \frac{4\pi}{c}\int d\nu\, J_\nu$$

Radiation pressure (reflected at dA)

$$p = \frac{2}{c}\int d\Omega\, I \cos^2\theta$$



For isotropic radiation & integrating over 2π

$$= \frac{1}{c}\, 4\pi \int_0^1 d\cos\theta\, J_\nu \cos^2\theta = \frac{4\pi}{c} J_\nu \times \frac{1}{3}$$

$$= \frac{1}{3}\, u$$

Radiation pressure of isotropic field is $\frac{1}{3}$ of energy density