Astrophysics I: Stars and Stellar Evolution
AST 4001

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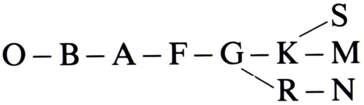
Stars and Stellar Evolution, Fall 2008

Overview

Classification of Stars by Spectral Type

- We classify stars by their spectral type:



blue white red

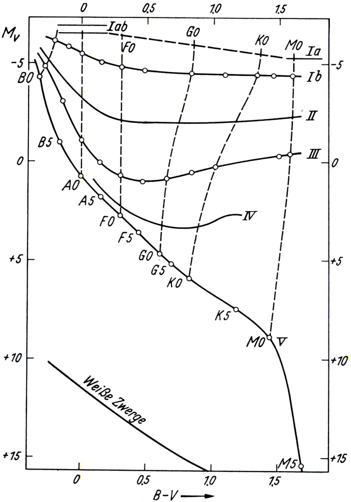
- We use subtypes 0-9 with 0 being the hottest and 9 the coolest within each class.
- That is, O9 is followed by B0.

Classification of Stars by Luminosity

Classification of stars by luminosity classes:

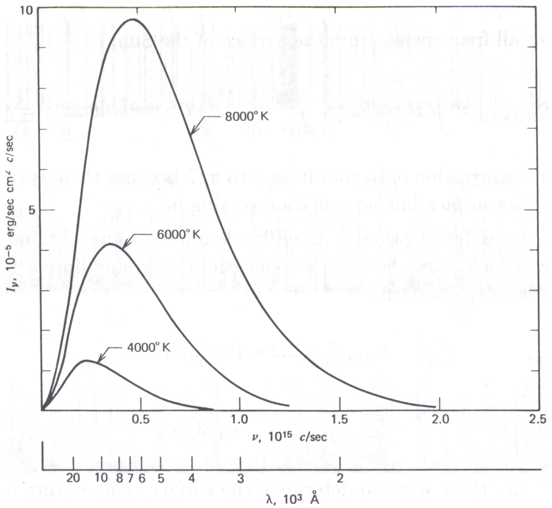
I a –	Hypergiants
I	Supergiants
II	Bright Giants
III	Giants
IV	Subgiants
V	Main Sequence (Dwarfs)
VI	Subdwarfs.

Classification in the HRD



Spectral type and luminosity class in the HRD.

Planck Spectrum



Planck Function - Limiting Cases

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1}\,, \quad B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}\,,$$

Rayleigh-Jeans for long wavelength ($h\nu/kT \ll 1$):

$$B_\nu(T) = \frac{2h\nu^2 kT}{c^2}$$

Wien Limit for short wavelength ($h\nu/kT \gg 1$):

$$B_\nu(T) = \frac{2h\nu^3}{c^2}e^{-h\nu/kT}$$

Wien Displacement law:

$$\lambda_{\max} T = 2.9 \times 10^{-3}\mathrm{m\,K}\,, \quad \frac{c}{\nu_{\max}} T = 5.1 \times 10^{-3}\mathrm{m\,K}$$

Overview

1. Recap
   - Spectral Type
   - Luminosity Class
   - Planck Spectrum
2. Stellar Atmospheres
   - Kirchhoff's Law

Input for Atmosphere Model

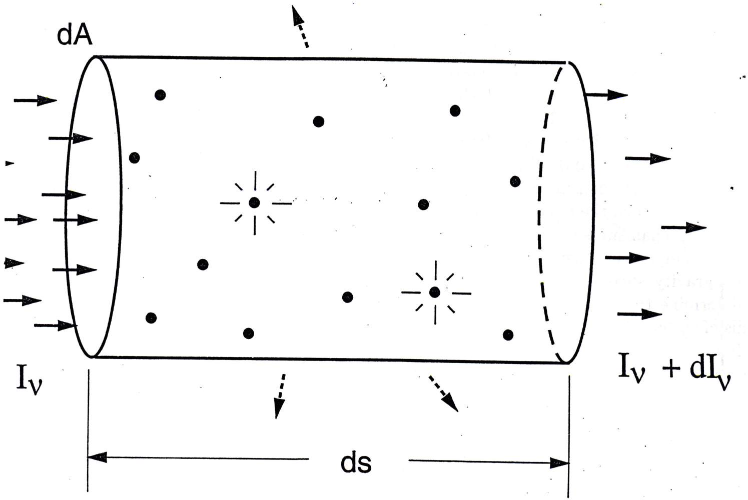
An atmosphere model determines T and ρ at the surface of the star as a function of depth.
As input parameters from the star we require

1. T_{eff}
2. $g = GM/R^2$
3. chemical composition (X, Y, Z), likely even the abundances of individual elements within Z

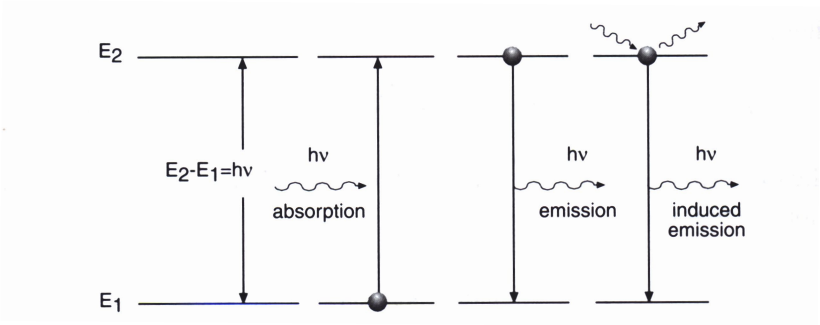
The output of an atmosphere model should provide the details of continuous and spectral energy distribution, colors, and angle dependence of the radiation field.

Generally, such a model is very complicated. In this class will examine some simplified models.

Scattering of photons



Absorption and Emission



Emission Coefficient

Given a frequency-dependent volume emission coefficient, j_ν, the energy that is emitted per unit volume $\mathrm{d}V$ per opening angle $\mathrm{d}\omega$ per frequency bin $\nu + \mathrm{d}\nu$ is given by

$$\mathrm{d}\epsilon_\nu = j_\nu \mathrm{d}\nu \mathrm{d}V \mathrm{d}\omega$$

If the emission is isotropic, the total energy emitted in all directions per second is then given by

$$4\pi \mathrm{d}V \int j_\nu \mathrm{d}\nu$$

Absorption Coefficient

Given an absorption coefficient κ_ν the initial intensity I_ν is reduced due to absorption by $\mathrm{d}I_\nu$ according to

$$\frac{\mathrm{d}I_\nu}{I_\nu} = -\kappa_\nu \mathrm{d}s = -\kappa_{\nu,\mathrm{M}} \rho \mathrm{d}s$$

where $\kappa_{\nu,\mathrm{M}}$ is called the mass absorption coefficient.
$([\kappa_{\nu,\mathrm{M}}] = \mathrm{cm}^2/\mathrm{g})$
We define the optical depth τ at frequency ν by

$$\tau_\nu = \int \kappa_\nu \mathrm{d}s$$

or $\tau_\nu = \kappa_\nu s$ if κ_ν is independent of location. The intensity then drops as from its initial value $I_{\nu,0}$ according to extinction law

$$I_\nu = I_{\nu,0} e^{-\tau_\nu}$$

Kirchhoff's Law

- In strict *thermodynamic equilibrium* the total emission from a cylinder with base $\mathrm{d}A$ and thickness $\mathrm{d}s$, per $\mathrm{d}\omega$ and $\mathrm{d}\nu$ – $j_\nu \, \mathrm{d}\nu \, \mathrm{d}A \, \mathrm{d}s \, \mathrm{d}\omega$ – has to be equal to the absorption – $\mathrm{d}I_\nu \, \mathrm{d}A \, \mathrm{d}\omega \, \mathrm{d}\nu$.
- Using

$$\frac{\mathrm{d}I_\nu}{I_\nu} = -\kappa_\nu \mathrm{d}s$$

  and the fact that in thermodynamic equilibrium the specific intensity $I_\nu = B_\nu$ (Planck function) we obtain

$$j_\nu = \kappa_\nu B_\nu(T) \; .$$

- This relation is called Kirchhoff's Law.