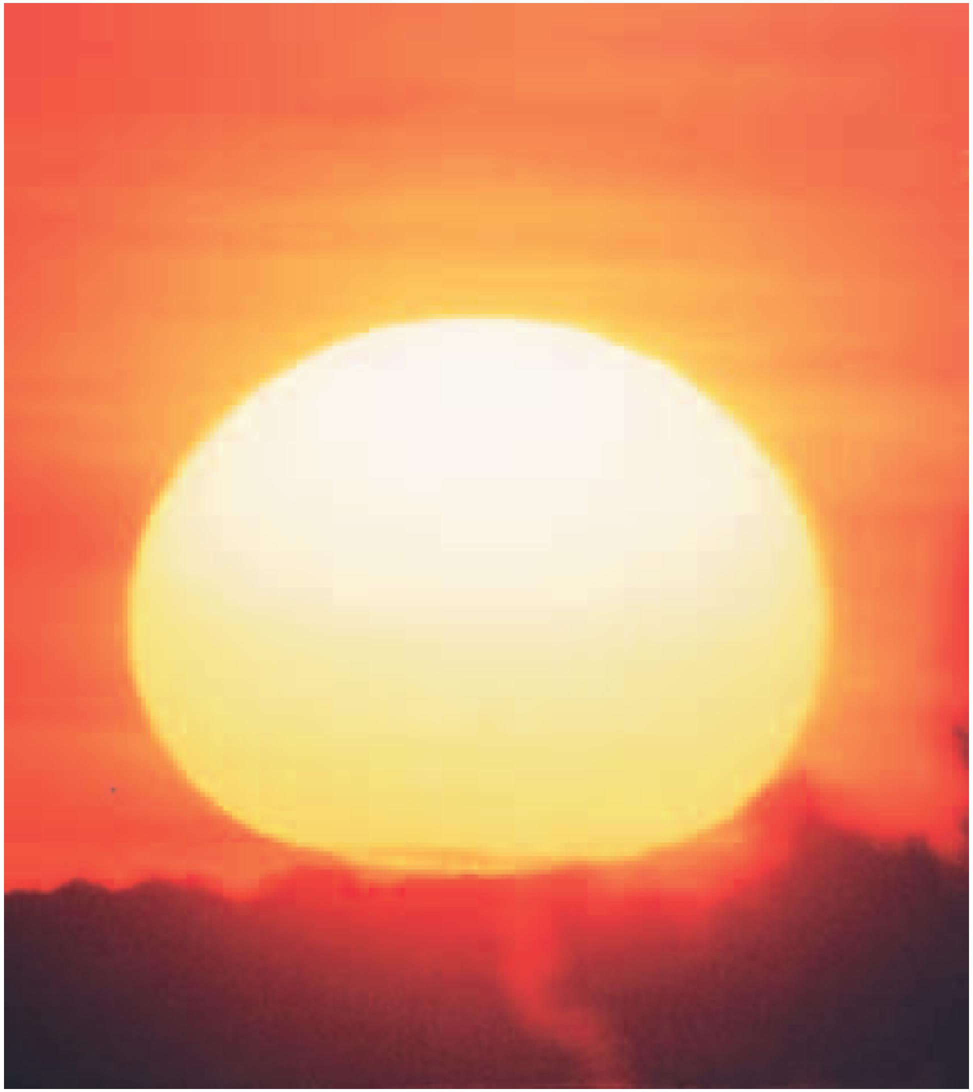
Atmosferas Estelares

prof. Marcos Diaz

IAG-USP 2023



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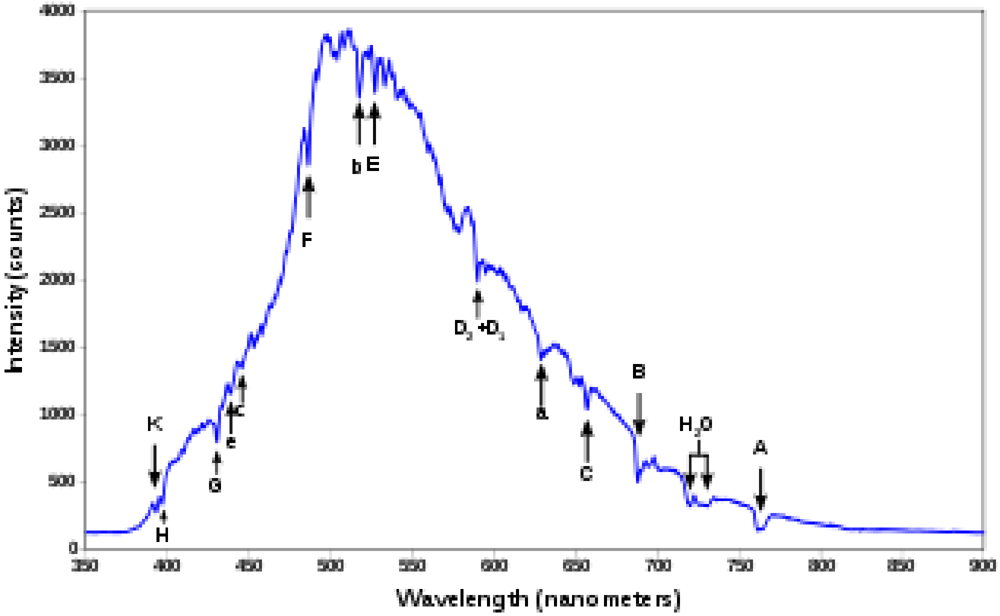
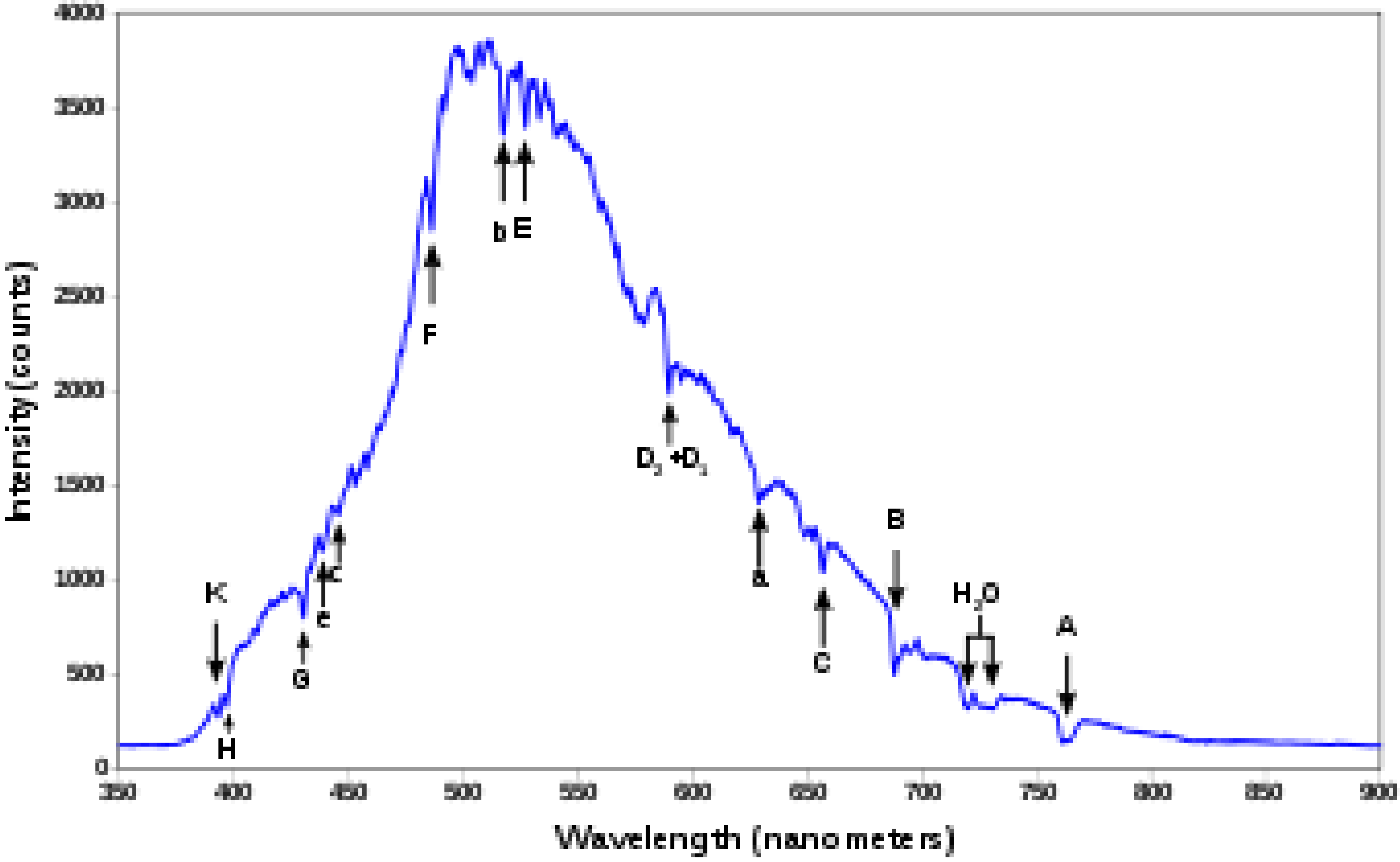




Intensity (counts)
Wavelength (nanometers)
0
500
1000
1500
2000
2500
3000
3500
4000
350
400
450
500
550
600
650
700
750
800
850
900
K
H
G
e
F
b
E
a
C
B
A

Lecture 1

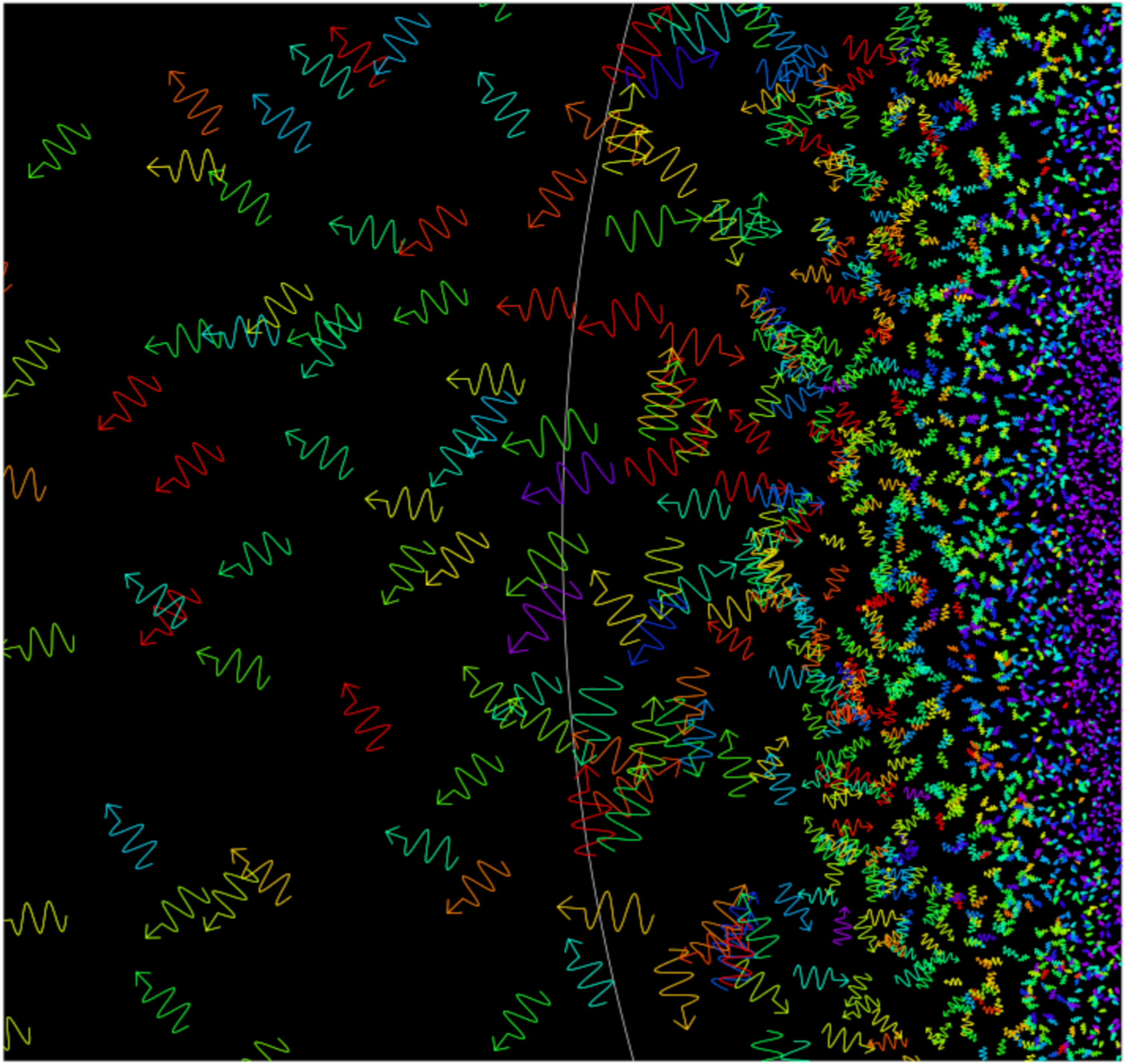
treasure map:

H&M: pg 61

Rutten: pg1

Vitense: pg 26

Gray: pg 127



from Rutten, 1995

PARTICLES:

$$\frac{\partial f_i}{\partial t} + (\mathbf{u} \cdot \nabla) f_i + (\mathbf{F} \cdot \nabla_p) f_i = \left(\frac{\mathrm{D} f_i}{\mathrm{D} t}\right)_{\mathrm{coll}}$$

Boltzmann kinetic equation

$f_i(\mathbf{r}, \mathbf{p}, t)\mathrm{d}\mathbf{r}\,\mathrm{d}\mathbf{p}$ *is the distribution of particle @ state i in phase and position space*

$$\frac{\partial f_i}{\partial t} + (\mathbf{u} \cdot \nabla) f_i + (\mathbf{F} \cdot \nabla_p) f_i = \left(\frac{\mathrm{D} f_i}{\mathrm{D} t} \right)_{\mathrm{coll}}$$

integrating over *p* with each term multiplied by p^j :

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

continuity

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot (\rho \mathbf{v} \mathbf{v}) = -\nabla P + \mathbf{f}$$

momentum

$$\frac{\partial}{\partial t} \left(\frac{1}{2} \rho v^2 + \rho \epsilon \right) + \nabla \cdot \left[\left(\frac{1}{2} \rho v^2 + \rho \epsilon + P \right) \mathbf{v} \right] = \mathbf{f} \cdot \mathbf{v} - \nabla \cdot (\mathbf{F}_{\mathrm{rad}} + \mathbf{F}_{\mathrm{con}})$$

energy

i. stationary ii. static iii. 1D (e.g. plane-parallel)

$$\left(\frac{\mathrm{D}n_i}{\mathrm{D}t}\right)_{\mathrm{coll}} = 0 \ ,$$

statistical equilibrium

$$\nabla P = \mathbf{f} \quad \Longrightarrow \quad \frac{\mathrm{d}P}{\mathrm{d}z} = -\rho g \ ,$$

hydrostatic equilibrium

$$\nabla F_{\mathrm{rad}} = 0 \quad \Longrightarrow \quad F_{\mathrm{rad}} = \mathrm{const} \equiv \sigma T_{\mathrm{eff}}^4$$

radiative equilibrium

$$F_{\mathrm{rad}} + F_{\mathrm{conv}} = \sigma T_{\mathrm{eff}}^4$$

Specific Intensity (or simply Intensity)

is energy

$$dE \quad = \quad I\,(\boldsymbol{n}, \boldsymbol{r}, \nu, t)\;\; cos\theta\; dS\; d\omega\; d\nu\; dt$$

(erg cm^{-2} sec^{-1} hz^{-1} sr^{-1})

The distribution function for photons is: $f_{ph}(\boldsymbol{n},\boldsymbol{r},\nu,t)$

at velocity *c*, the energy crossing *dS* during *dt*:

$$dE = f_{ph}\;\; c\;\; h\nu\; dt\; \boldsymbol{n.dS}\; d\omega\; d\nu \quad \Rightarrow \quad I \;=\; (ch\nu)\;\; f_{ph}$$

Moments of the radiation field

$p^{\,j} \;\; ➡ \;\; (\cos\theta)^{\,j}$

$$\begin{pmatrix} cE_\nu \\ \mathbf{F}_\nu \\ c\mathrm{P}_\nu \end{pmatrix} = \oint \begin{pmatrix} 1 \\ \mathbf{n} \\ \mathbf{nn} \end{pmatrix} I_\nu \, \mathrm{d}\omega$$

or

$$\begin{pmatrix} J_\nu \\ \mathbf{H}_\nu \\ \mathrm{K}_\nu \end{pmatrix} = \frac{1}{4\pi} \begin{pmatrix} cE_\nu \\ \mathbf{F}_\nu \\ c\mathrm{P}_\nu \end{pmatrix} = \frac{1}{4\pi} \oint \begin{pmatrix} 1 \\ \mathbf{n} \\ \mathbf{nn} \end{pmatrix} I_\nu \, \mathrm{d}\omega$$

angle averaged instead of integrated

Moments of the radiation field

in a plane-parallel geometry

$$J_\nu = \frac{1}{2}\int_{-1}^{1} I_\nu(\mu)\mathrm{d}\mu$$

$$H_\nu = \frac{1}{2}\int_{-1}^{1} \mu\, I_\nu(\mu)\mathrm{d}\mu$$

$$K_\nu = \frac{1}{2}\int_{-1}^{1} \mu^2 I_\nu(\mu)\mathrm{d}\mu$$

with $\mu = \cos\theta$, angle between ***z*** and ***n***