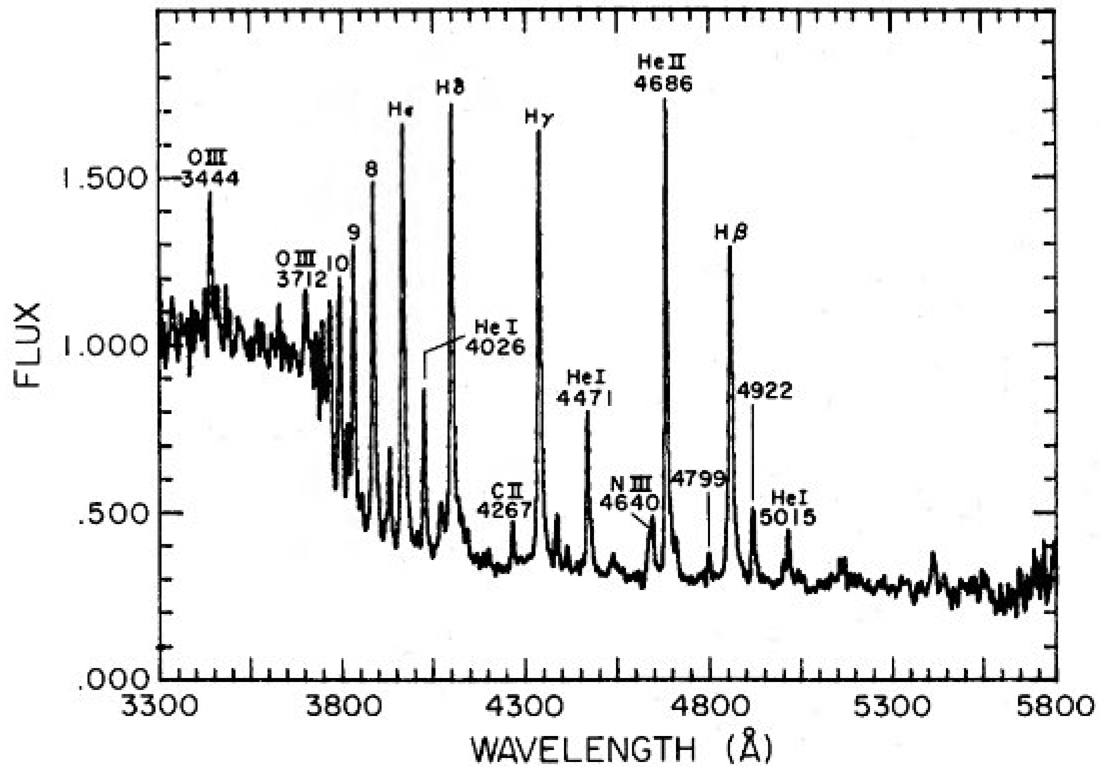
Atmosferas Estelares

prof. Marcos Diaz

IAG-USP 2024



Optically thick Balmer lines in the polar MR Ser

from Liebert et al. 1982

Lecture 3

treasure map:

H&M: pg 98

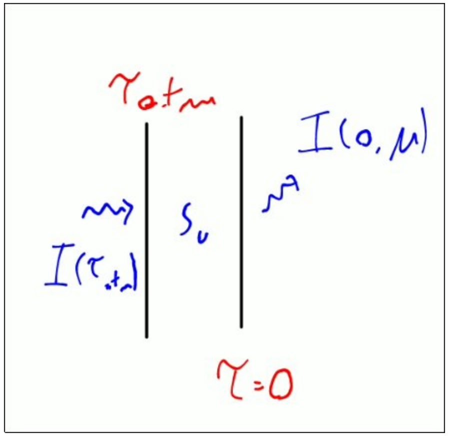
Rutten: pg 4

Vitense: pg 29

Finite slab atmosphere with S_ν = constant (e.g. isothermal atmosphere)

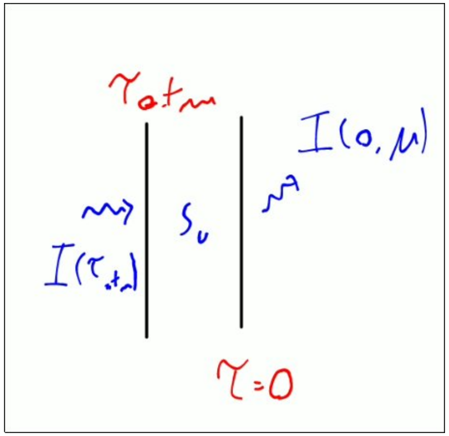
from formal solution with: $\tau_2 = \tau_{atm}$, $\tau_1 = 0$:

$$I_\nu(0) = I_\nu(\tau_{atm}) e^{\frac{-\tau_{atm}}{\mu}} + \frac{S_\nu}{\mu} \int_0^{\tau_{atm}} e^{\frac{-\tau'}{\mu}} d\tau'$$



i. Finite slab atmosphere with S_ν = constant (e.g. isothermal atmosphere)

from formal solution with: $\tau_2 = \tau_{atm}$, $\tau_1 = 0$:

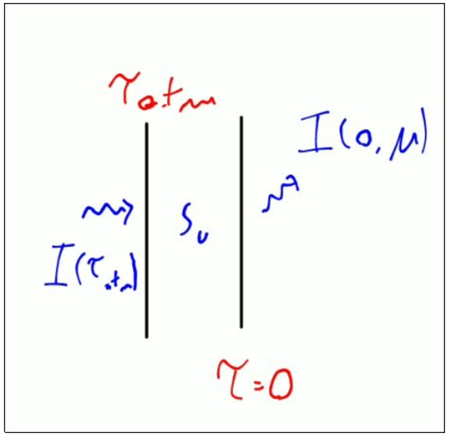


$$I_\nu(0) = I_\nu(\tau_{atm}) e^{\frac{-\tau_{atm}}{\mu}} + \frac{S_\nu}{\mu} \int_0^{\tau_{atm}} e^{\frac{-\tau'}{\mu}} d\tau'$$

$$I_\nu(0) = I_\nu(\tau_{atm}) e^{\frac{-\tau_{atm}}{\mu}} - S_\nu e^{\frac{-\tau'}{\mu}}$$

Finite slab atmosphere with S_ν = constant (e.g. isothermal atmosphere)

from formal solution with: $\tau_2 = \tau_{atm}$, $\tau_1 = 0$:



$$I_\nu(0) = I_\nu(\tau_{atm})\, e^{\frac{-\tau_{atm}}{\mu}} + \frac{S_\nu}{\mu}\int_0^{\tau_{atm}} e^{\frac{-\tau'}{\mu}}\, d\tau'$$

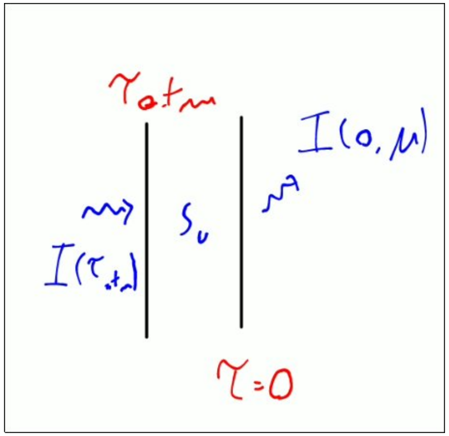
$$I_\nu(0) = I_\nu(\tau_{atm})\, e^{\frac{-\tau_{atm}}{\mu}} - S_\nu\, e^{\frac{-\tau'}{\mu}}$$

$$I_\nu(0) = I_\nu(\tau_{atm})\, e^{\frac{-\tau_{atm}}{\mu}} + S_\nu\left(1 - e^{\frac{-\tau_{atm}}{\mu}}\right)$$

Finite slab atmosphere with S_ν = constant
(e.g. isothermal atmosphere)

from formal solution with: $\tau_2 = \tau_{atm}$, $\tau_1 = 0$:

$$I_\nu(0) = I_\nu(\tau_{atm})\, e^{\frac{-\tau_{atm}}{\mu}} + S_\nu\left(1 - e^{\frac{-\tau_{atm}}{\mu}}\right)$$



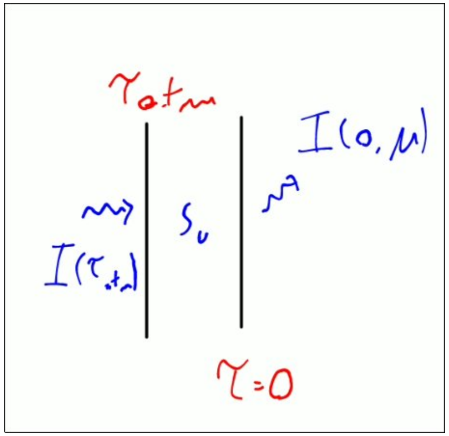
i. $\tau_{atm} >> 1$ ➡ $I_\nu(0) = S_\nu$

ii. $\tau_{atm} << 1$ ➡ $I_\nu(0, \mu=1) = [S_\nu - I_\nu(\tau_{atm})]\tau_{atm} + I_\nu(\tau_{atm})$

Kirchhoff´s Laws

$\tau_{atm} < 1;\ \tau_1 = 0$ - a moderately thin atmosphere with

$$\tau_{atm,\nu} = \tau_{continuum} + A\,e^{-\beta(\nu-\nu_0)^2}$$



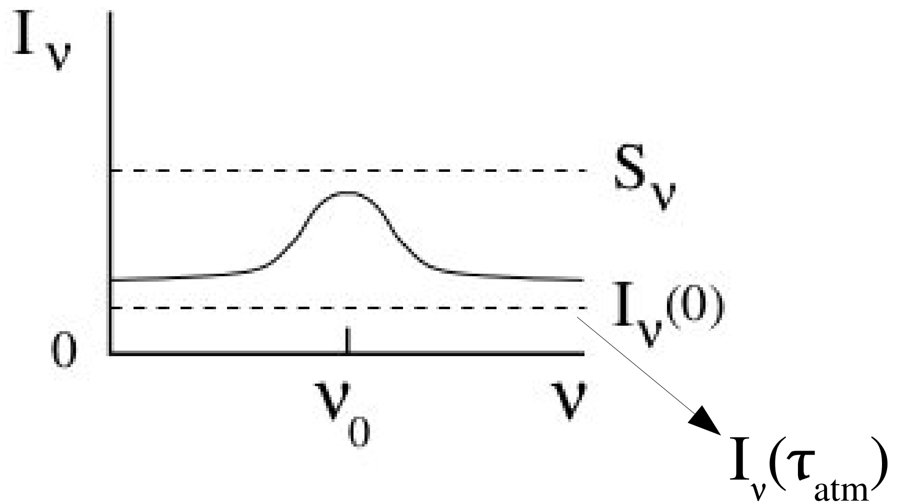
apply the formal solution for thin atmosphere:

$$I_\nu(0, \mu=1) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\tau_{atm}$$

1.a $S_\nu > I_\nu(\tau_{atm})$; $\tau_{cont} << 1$; $\tau_{line} < 1$

a thin continuum, weakly illuminated atmosphere

$$I_\nu(0, \mu=1) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})] \{\tau_{cont} + A\exp[-\beta(\nu-\nu_0)^2]\}$$



$$I_{cont}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})] \tau_{cont}$$
$$\sim I_\nu(\tau_{atm})$$

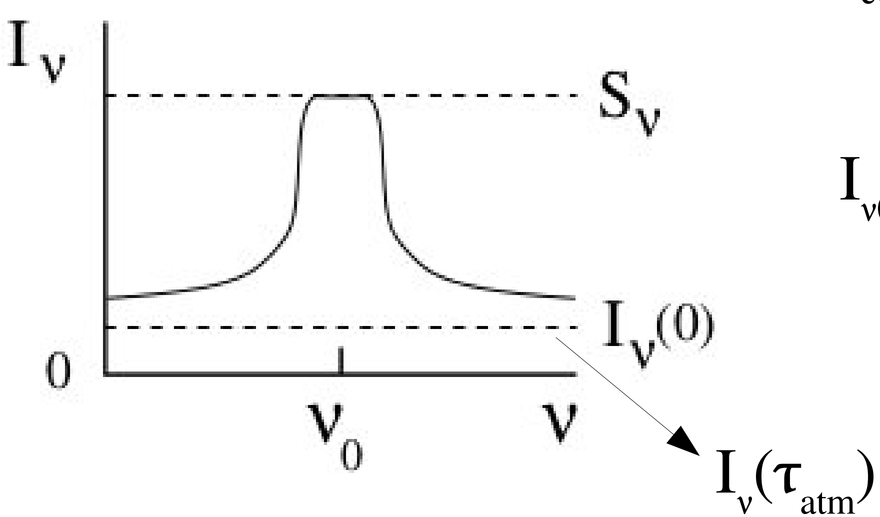
$$I_{\nu 0}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})] (\tau_{cont} + A)$$
$$\sim S_\nu A + (1-A) I_\nu(\tau_{atm})$$

with $A < 1$

1.b $S_\nu > I_\nu(\tau_{atm})$; $\tau_{cont} << 1$; $\tau_{line} = 1$

a continuum thin, line thick, weakly illuminated atmosphere

$$I_\nu(0, \mu=1) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\{\tau_{cont} + \exp[-\beta(\nu-\nu_0)^2]\}$$



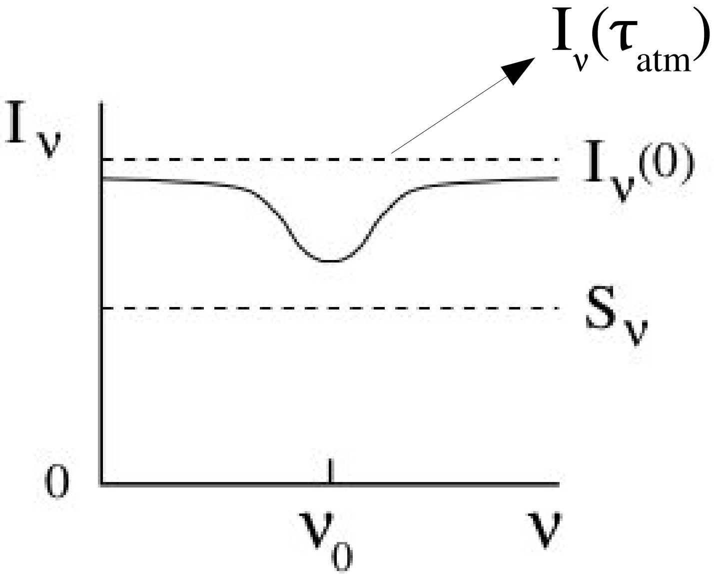
$$I_{cont}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\,\tau_{cont}$$
$$\sim I_\nu(\tau_{atm})$$

$$I_{\nu 0}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\,(\tau_{cont} + 1)$$
$$\sim S_\nu$$

2.a $I_\nu(\tau_{atm}) > S_\nu$; $\tau_{cont} << 1$; $\tau_{line} < 1$

a continuum thin, line thin, strongly illuminated atmosphere

$$I_\nu(0, \mu=1) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\{\tau_{cont} + A\exp[-\beta(\nu-\nu_0)^2]\}$$



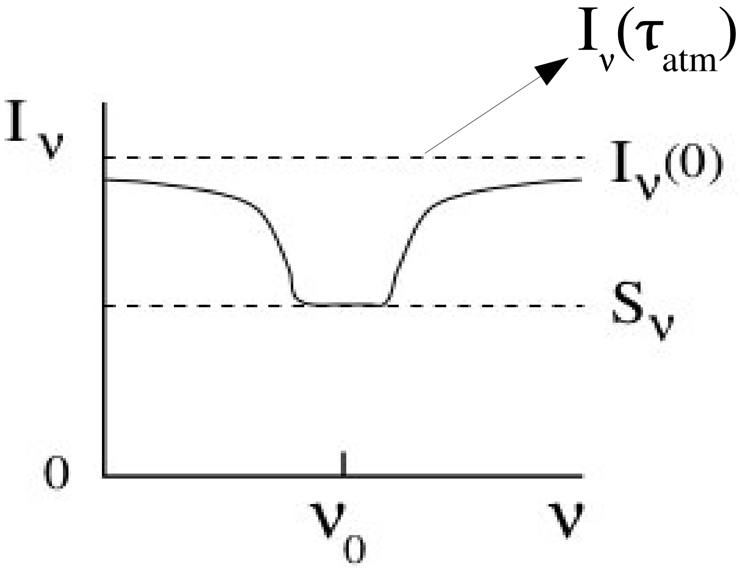
$$I_{cont}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\,\tau_{cont}$$

$$I_{\nu 0}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\,(\tau_{cont} + A)$$

2.b $I_\nu(\tau_{atm}) > S_\nu$; $\tau_{cont} << 1$; $\tau_{line} = 1$

a continuum thin, line thick, strongly illuminated atmosphere

$$I_\nu(0, \mu=1) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\{\tau_{cont} + \exp[-\beta(\nu-\nu_0)^2]\}$$



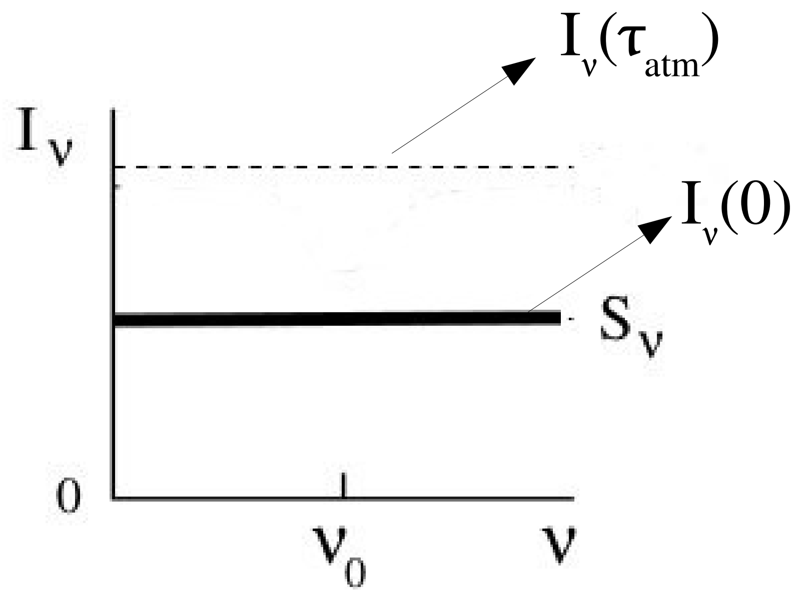
$$I_{cont}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\,\tau_{cont} \sim I_\nu(\tau_{atm})$$

$$I_{\nu 0}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\,(\tau_{cont} + 1) \sim S_\nu$$

3.a $I_\nu(\tau_{atm}) > S_\nu$; $\tau_{cont} = 1$;

a continuum thick, small A, strongly illuminated atmosphere

$$I_\nu(0, \mu=1) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\{\tau_{cont} + A\exp[-\beta(\nu-\nu_0)^2]\}$$



$$I_{cont}(0) = I_\nu(\tau_{atm}) + [S_\nu - I_\nu(\tau_{atm})]\,\tau_{cont} \sim S_\nu$$

$$I_{\nu 0}(0) \sim S_\nu$$

ii. Semi-infinite atmosphere with a linear source function

$S_\nu = a + b\tau_\nu$

$$I(0,\mu) = \frac{1}{\mu}\int_0^\infty (a+b\tau')e^{-\frac{\tau'}{\mu}}d\tau'$$

$$I(0,\mu) = a+b\mu = S_\nu(\tau_\nu=\mu)$$

(Eddington-Barbier relation)

The evaluation of $I_\nu(0)$ at a given "μ" provides an good approximation to the actual value of the source function at depth $\tau_\nu = \mu$.