Escape of Lyβ from Hot and Optically Thick Media

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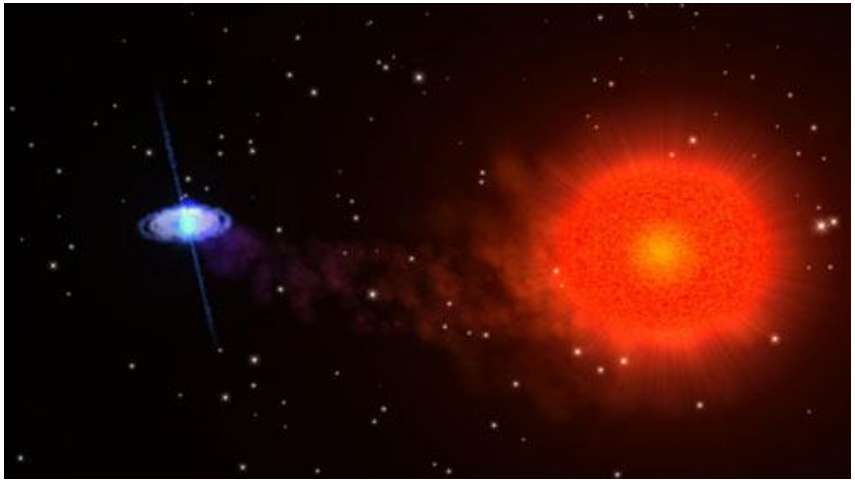
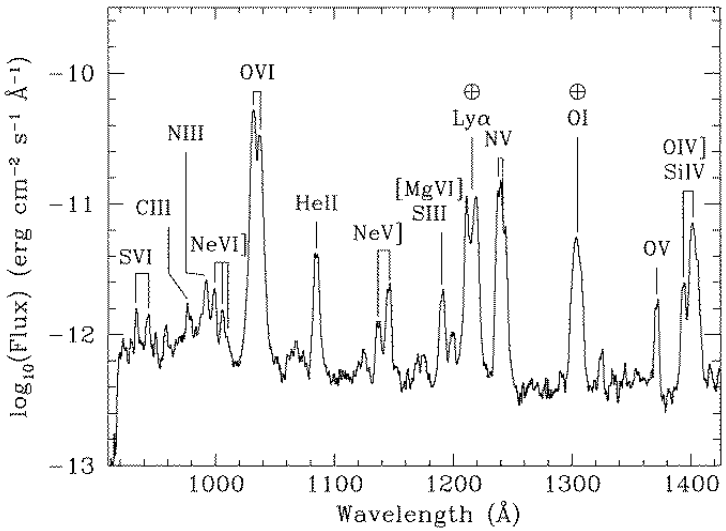
Introduction – Symbiotic Stars



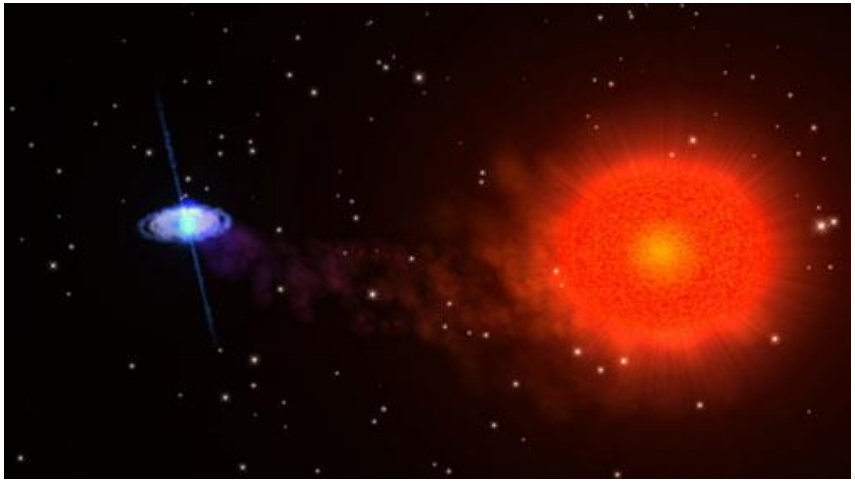
Symbiotic Stars



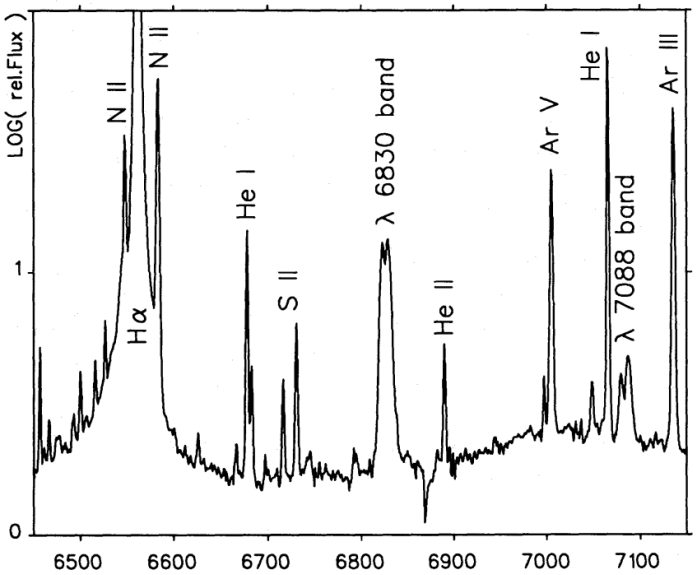
UV Spectrum of Symbiotic Stars

- Symbiotic stars are interacting binary system composed of a mass losing red giant and a white dwarf.
- The spectra of symbiotic stars show strong emission lines including highly ionized lines.
- The lines Raman scattered by atomic hydrogen are exhibited in the optical spectra.

Introduction – Symbiotic Stars



Symbiotic Stars



Optical Spectrum of Symbiotic Stars

- Symbiotic stars are interacting binary system composed of a mass losing red giant and a white dwarf.
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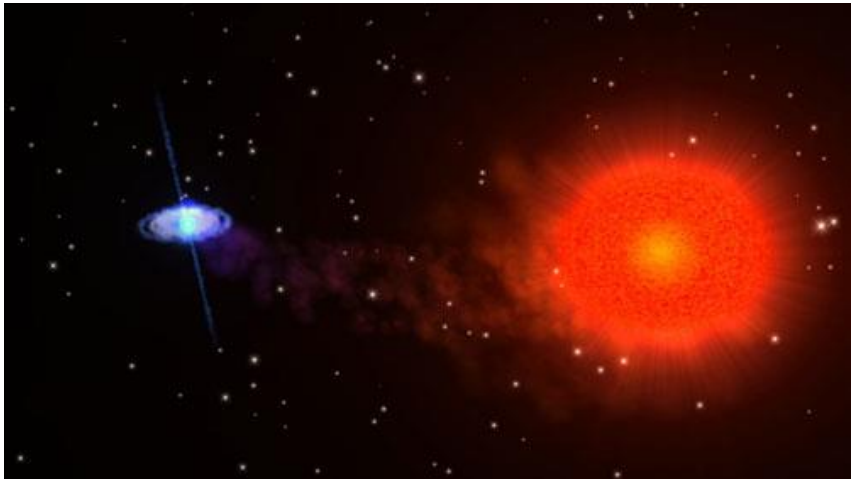
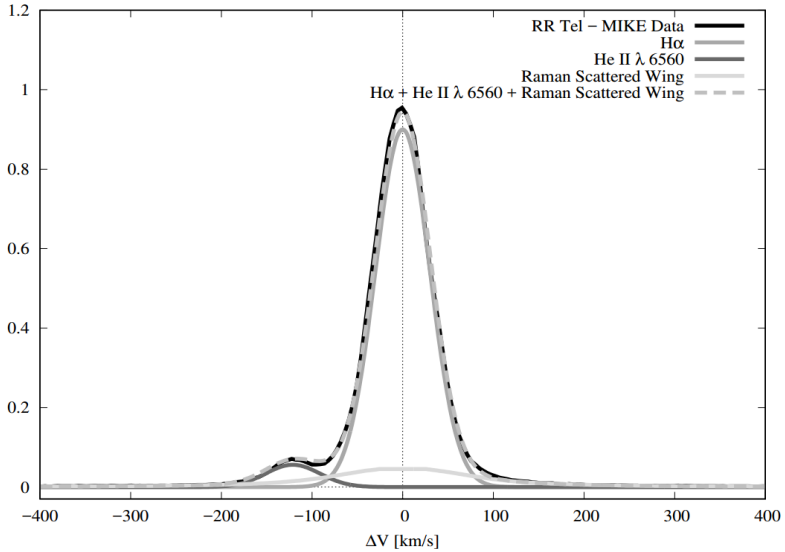
Introduction – Symbiotic Stars



Symbiotic Stars



Broad Hα Wing of Symbiotic Stars

- **Symbiotic stars are interacting binary system composed of a mass losing red giant and a white dwarf.**
- **The spectra of symbiotic stars show strong emission lines including highly ionized lines.**
- **The lines Raman scattered by atomic hydrogen are exhibited in the optical spectra.**

Introduction – Lyα Emitter (LAE)

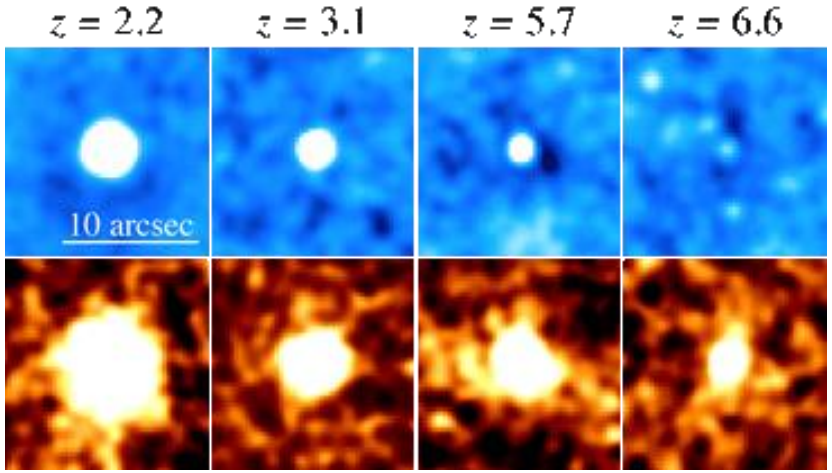
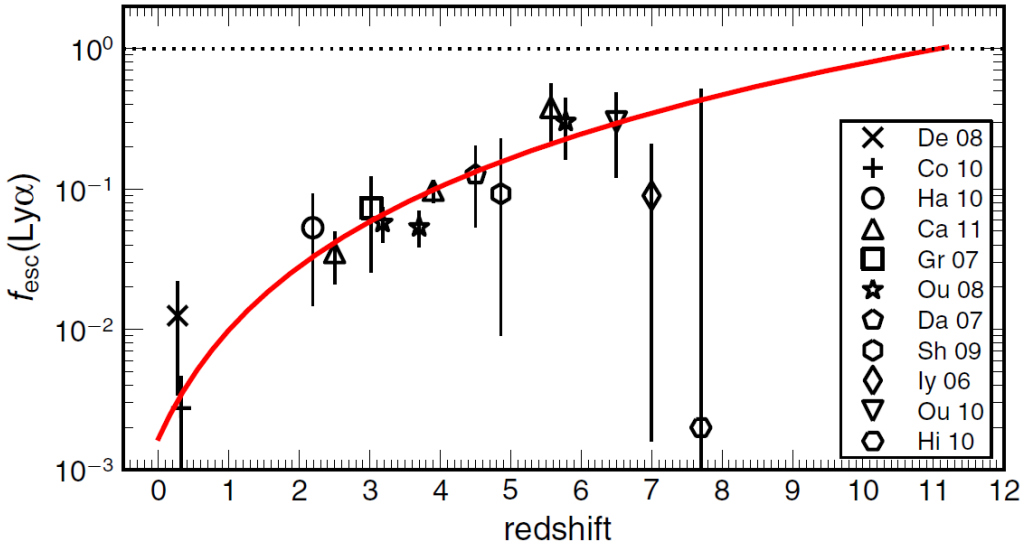


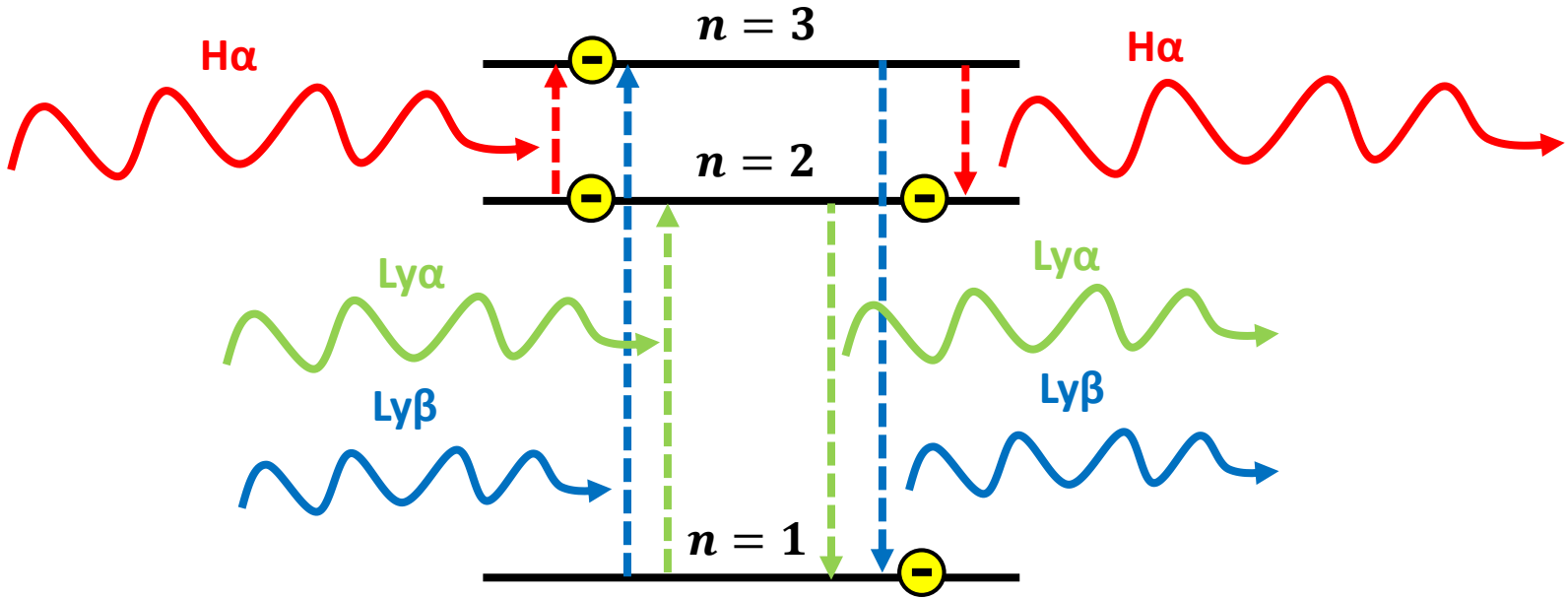
Image of Lyman alpha emitter



Lyα escape fraction in Heyse et al. 2012

- **Lyα is one of the strong emission lines from starforming region and quasars in the early universe.**
- **LAE show large equivalent widths of Lyα.**
- **The Lyα escape fraction is very important the measureable parameter to get a starforming rate of LAE.**

Resonance Scattering



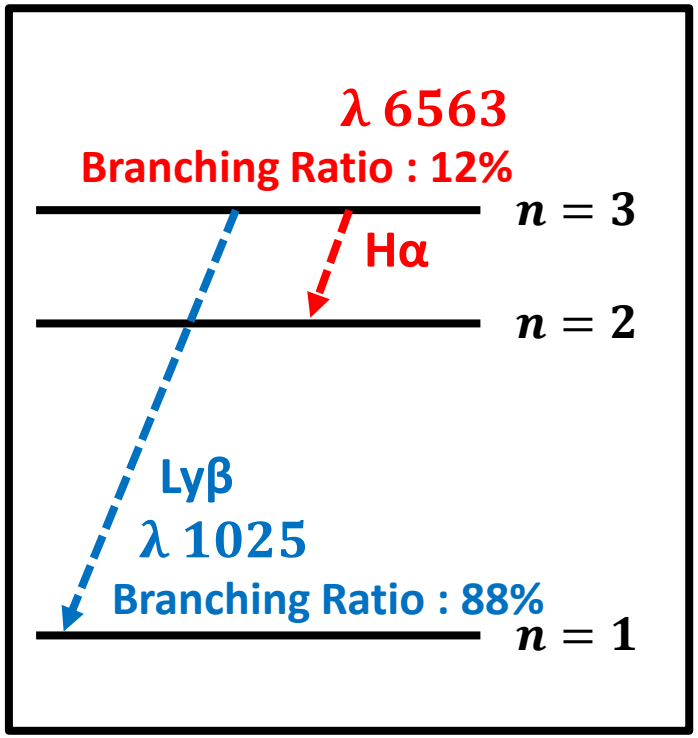
Energy Level of Atomic Hydrogen

- **In the rest frame of the atomic hydrogen, the energy of photons have to be**

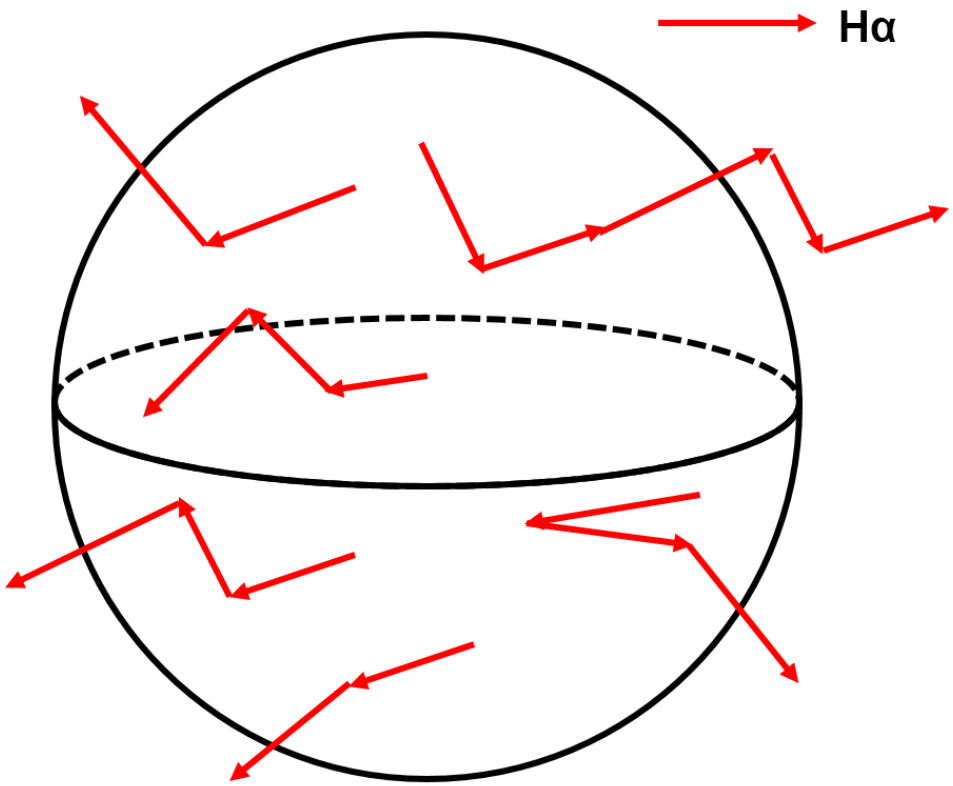
$$E_{photon} = -13.6eV\left(\frac{1}{m^2} - \frac{1}{n^2}\right).$$

- **Resonance scattering dominates the radiative transfer of hydrogen lines in H II region.**

Radiative Transfer of Hα in H II Region

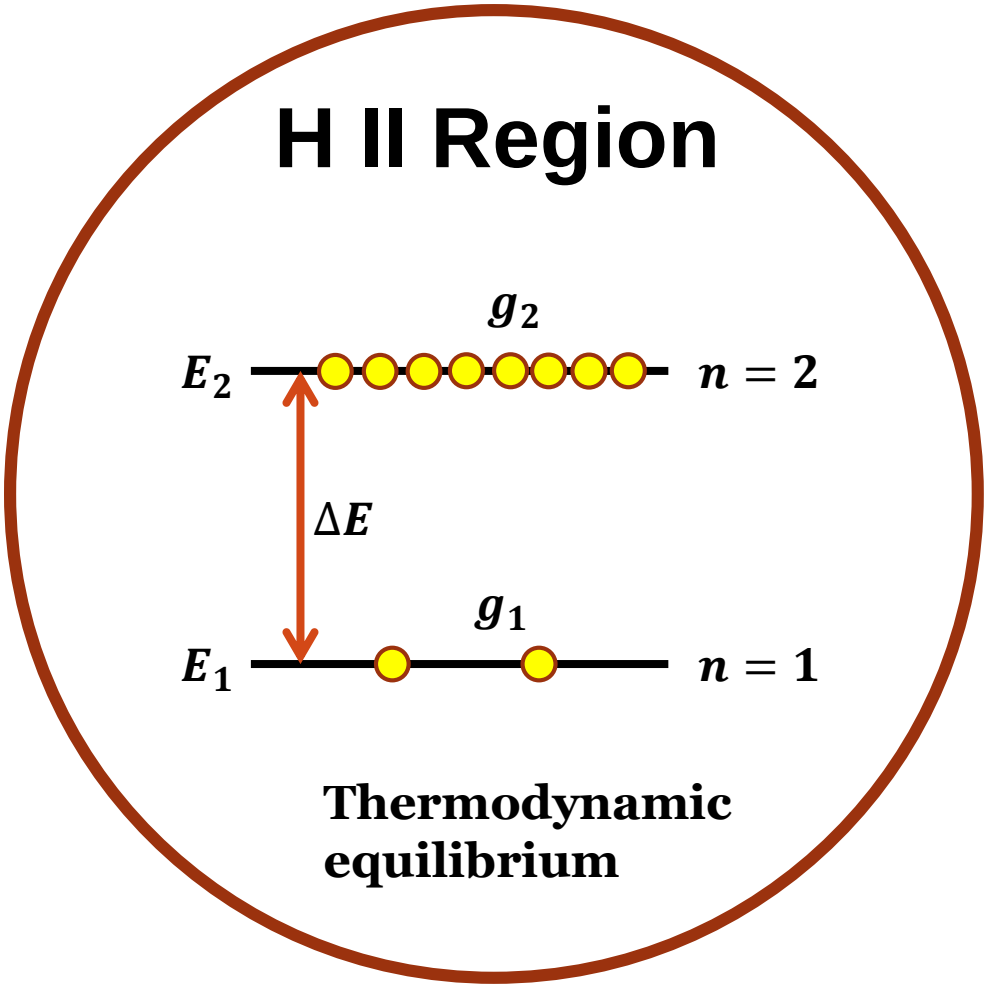


Energy Level and Branching Ratio



H II Region

Population of n=1 and n=2 states



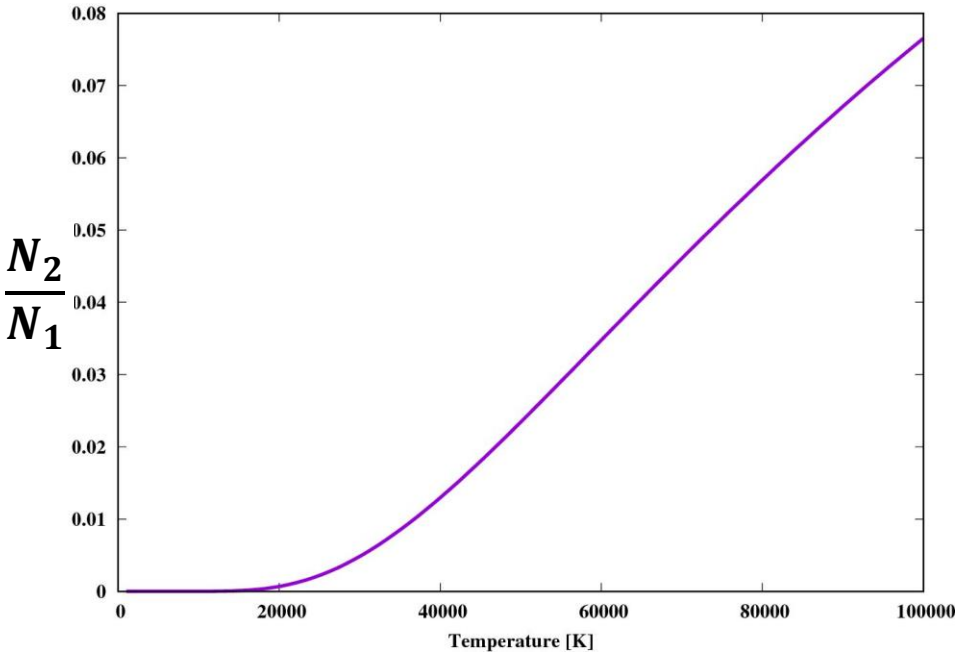
- **Level population N_1 and N_2 are followed Boltzmann distribution.**

$$\frac{N_2}{N_1} = \frac{g_2 e^{-\frac{E_1}{kT}}}{g_1 e^{-\frac{E_1}{kT}}} = \frac{1}{4} e^{-\frac{10.2eV}{kT}}$$

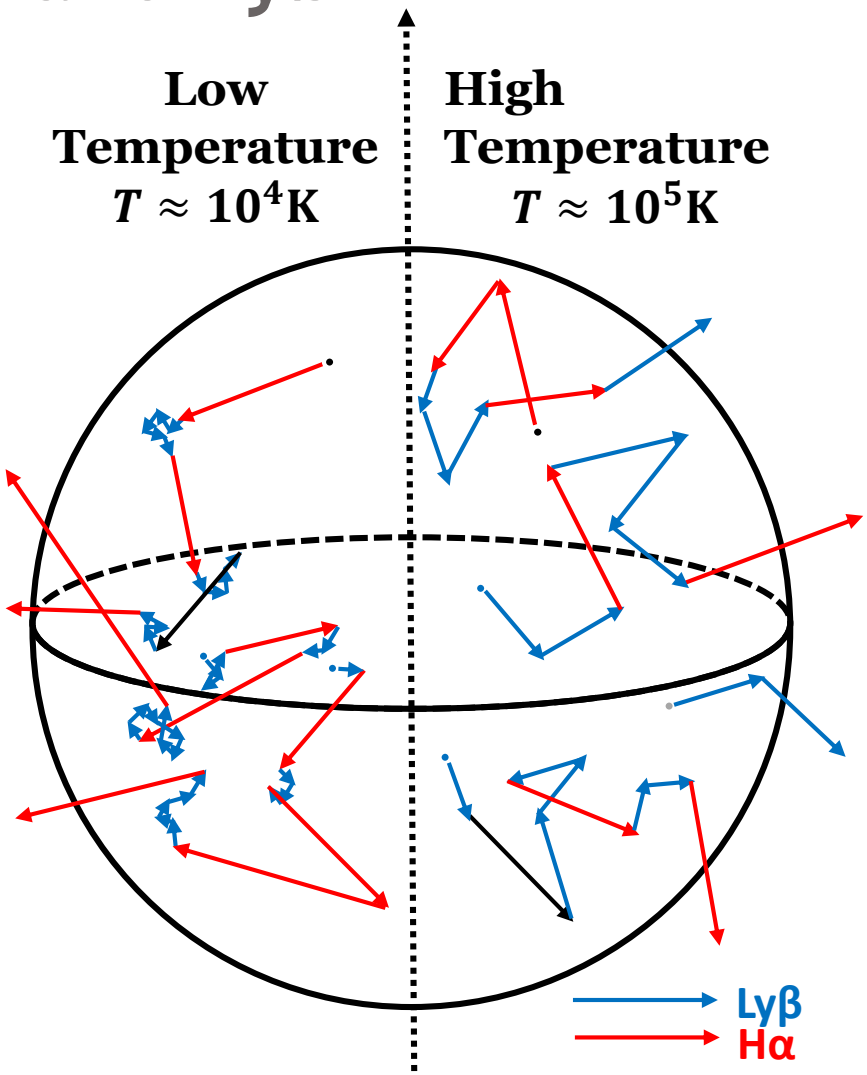
- **Level population N_1 and N_2 are proportional to optical depth τ_α and τ_β.**

$$\frac{\tau_\alpha}{\tau_\beta} \propto \frac{N_2}{N_1}$$

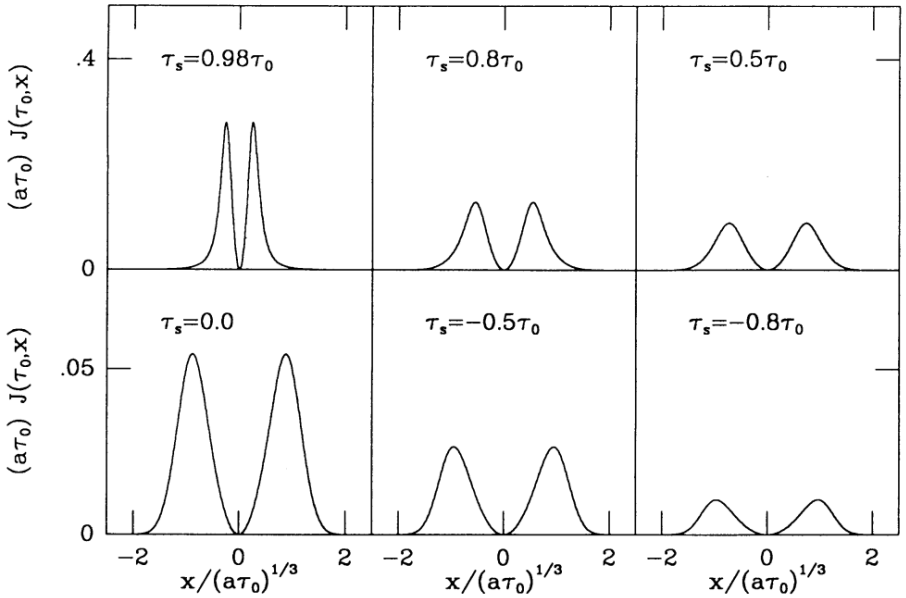
Radiative Transfer of Hα and Lyβ



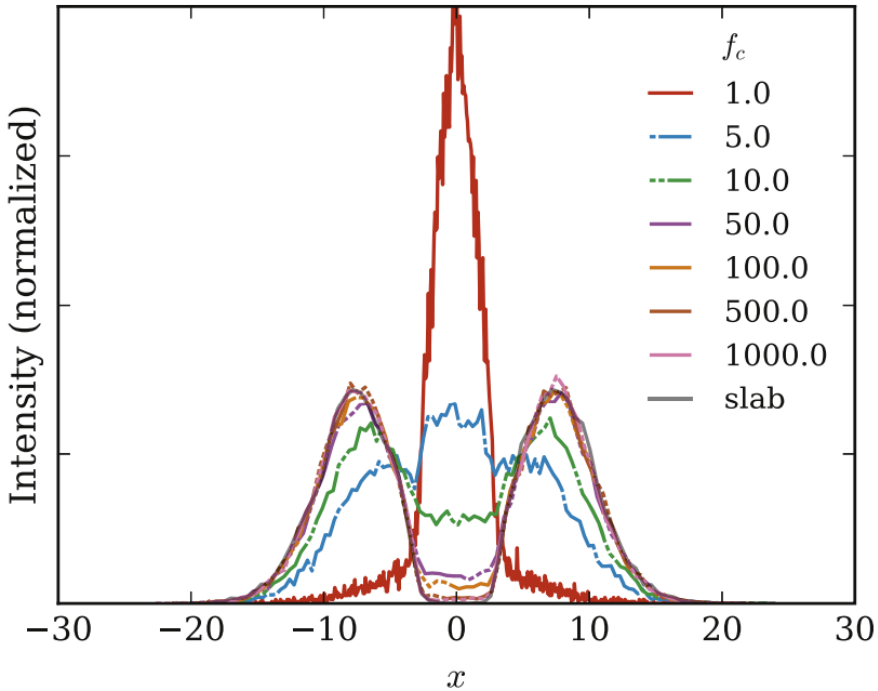
Level Population Ratio N_2/N_1



Line Profiles of Resonance Scattered Photons

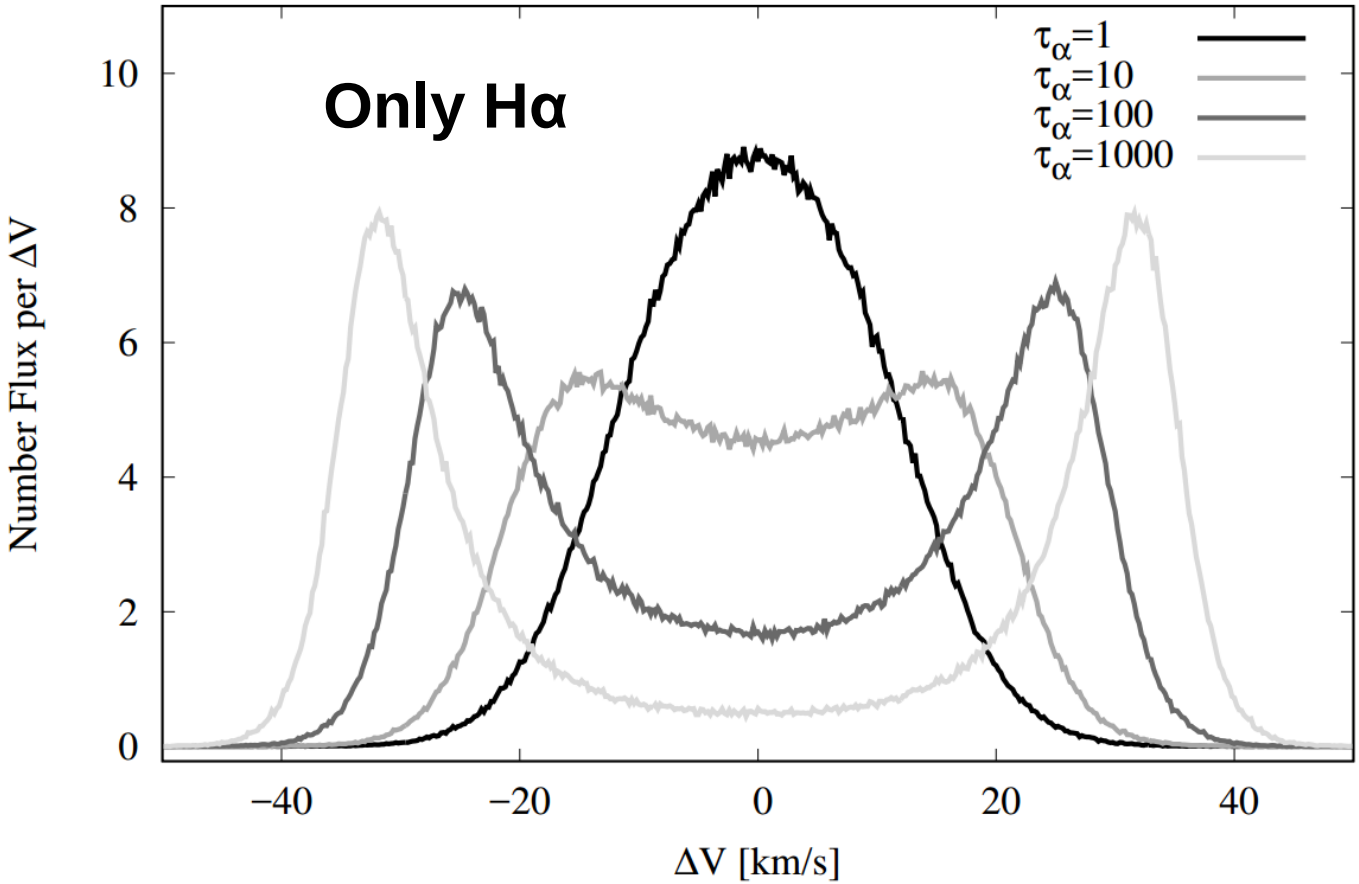


Neufeld 1990



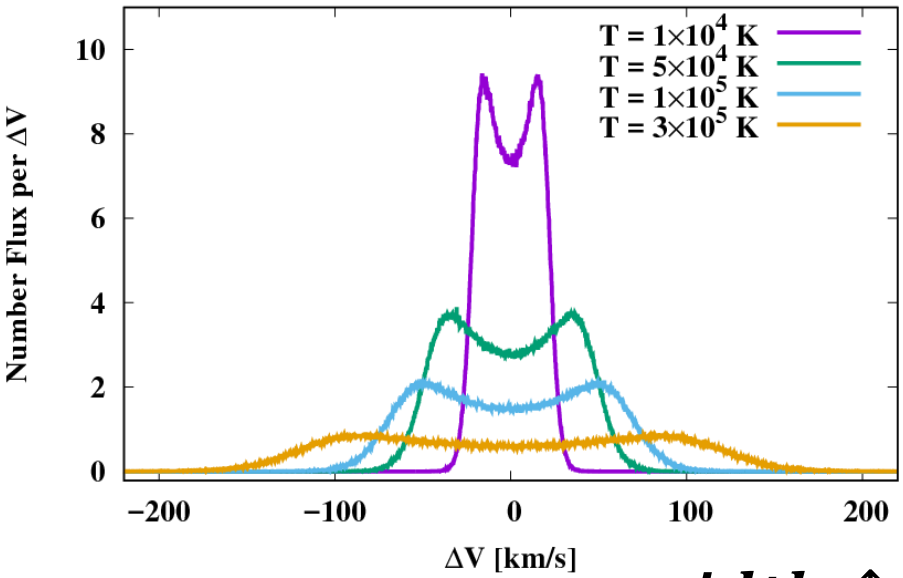
Gronke et al. 2016

Line Profiles of Resonance Scattered Photons

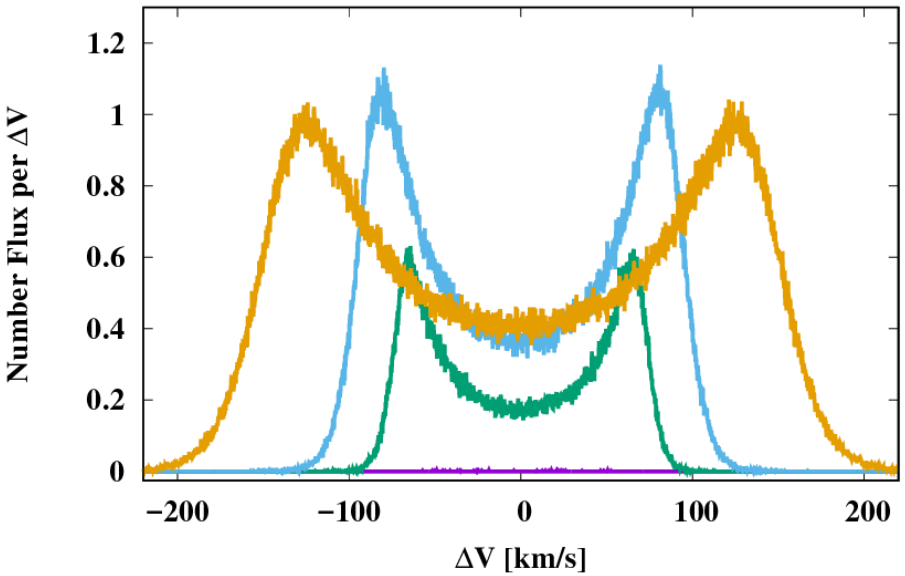


Dependence of T at $\tau_\alpha = 10$

Hα



Lyβ

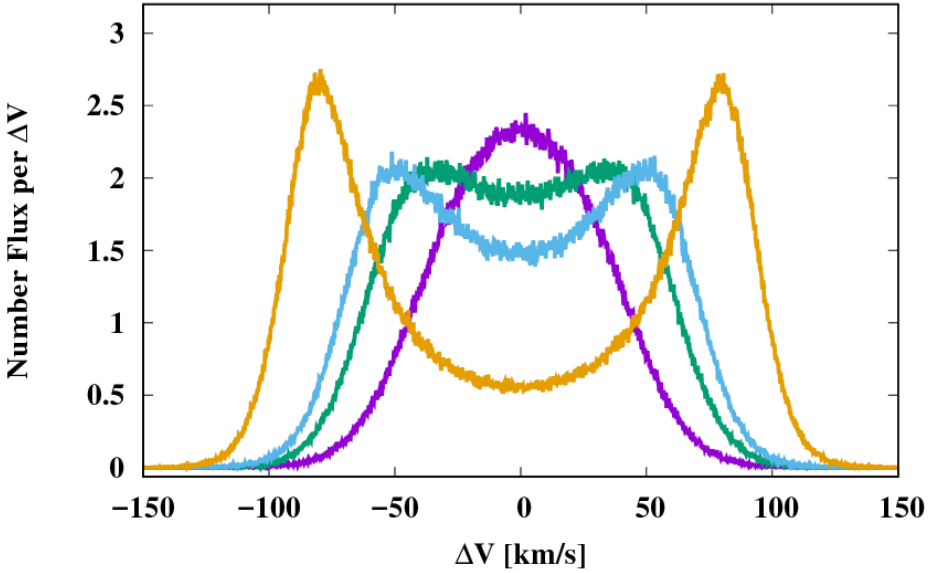


$$T \uparrow \;\rightarrow\; width \uparrow$$

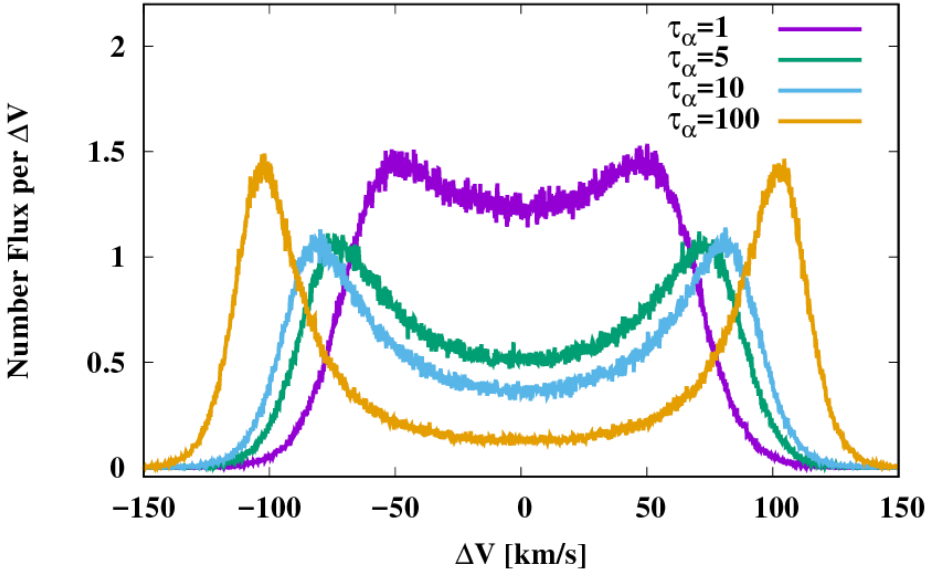
$$T \uparrow \;\rightarrow\; \frac{N_1}{N_2} \downarrow \;\rightarrow\; \frac{\tau_\beta}{\tau_\alpha} \downarrow \;\rightarrow\; \frac{\varphi_\beta}{\varphi_\alpha} \uparrow$$

Dependence of τ_α at $T = 10^5$

Hα



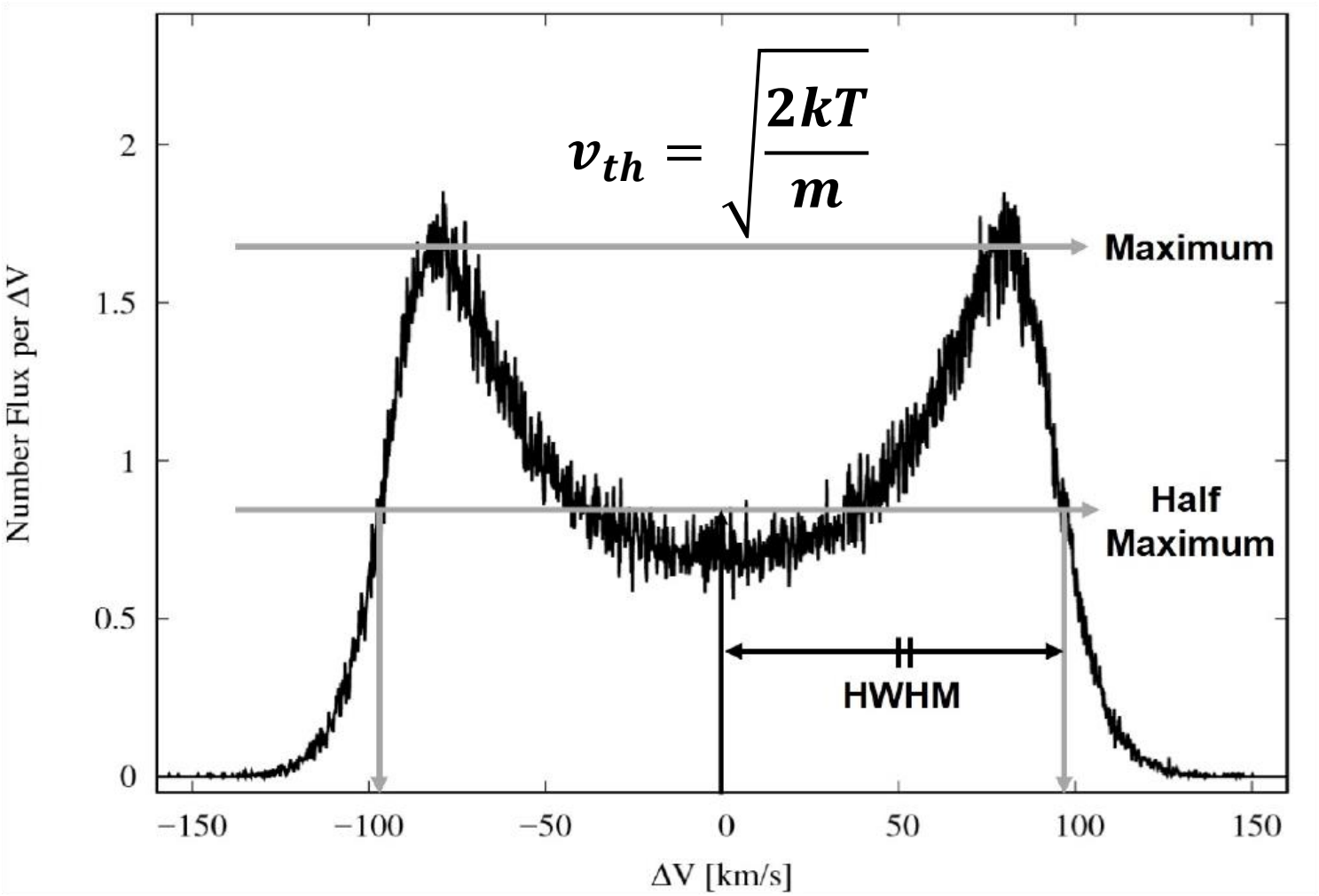
Lyβ



$\tau_\alpha \uparrow$ → $center\ deep \uparrow$

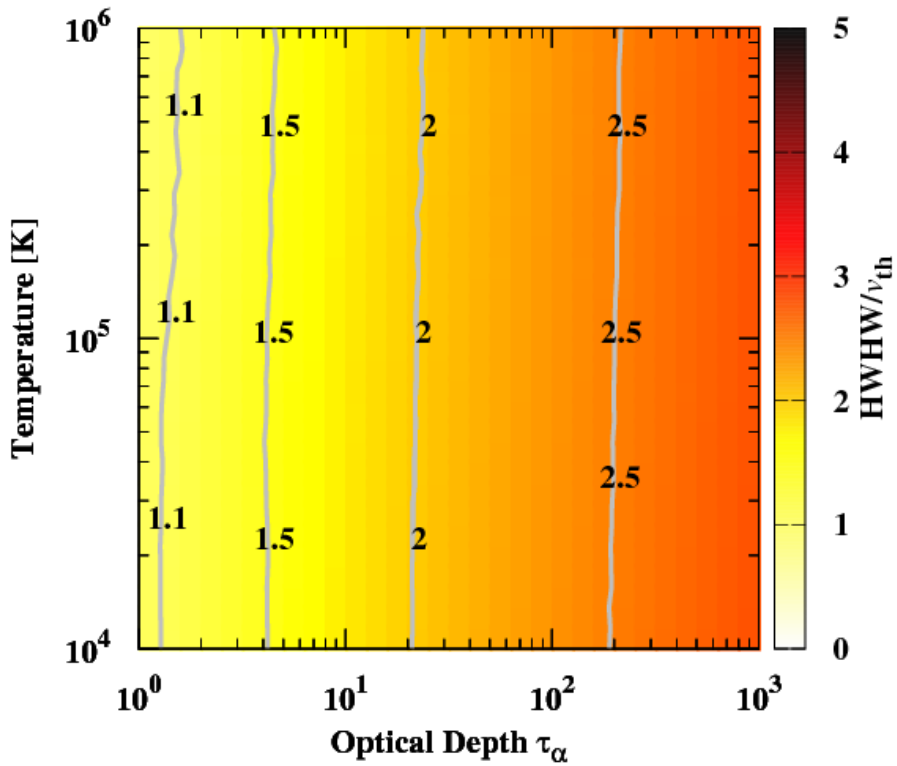
$\tau_\alpha \uparrow$ → $\frac{\varphi_\beta}{\varphi_\alpha} \uparrow$ → **The effect from Branching Ratio get weaker.**

(T-tau) Map of Width

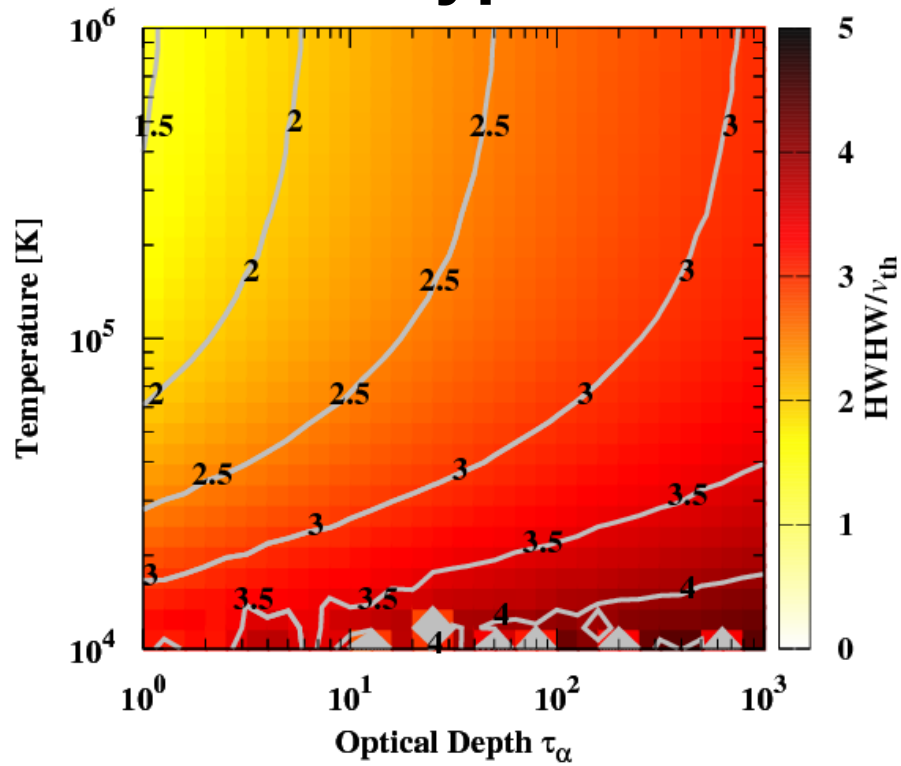


(T-tau) Map of Width

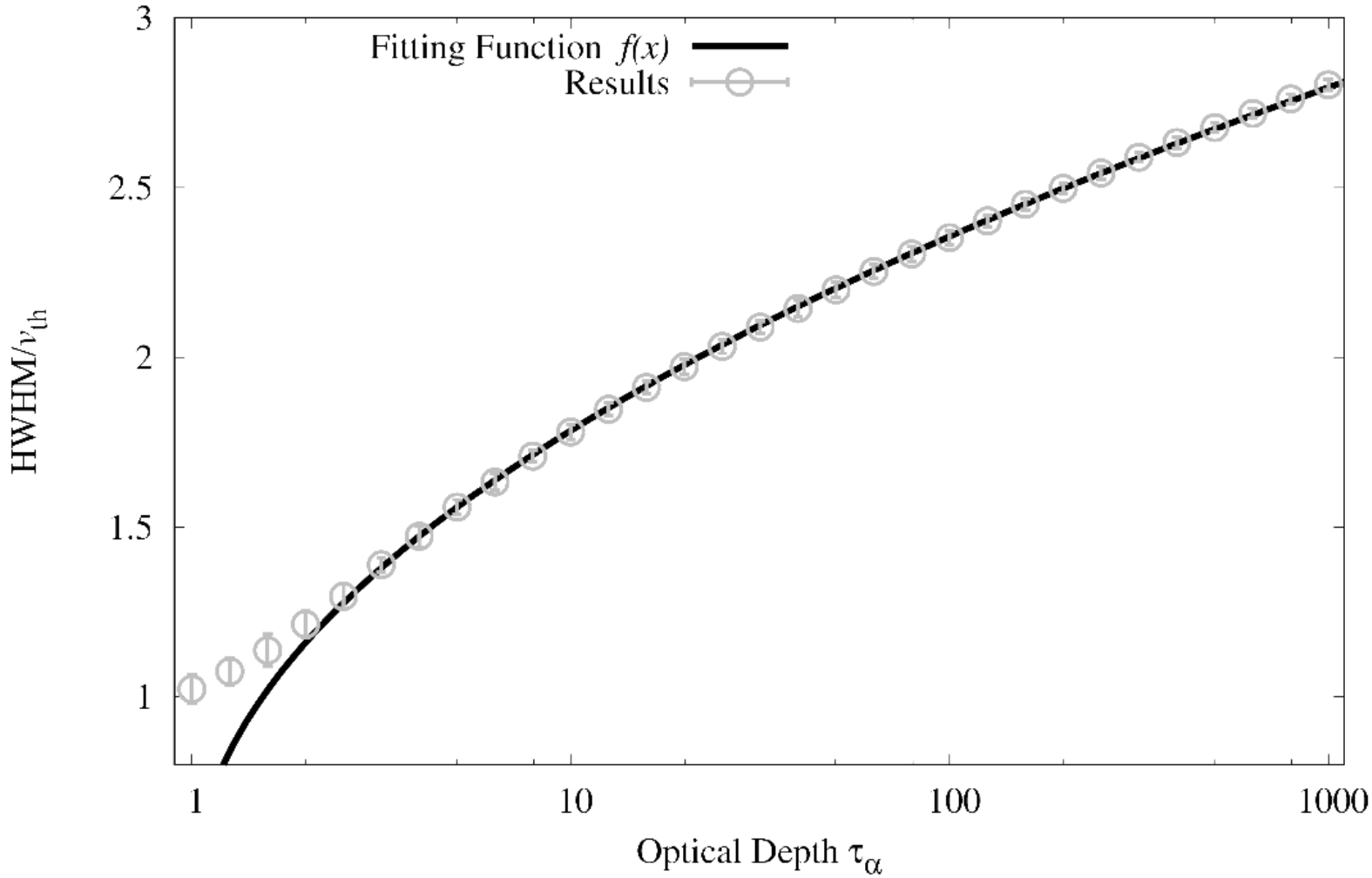
Hα



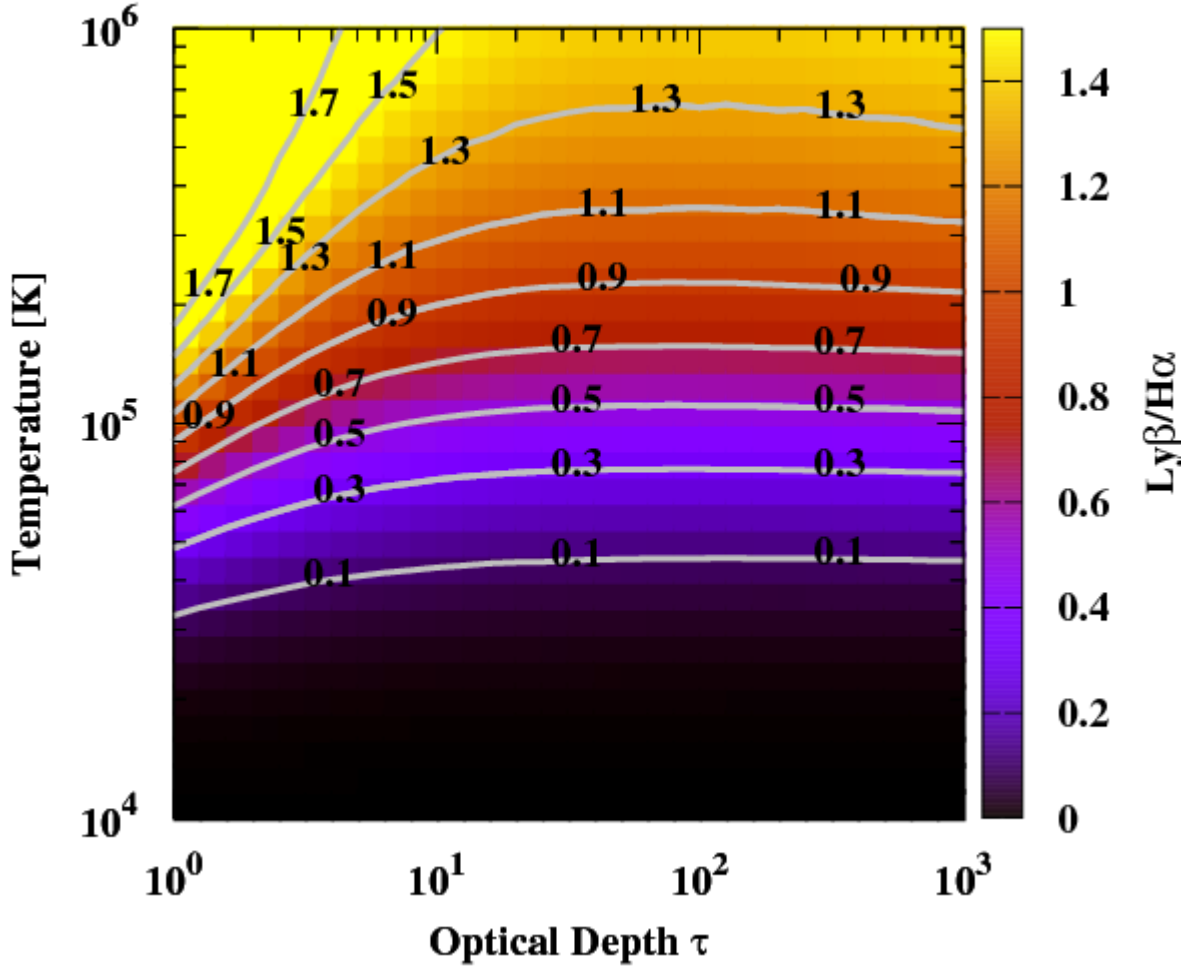
Lyβ



(T-tau) Map of Width



$(\tau_\alpha - T)$ Map of Flux Ratio Lyβ/ Hα



Summary and Discussion

1. Lyβ transition is non-neglected process by atomic hydrogen in the hot and optically thick region.

2. The widths of resonance scattered lines are increased as τ_α and T get higher.

3. The flux ratio Lyβ/Hα at $T = 10^5\ K$ is ~ 0.5.

4. In symbiotic stars, the broad wings around Hα can be originated from the Raman scattering of the escaped Lyβ photons.

5. It is expected that scattered wings around Hα in LAE can be detected at IR wavelength.