Hα - Lyβ Formation in Optically Thick Media

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1. Abstract

Symbiotic stars and quasars exhibit prominent Hα emission lines often accompanied with broad wings. Hα emission nebulae in these objects are proposed to be optically thick to resonance scattering. The transfer of Hα line photons is further complicated by the existence of another scattering channel leading to re-emission of Lyβ. In this work we develop a Monte Carlo code to simulate the transfer of Hα line photons incorporating the scattering channel into Lyβ. We show various line profiles of Hα and Lyβ emergent from our model nebulae. It is shown that temperature is a critical parameter which controls the ratio of emergent Lyβ flux to that of Hα.

2. Introduction

① Emission Nebulae in Symbiotic Stars and Quasars

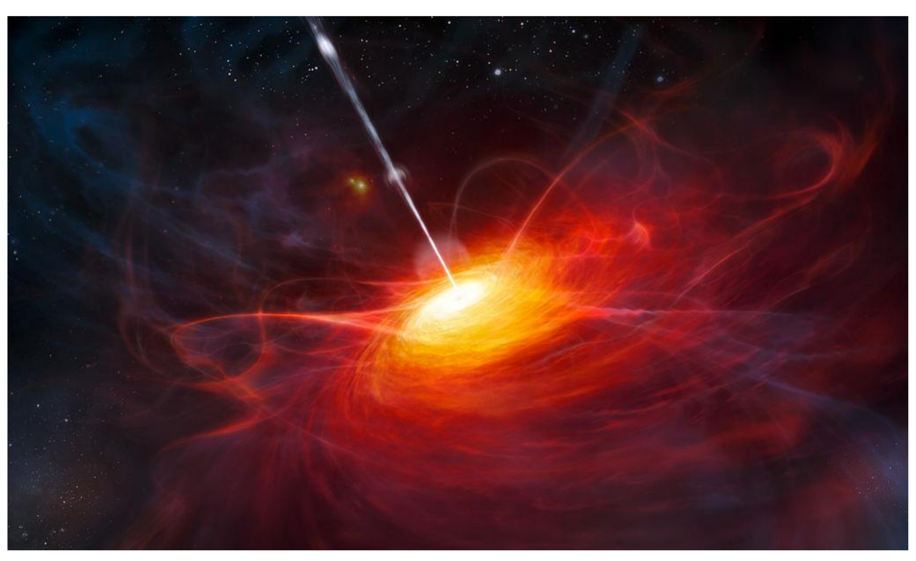


Figure 1 Quasar

Figure 2 Symbiotic Stars

- Quasars and symbiotic stars are examples of compact objects (a super massive black hole and a white dwarf, respectively) with an accretion disk that powers emission nebulae around them
- Hα is often the strongest emission line in the optical, and the scattering optical depth in the emission nebulae of symbiotic stars and quasar may exceed unity depending on various physical conditions. In particular, the scattering optical depth is highly sensitive to the temperature of the nebulae, which mainly controls the population of the n=2 state.
- Further complications in the radiative transfer of Hα arise from the existence of another scattering channel leading to the emission of Lyβ. Because Lyβ is a resonance line, the optical depth is expected to be huge. In this work, we investigate the transfer of Hα incorporating the additional Lyβ scattering channel using a Monte Carlo technique.

② Transfer of Resonance Line Photons

Escape is made through diffusion into wing regions after a large number of local scatterings. The optical depth being huge, escape is impossible at line center. A large number of resonance scattering leads to diffusion in frequency space, which results in outgoing photon with large off-center frequency

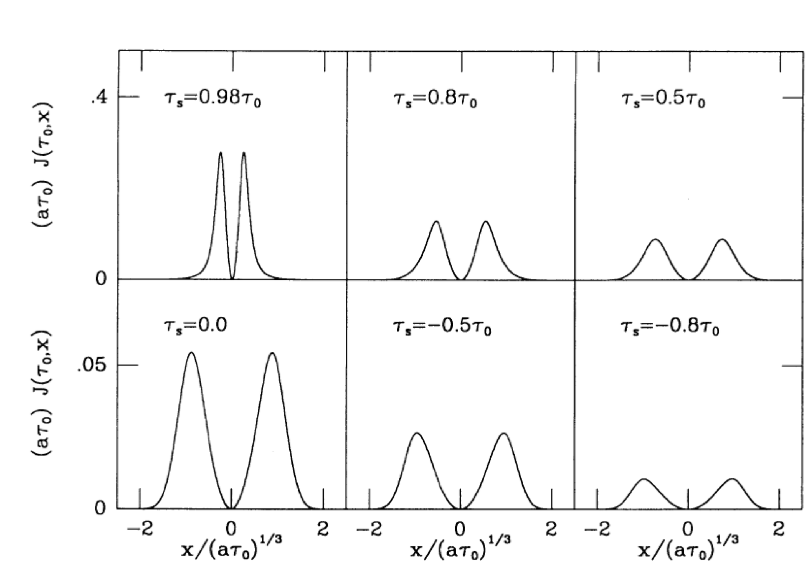


Figure 3 Resonance Line Profile

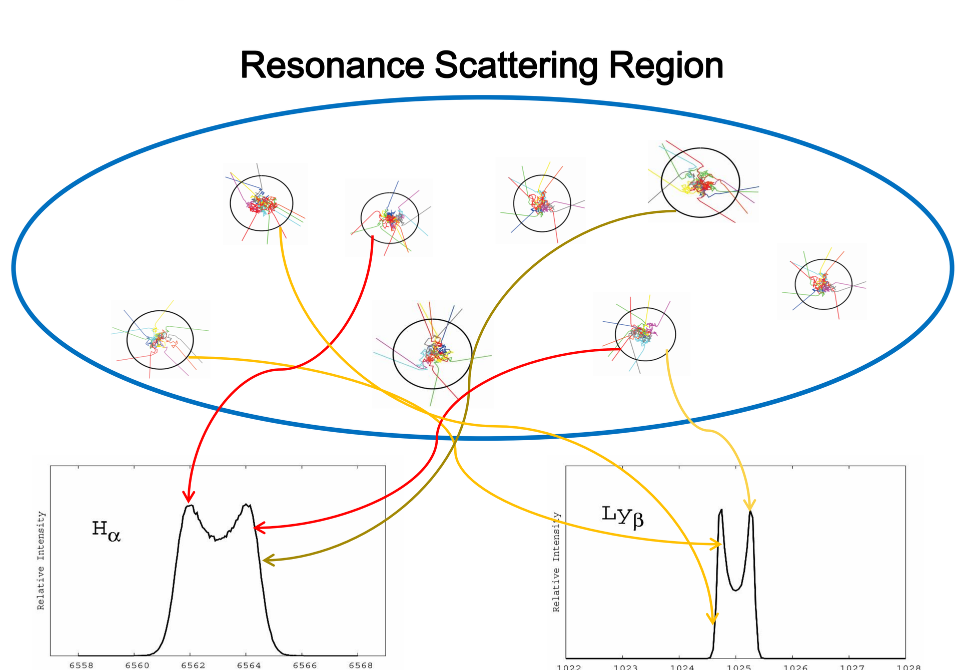


Figure 4 Escape of Resonance Line Photons

③ Transfer of Hα - Lyβ Photons

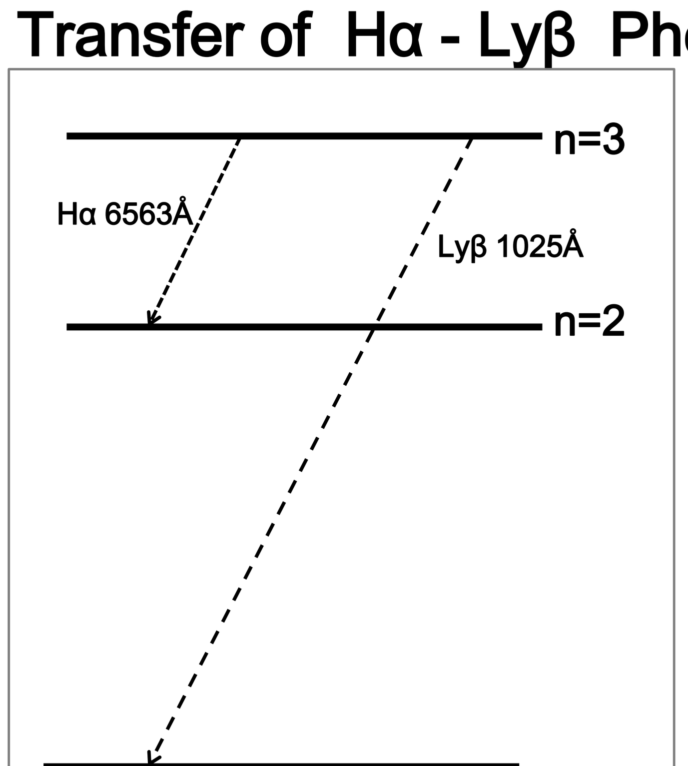


Figure 5 Energy Level Diagram for Hydrogen

a. Hα photons can be scattered and changed to Lyβ and vice versa.

b. The branching ratio

Hα: Lyβ ≃ 1:7

c. A Monte Carlo code is developed to treat Hα – Lyβ hybrid radiative transfer

3. Result

① Monte Carlo Profiles for a Resonance Line

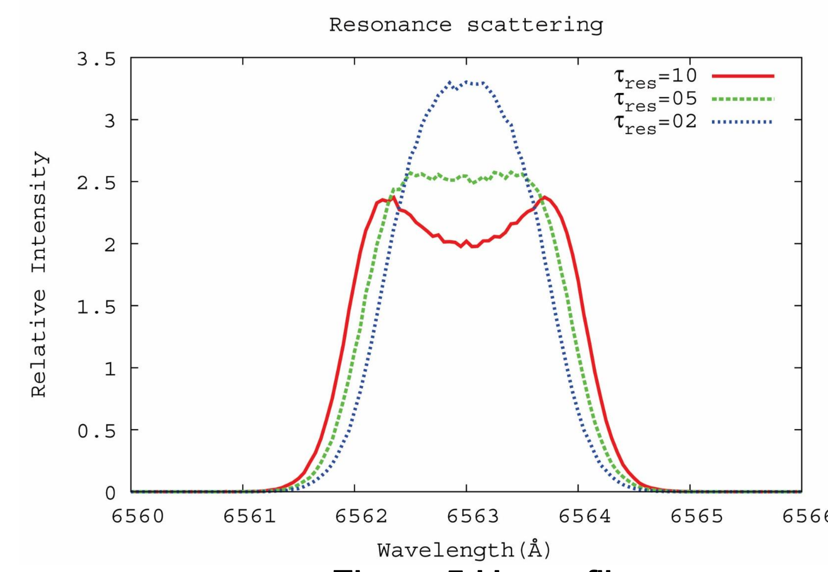
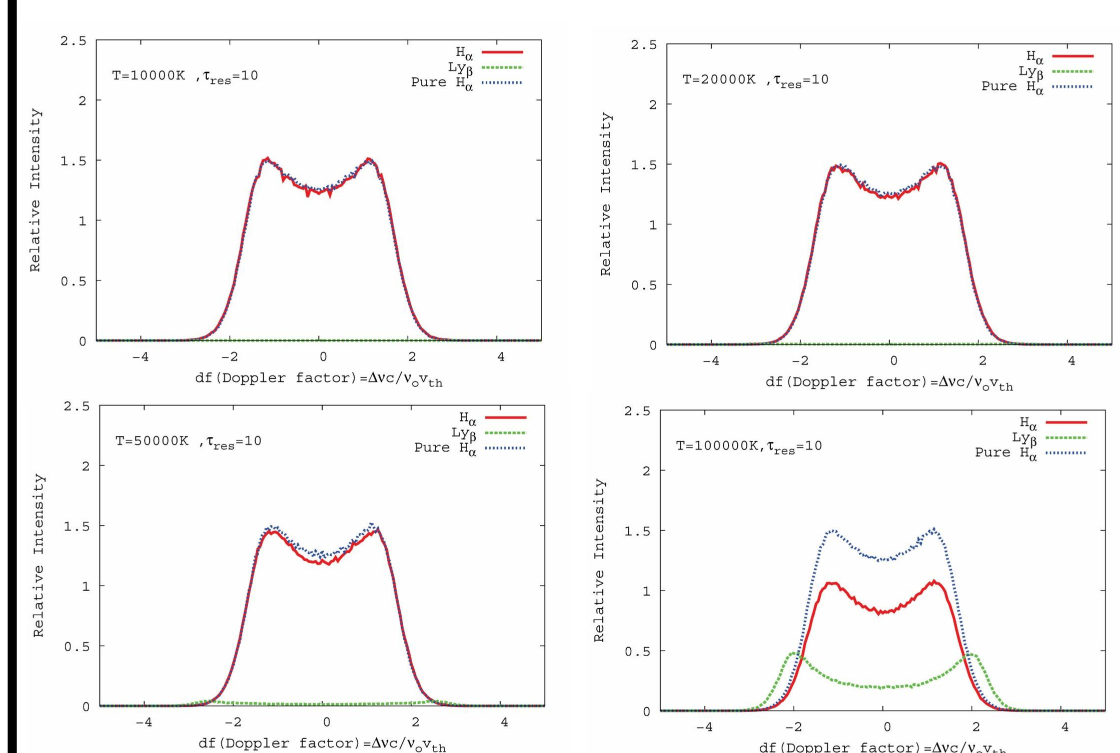


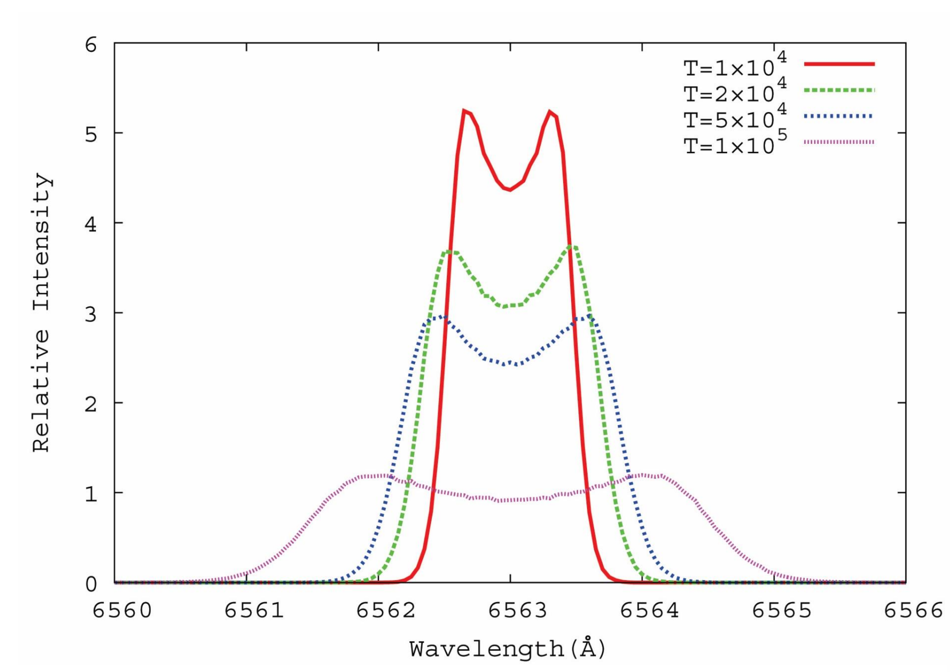
Figure 5 Hα profile

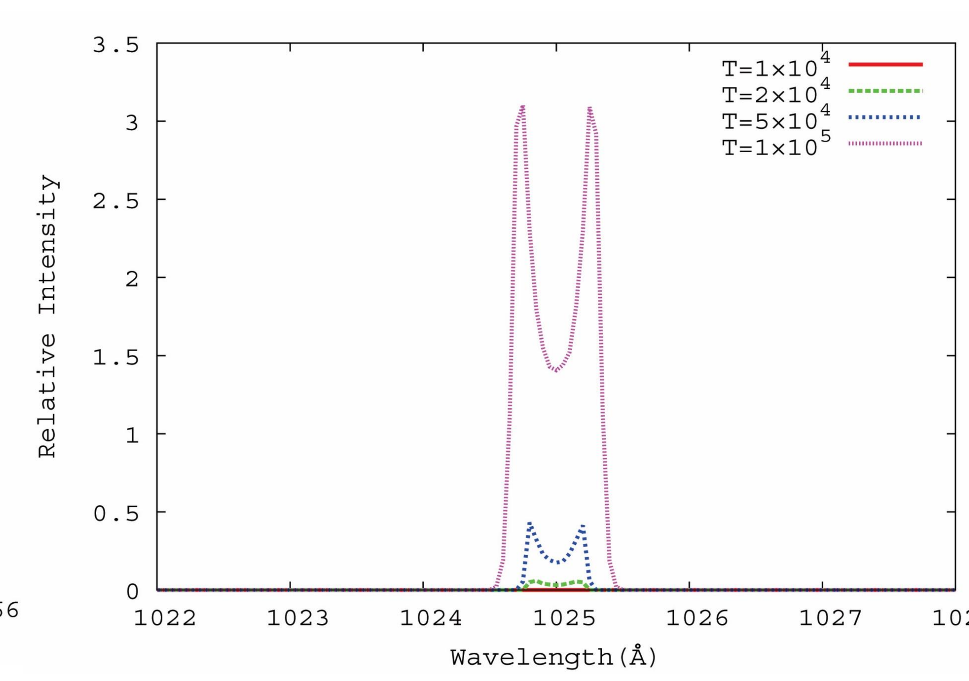
- The Monte Carlo code is used to produce typical profiles for a resonance line.
- The optically thick medium is taken to be a spherical shell, where the thickness is described by the line center optical depth τ_{res}.
- A line photon is generated uniformly inside the shell and followed until it escapes the region recording its wavevector and frequency.
- As the line center optical depth increases, the escape at line core is significantly suppressed forming a central dip.
- Diffusion in frequency space results in escape of photons at for wing regions as to increases.

② Temperature Effect on the Hybrid Transfer

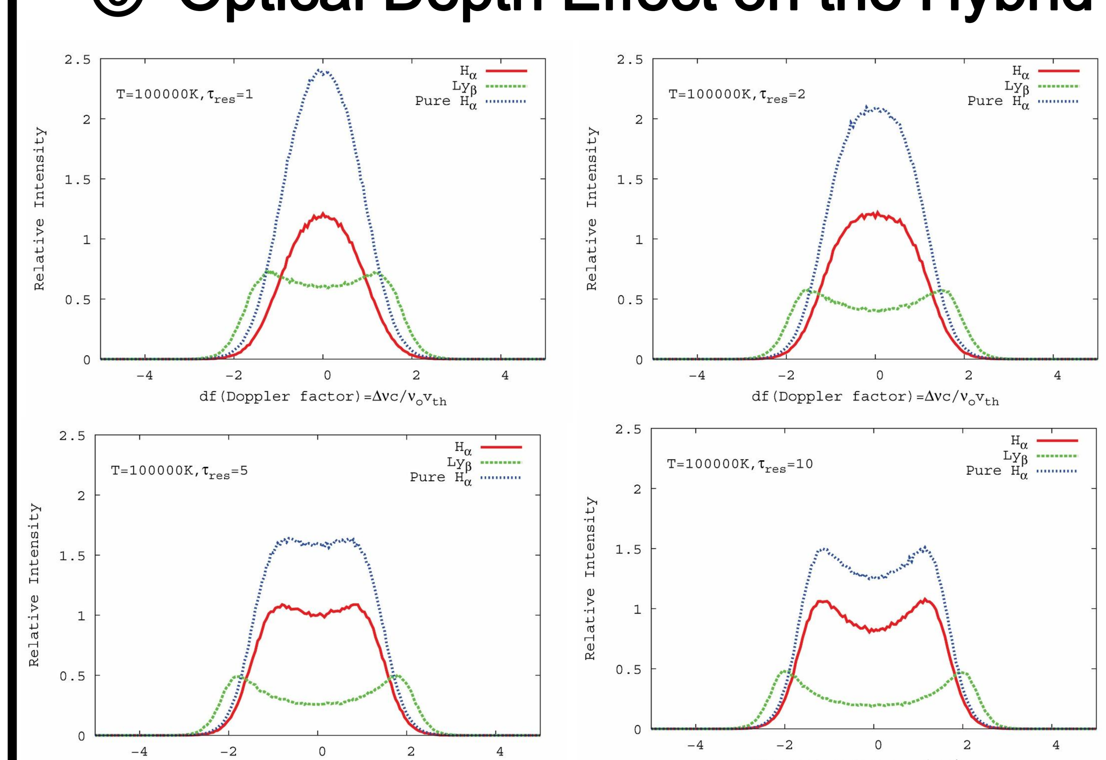


- Treating the Hα line transfer we include the additional scattering channel into Lyβ.
- The red solid line represents emergent Hα profiles, The green dotted line shows the profiles of emergent Lyβ. The blue lines shows the H profiles when Hα line is treated as a pure resonance line.
- When the temperature is less than 20,000K, the line center optical depth of Lyβ is so great due to the dominant Boltzmann factor favoring the ground state that little flux for Lyβ is obtained. Hα - Lyβ
- As T increases the Hα optical depth becomes comparable to that of Lyβ, which significantly enhances the emergent flux of Lyβ.

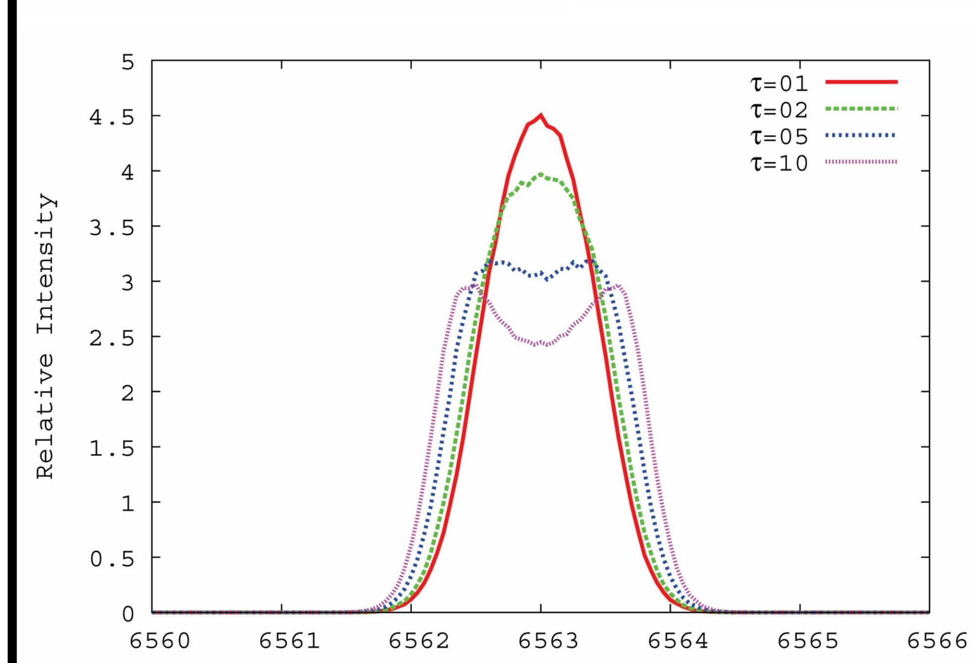


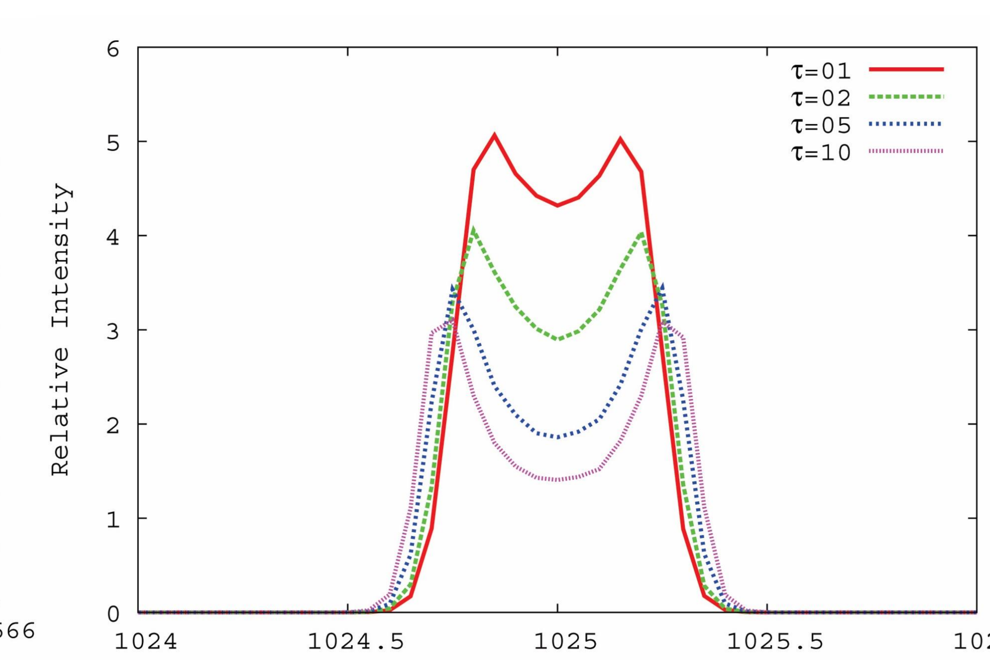


③ Optical Depth Effect on the Hybrid Transfer



- We investigate the effect of the optical depth on the Hα and Lyβ profiles for a given temperature.
- Here, we fix the temperature to 10^5 K for which the escape fraction Lyβ is significant.
- The two profiles are similar in shape, both developing a central dip with the increase of the optical depth.





4. Summary and Discussion

1. In this work we developed a Monte Carlo for the radiative transfer of Hα – Lyβ line photons in a spherical shell.
2. When the temperature of the medium is of temperature less than 50,000 K, the escape through Ly beta is quite insignificant due to small population in n=2 levels.
3. In a medium with temperature 100,000 K, emergent Ly beta flux is comparable to that of H alpha.
4. This work can be applied to the analysis of Ly beta emission from quasars.

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