Raman Scattering Wings of Hydrogen in Active Galactic Nuclei.

Seok-Jun Chang[1], Jeong-Eun Heo[1], Francesco Di Mille[2], Rodolfo Angeloni[3], Tail Palma[4], Chae-Lin Hong[1] and Hee-Won Lee[1]

[1]Department of Physics and Astronomy ,Sejong University,Korea
[2]Las Companas Observatory, Chile
[3]AURA-GEMINI Observatory, Chile
[4]Millennium Institute of Astrophysics, Chile
[5]A Pontificia Universidad Catolica de Chile, Chile

The Lab of Astrophysical Spectroscopy at Sejong Univ.

1. Abstract

Active galactic nuclei (AGNs) are powered by a supermassive black hole (SMBH) with an accretion disk and exhibit prominent broad and narrow emission lines. The unification model of AGNs requires the presence of a geometrically and optically thick torus component that hides the broad line region from observers lying in the equatorial direction. The strong far UV radiation characterizing AGN spectra is expected to be scattered inelastically in the torus region to reappear around hydrogen Balmer lines or Paschen lines in the form of broad wings. Adopting a Monte Carlo technique we produce broad wings around Hα, Hβ and Paα that are formed through Raman scattering. The widths of the wings are mainly affected by the neutral column density of the torus, and the overall strengths are primarily determined by the covering factor and the column density of the neutral region. It is concluded that deep spectroscopy of AGNs of broad wings around hydrogen emission lines may shed much light on the AGN unification model.

2. Introduction

① Active Galactic Nuclei

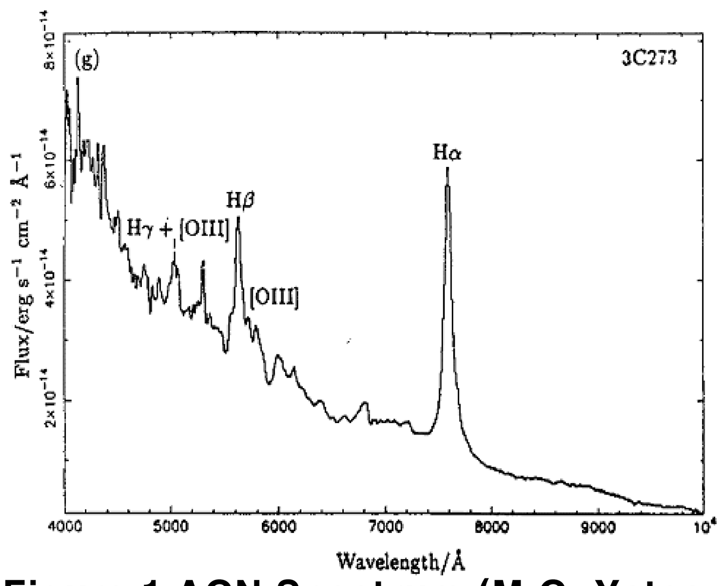

Figure 1 AGN Spectrum (M.G. Yates et al. 1989)

1. AGNs are characterized by a nonthermal and featureless continuum with prominent broad and narrow emission lines that cover wide range of ionization and excitation.
2. Type 1 AGNs have broad permitted lines and semi-forbidden lines with a width of 5,000km/s. They also exhibit forbidden lines that are narrow with a width ~500km/s.
3. Type 2 AGNs show only narrow emission lines.
4. The hardness of X-ray spectra of Type 2 AGNs is larger than Type 1 AGNs.

② AGN Unification Model

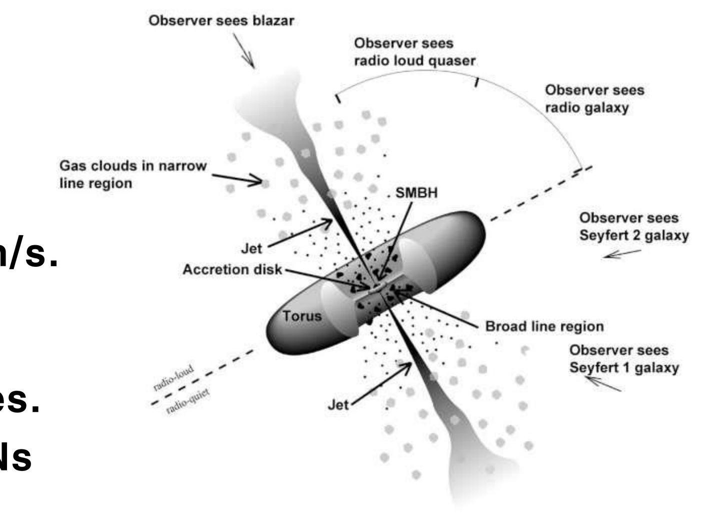

Figure 2 Unification Model

- In AGN unification models it is assumed that most AGNs have a similar structure composed of a SMBH, a broad line region, a narrow line region and a geometrically thick molecular torus.
- The molecular torus is optically thick and it is natural to expect that there is a neutral region with a high H I column density.
- Illuminated by the strong far UV continuum from the AGN center, the neutral region is an ideal place for the operation of Raman scattering by atomic hydrogen which results in broad wings around Balmer and Paschen lines.

3. Raman scattering in Unification Model

Far UV continuum around higher Lyman series is incident on a hydrogen atom in the ground state can be inelastically scattered to be re-emitted around Balmer lines or Paschen lines. These scattered features form broad wing features that may be approximated by the Lorentzian representing the cross section multiplied by the branching ratio that is quite asymmetric with respect to the line center.

Raman scattering appears to be responsible for broad Hα wings prevalently seen in many symbiotic stars and in a number of young planetary nebulae, where a neutral region with H I column density of $10^{20}\mathrm{cm}^{-2}$ surrounds a hot white dwarf as a result of mass loss process. Figures 4-5 show the total cross section and the branching ratio for the formation of Balmer and Paschen wings.

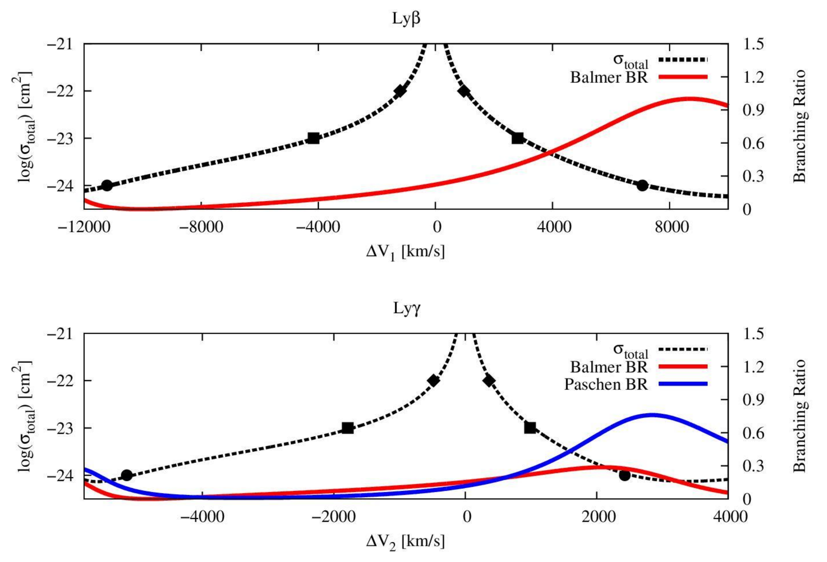

Figure 4 Cross Section and Branching Ratio

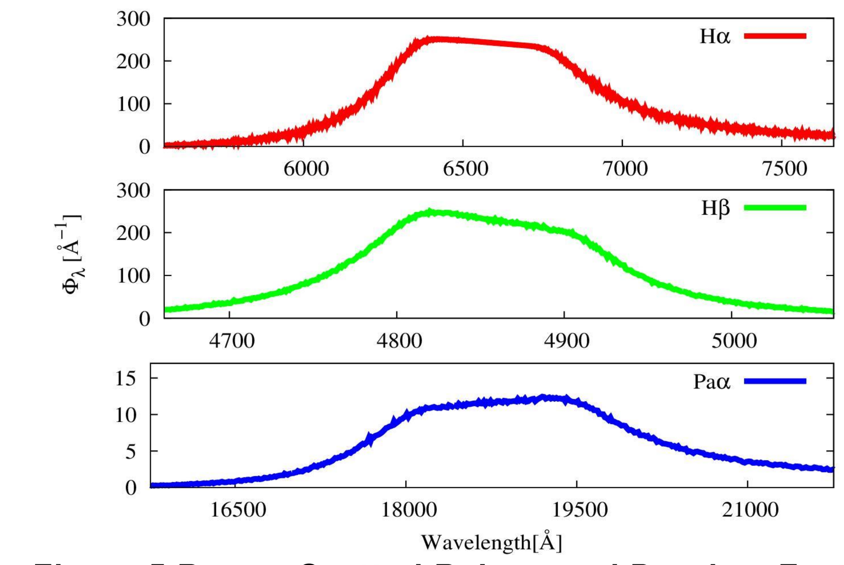

Figure 5 Raman Scatted Balmer and Paschen Feature

4. Models of Monte Carlo Simulation

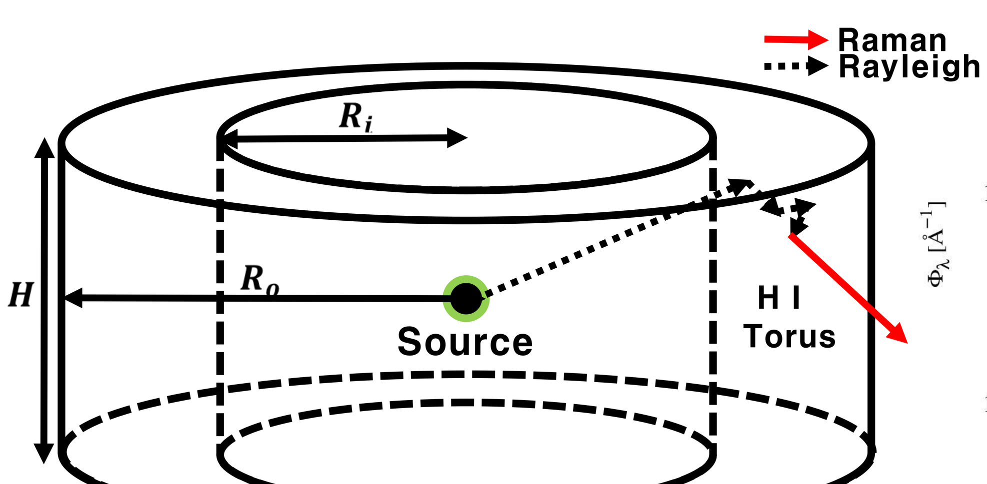

Figure 6 Cylindrical Shell(torus) Model Geometry

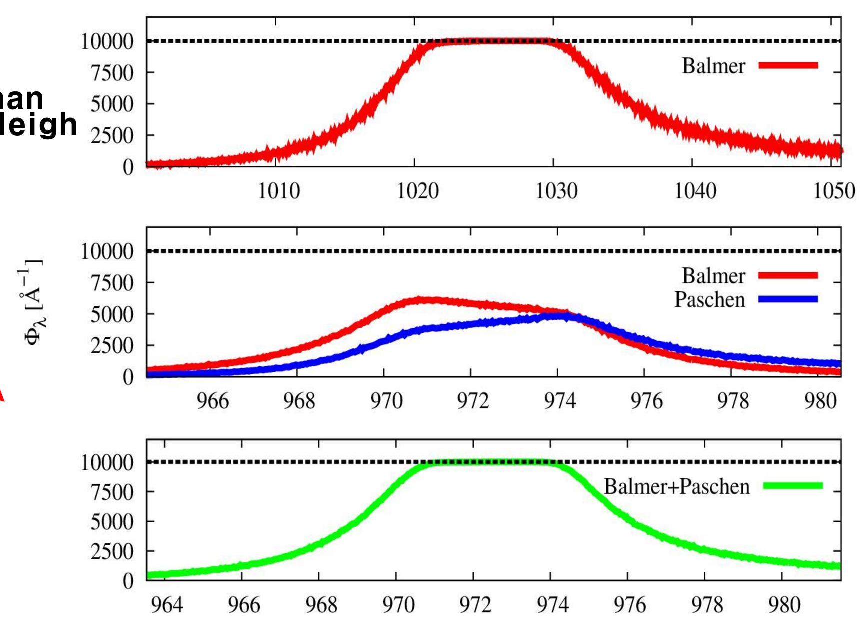

Figure 7 Raman scattering wing in Model I

We adopt a Monte Carlo technique to investigate the formation of Raman scattering wings in AGN. First we approximate the molecular torus as a cylindrical shell with a finite thickness. The we vary the height which mimics the covering factor of the scattering region and also consider the effect of the HI column density. The AGN engine is assumed to be located at the center and characterized by a flat continuum around Lyman series.

In Model I we consider a cylindrical shell with an infinite height that covers the AGN center entirely in order to study the basic properties of Raman wings in the case of full covering. . In this model, we set $\Delta R = R_0 - R_i = 10\,pc$, $A = H/\Delta R = \infty$ and $N_{HI} = n_{HI}\Delta R = 10^{23}\mathrm{cm}^{-2}$.

In Model II a cylindrical shell with a finite height is considered in order to investigate the effect of covering factor. In this model, we fix ΔR and set various parameters, $N_{HI} = 10^{22\sim24}\mathrm{cm}^{-2}$ and $A = 0.5 - 2.0$.

5. Result

① Effect of N_HI

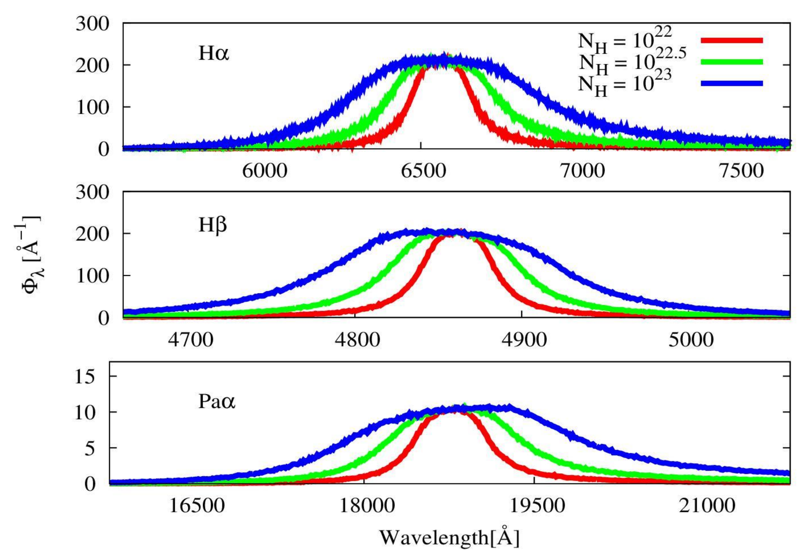

Figure 8 Raman scattering wings for Model II

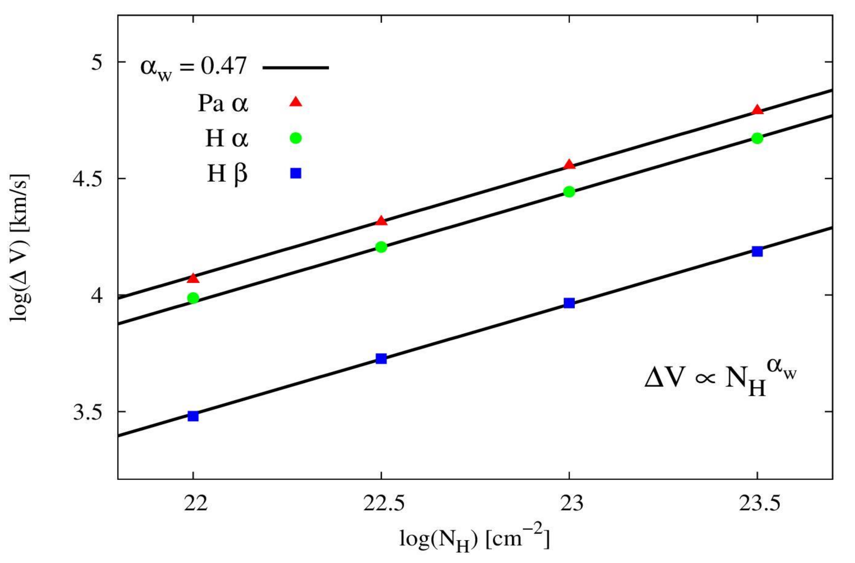

Figure 9 Wing width ΔV vs. HI column density N_{HI}

② Effect of Covering Factor

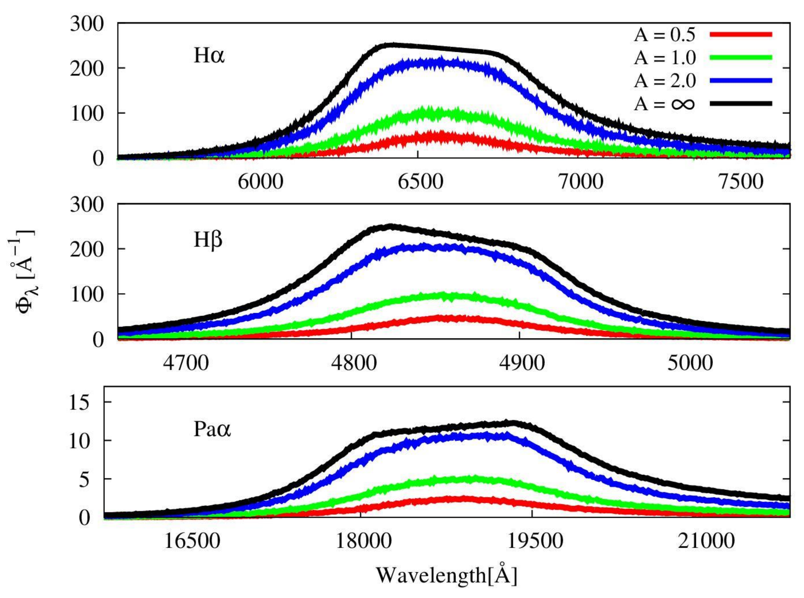

Figure 10 Raman scattering wings for Model II

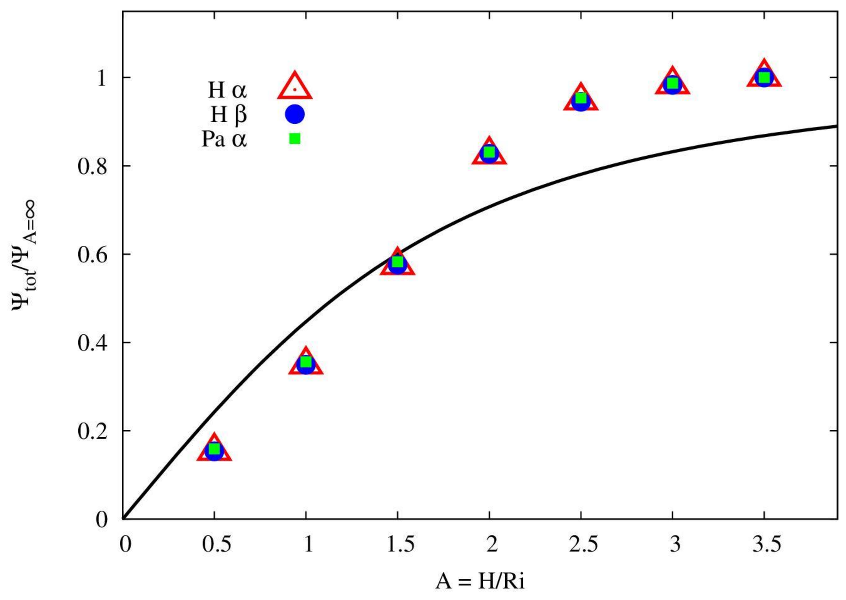

Figure 11 Wing strength $\frac{\Psi_{tot}}{\Psi_{A=\infty}}$ vs. covering factor A

③ A Mock Spectrum

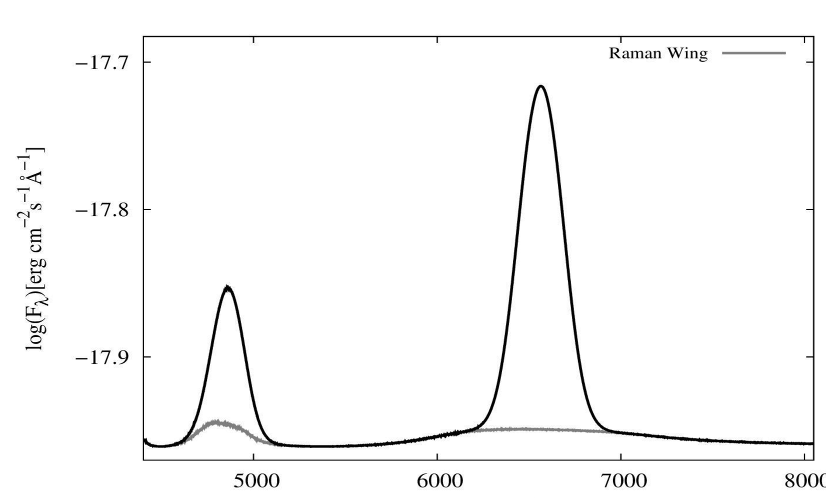

Figure 12 A Mock Spectrum

- We produce a mock spectrum as a feasibility test of our model.
- The far continuum level is given by the fixed value of $\lambda L_\lambda = 10^{44}\,erg/s$ and that the continuum between Hβ and Hα is given in such a way that $\lambda L_\lambda = 5\times10^{43}\,erg/s$. The luminosity distance is set to be $D_L = 0.3\,Gpc$.

6. Summary and Discussion

1) Raman scattering can be an important mechanism to produce Balmer and Paschen wings in the standard AGN unification scheme.
2) The wing widths are primarily dependent on the neutral hydrogen column density N_{HI} being roughly proportional to $N_{HI}^{1/2}$.
3) The covering factor affects the overall strength of the wings.
4) Spectropolarimetry will be useful to identify the Raman wings in AGN.
5) We predict that a type 2 AGN may also show detectable Raman Hβ wings, which will be seen outside of the narrow Hβ emission line.

The 2015 Fall Meeting of the Korean Astronomical Society