Simulated Imaging Polarimetry of Lyα Scattered in a Thick Neutral Medium : Preliminary Results

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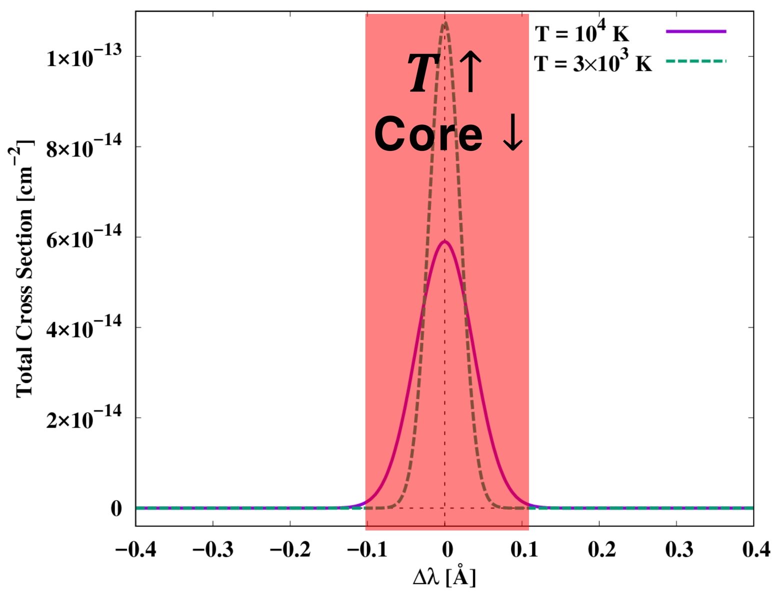
I. Abstract

Observational evidence points out that Lyα observed in Lyα emitters (LAEs) and Lyα blobs (LABs) are scattered many times in a neutral region before reaching the observer. The escape of Lyα being made in the wing regime characterized by the Rayleigh phase function, we expect that Lyα can be strongly polarized depending on the scattering geometry and line optical depth. One important result obtained by Chandrasekhar is 11.7 percent of polarization degree for the Thomson scattered (or Rayleigh scattered) radiation emergent in the grazing direction from a sufficiently thick slab ($\tau > 5$), where the polarization develops in the direction parallel to the slab. We study the imaging polarimetry of Lyα, where we assume a point-like emission source surrounded by a cylindrical neutral shell. Concentric ring patterns of polarization apparent to an observer in the direction normal to the slab become distorted as the slab inclination changes. The difference in polarization between the upper and lower hemispheres leads to polarization flip that takes place as the line optical depth becomes sufficiently large. In this poster presentation, we show some preliminary results of our simulated imaging polarimetry of Lyα.

II. Introduction

① Off-Resonance Scattering



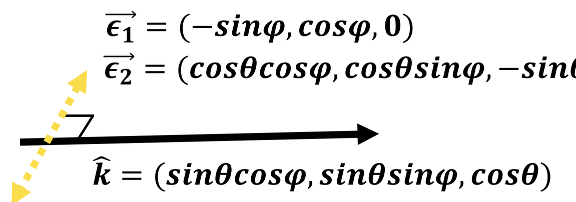
Total cross section near Lyα

The scattering cross section near line center is approximated by a Voigt function. Lyα photons make physical excursions and finally escape through frequency diffusion into the far wing regime, where scattering is Rayleigh or off-resonance. In this presentation, we compute the surface brightness and polarization of Rayleigh scattered photons from the monochromatic source.

② Density Matrix

$\vec{\epsilon_1} = (-\sin\varphi, \cos\varphi, 0)$

$\vec{\epsilon_2} = (\cos\theta\cos\varphi, \cos\theta\sin\varphi, -\sin\theta)$



$\hat{k} = (\sin\theta\cos\varphi, \sin\theta\sin\varphi, \cos\theta)$

Wavevector $\hat{k}$ and the polarization basis vectors $\vec{\epsilon_1}$ and $\vec{\epsilon_2}$

$$\rho = \begin{pmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{pmatrix} = \begin{pmatrix} \frac{I+Q}{2} & \frac{U+iV}{2} \\ \frac{U-iV}{2} & \frac{I-Q}{2} \end{pmatrix}$$

Density Matrix Related to Stokes Parameters

$$\rho'_{11} = (\cos^2\Delta\varphi)\rho_{11} - (\cos\theta\sin2\Delta\varphi)\rho_{12} + (\sin^2\Delta\varphi\cos^2\theta)\rho_{22}$$

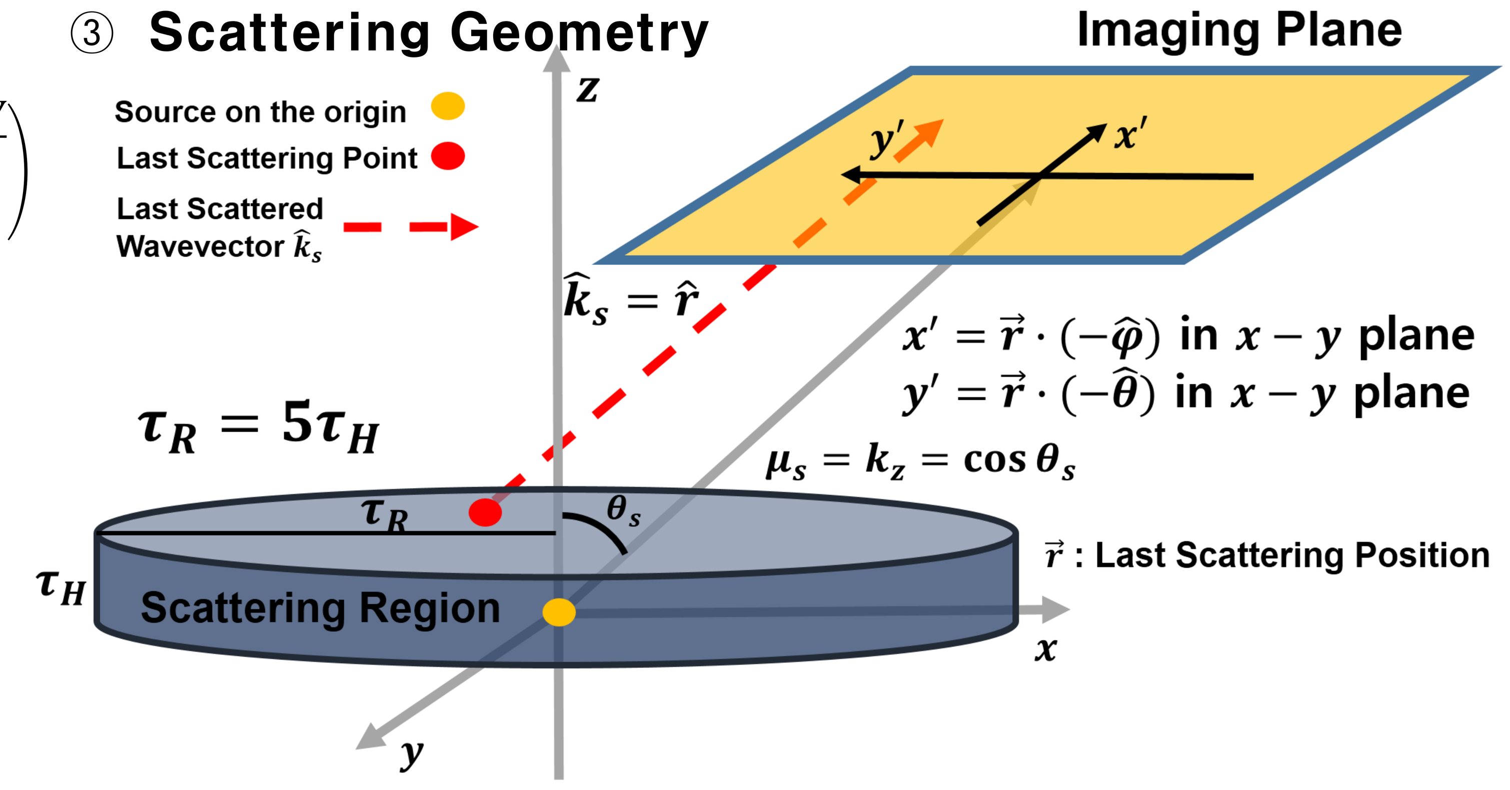
$$\rho'_{22} = (\cos^2\theta'\sin^2\Delta\varphi)\rho_{11} + \cos\theta'(2\sin\theta\sin\theta'\sin\Delta\varphi + \cos\theta\cos\theta'\sin2\Delta\varphi)\rho_{12} + (\cos\theta\cos\theta'\cos\Delta\varphi + \sin\theta\sin\theta')\rho_{22}$$

$$\rho'_{12} = (1/2\cos\theta'\sin2\Delta\varphi)\rho_{11} + (\cos\theta\cos\theta'\cos2\Delta\varphi + \sin\theta\sin\theta'\cos\Delta\varphi)\rho_{12} - \cos\theta(\sin\theta\sin\theta'\sin\Delta\varphi + 1/2\cos\theta\cos\theta'\sin2\Delta\varphi)\rho_{22}$$

Density Matrix Formulism for Rayleigh scattering (Ahn and Lee, 2015)

The density matrix formalism is adopted to describe the polarization in the simulation. The density matrix elements associated with the scattered radiation with the unit wavevector $\hat{k}'$ and polarization vectors $\vec{\epsilon_1}'$ and $\vec{\epsilon_2}'$ are related to those for the incident radiation denoted by $\hat{k}$, $\vec{\epsilon_1}$ and $\vec{\epsilon_2}$.

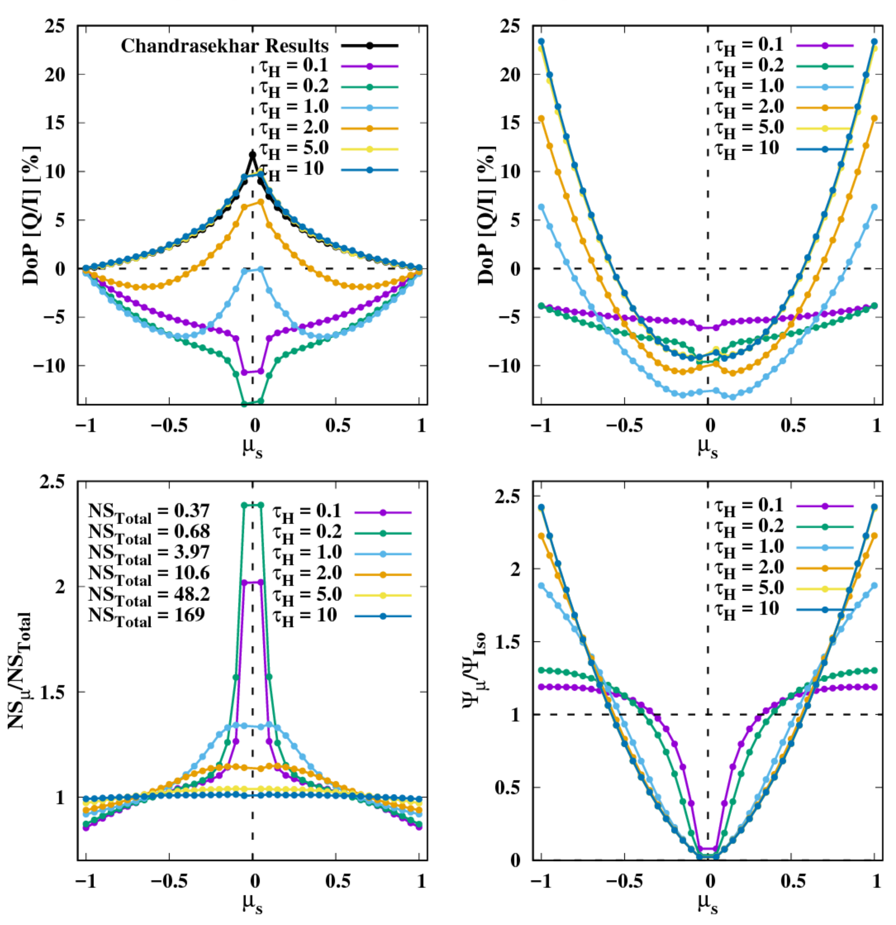
③ Scattering Geometry



In this simulation, we collect photons Rayleigh scattered by atomic hydrogen. When photons escape from the scattering region, the last scattering position is projected to the imaging x', y' plane, ignoring the z component of last scattering position. Also photons escaping only through the upper and lower surfaces of the scattering region are collected to produce polarimetric images.

III. Polarimetry by μ_s

Collective properties of scattered photons



Q/I of last scattered photons the left top panel

$\tau_H \uparrow \rightarrow Q/I \uparrow$ $|\mu_s| \uparrow \rightarrow Q/I \downarrow$

$\tau_H > 5 \rightarrow$ Following Chandrasekhar's Results

Q/I of photons before last scattering the right top panel

$|\mu_s| \uparrow \rightarrow Q/I \uparrow$

The Number of scattering NS_μ of scattered photons the right bottom panel

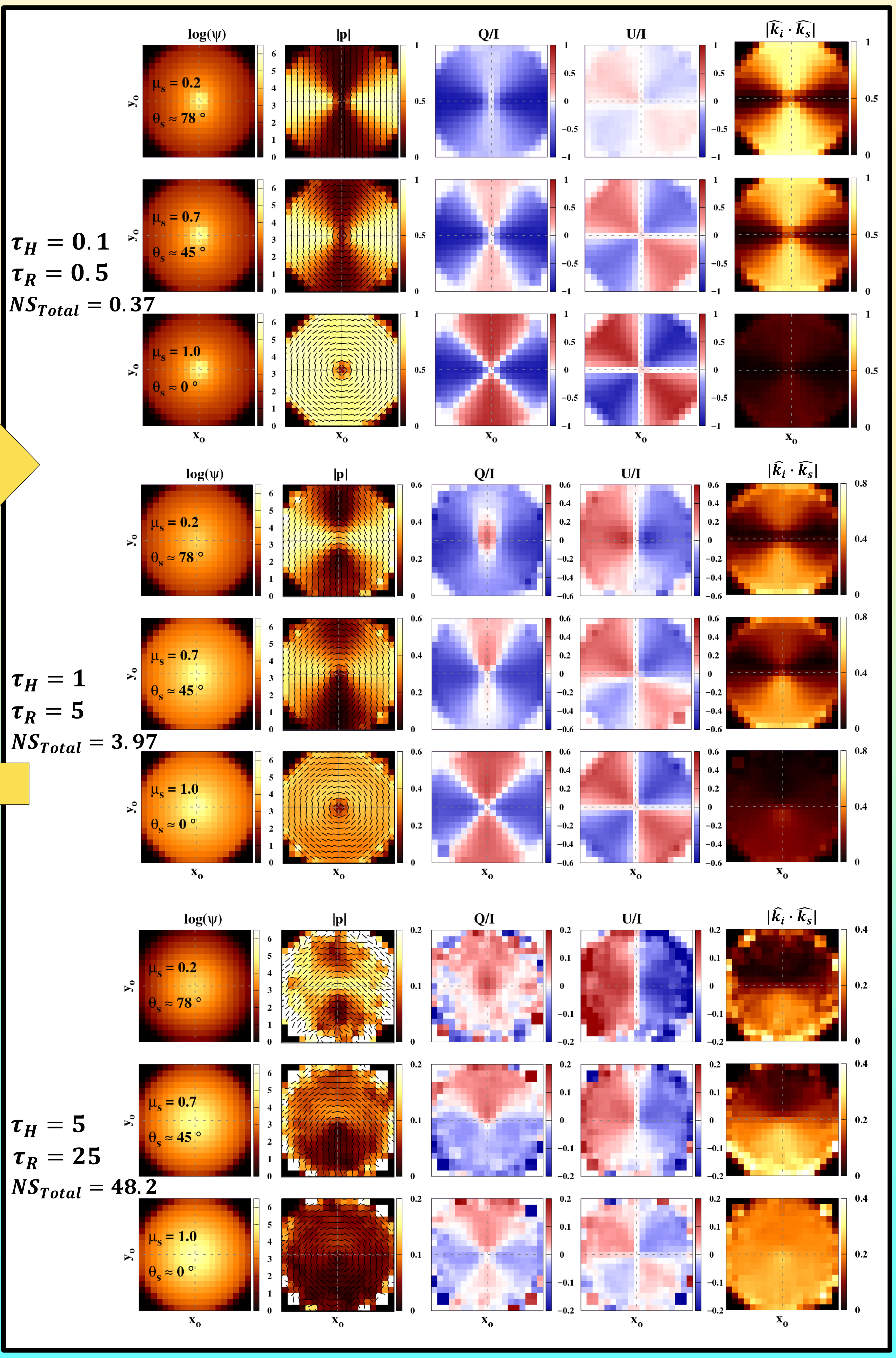
$|\mu_s| \uparrow \rightarrow NS_\mu \downarrow$

$\tau_H \uparrow \rightarrow NS_\mu/NS_{Total}$ get flatter

The Number of scattered photons Ψ_μ the right bottom panel

$|\mu_s| \uparrow \rightarrow \Psi_\mu/\Psi_{Total} \uparrow$

IV. Imaging Polarimetry for $\tau_H = 0.1$, 1 and 5



V. Discussion of Imaging Polarimetry

We simulated imaging polarimetry of Rayleigh scattered Lyα and presented the number of photons Ψ_μ, degree of polarization $|p|$, Stokes parameter Q/I, U/I and $|\hat{k}_i\cdot\hat{k}_s|$ with $\hat{k}_i$ and $\hat{k}_s$ being the wavevectors of incident and scattered photons just before escape. The three values of optical depth $\tau_H = 0.1$, 1 and 5 are chosen and also results for three values of $\mu_s = 0.2, 0.7$ and 1.0 are shown.

$\tau_H = 0.1$ case, $NS_{Total} = 0.37$

- Single scattering dominates.
- Point-symmetric pattern for all other parameters.
- For $\mu_s = 1$, a concentric-circular pattern is obtained.
- Stronger polarization is seen near y-axis than x-axis.

$\tau_H = 1$ case, $NS_{Total} = 3.97$

- Combined effects of multiple scattering and single scattering.
- Symmetric patterns similar to $\tau_H = 0.1$ case are obtained.

$\tau_H = 5$ case, $NS_{Total} = 48.2$

- Point-symmetric patterns disappear for all other parameters.
- Polarization flip between upper and lower hemispheres.

Our results show breaking of circular symmetry as τ_H increases.
The polarization flip in the optically thick case is attributed to the difference $|\hat{k}_i\cdot\hat{k}_s|$ just before ecape .

VI. Summary and Future Work

- In the optically thin case, the images formed by radiation Rayleigh scattered by atomic hydrogen show symmetric polarization pattern through single scattering.
- The multiple scattering destroys point-symmetric polarization pattern.
- We will perform simulations including core scattering in order to better understand the polarimetry of Lyman Alpha Blobs.

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