A Monte Carlo Study of Flux Ratios of Raman Scattered O VI Features at 6825 Å and 7082 Å in Symbiotic Stars

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1. Abstract

A symbiotic star is a wide binary system consisting of a hot white dwarf and a mass losing giant, where the giant loses its material in the form of a slow stellar wind resulting in accretion onto the white dwarf through gravitational capture. Symbiotic stars are known to exhibit unique spectral features at 6825 and 7082, which are formed from O VI 1032 and 1038 through Raman scattering with atomic hydrogen. In this Monte Carlo study we investigate the flux ratio of 6825 and 7082 in a neutral region with a geometric shape of a slab, cylinder and sphere. By varying the amount of neutral hydrogen parametrized by the column density along a specified direction, we compute and compare the flux ratio of Raman scattered O VI 6825 and 7082. In the column density around 10^{23} cm^{-2}, flux ratio changes in a complicated way, rapidly decreasing from the optically thin limit to unity the optically thick limit as the column density increases. It is also notable that when the neutral region is of a slab shape with the O VI source outside the slab, the optically thick limit is less than unity, implying a significant fraction of O VI photons escape through Rayleigh scattering near the boundary. We compare our high resolution CFHT data of HM Sge and AG Dra with the data simulated with finite cylinder models confirming that 'S' type symbiotic tend to be characterized by thicker HI region that 'D' type counterparts. It is expected that this study will be useful in interpretation of the clear disparity of Raman O VI 6825 and 7082 profiles, which will shed much light on the kinematics and the asymmetric distribution of O VI material around the hot white dwarf.

2. Introduction

Symbiotic Star

- Wide binary of a mass losing giant and a hot white dwarf.
- Accretion disk formed through gravitational capture of a fraction of the slow stellar wind.
- Unique broad emission features at 6825 Å and 7082 Å
- Classified into the 'S' type and 'D' type.
- Candidate of Type Ia Supernova Progenitors.

Fig 1. illustration of the symbiotic star

Raman Scattering

- Difference in wavelength of the incident and scattered radiation.
- Profile broadening.
- $\sigma_{tot,1032}$ = 41.5 σ_T , $\sigma_{ram,1032}$=7.5 σ_T
  $\sigma_{tot,1038}$ = 9.1 σ_T , $\sigma_{ram,1038}$=2.5 σ_T
- Branching ratio ≡ σ_{ram} / σ_{tot} = 0.18, 0.27 at O VI λλ 1032 and 1038, respectively.

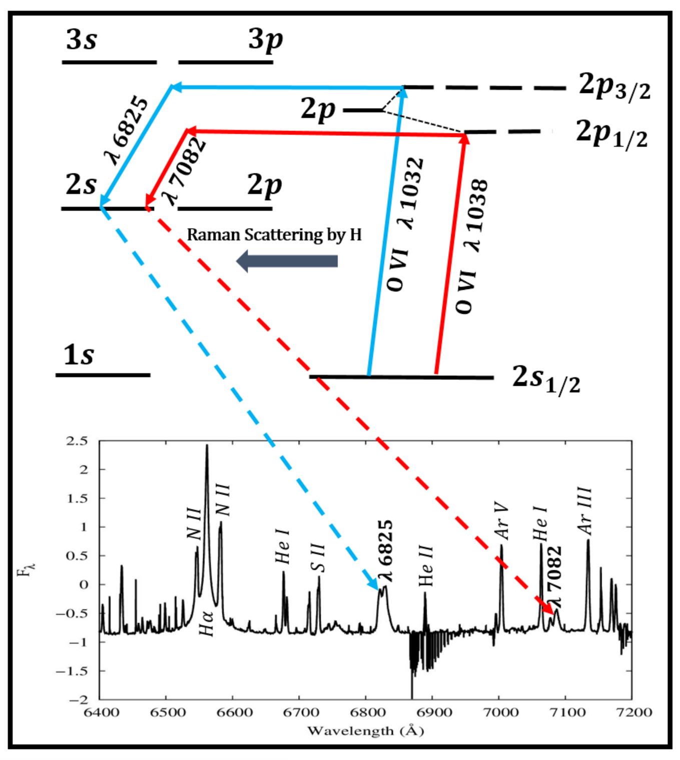


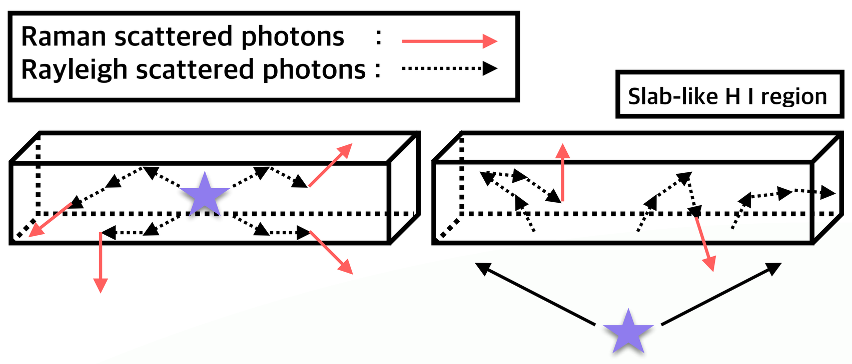
Fig 2. Raman scattering of O VI Photons with neutral Hydrogen

Flux Ratio

- Flux ratio of two Raman features depends on H I column density and geometric shape.

- In this work, we investigate flux ratios of the Raman 6825 and 7082 formed from a monochromatic O VI emission source embedded in or illuminating neutral slab, cylinder and sphere by varying H I column density.

3.1. Results - Slab, Cylinder and Sphere



- Upper Limit : ratio of the cross sections of O VI λλ 1032, 1038
- Flux ratio :F(6825)/F(7082).
- Raman conversion ratio : N(OVI)/N(total)
- Scattering number : mean scattering number of O VI photons in the scattering region.
- Optically thin regime: significantly small than upper limit.
- Moderate column density of embedded case : bump feature due to nonlinear behavior between scattering number and O VI λλ 1032, 1038.
- Optically thick regime of embedded and illuminated case : 1, 0.8

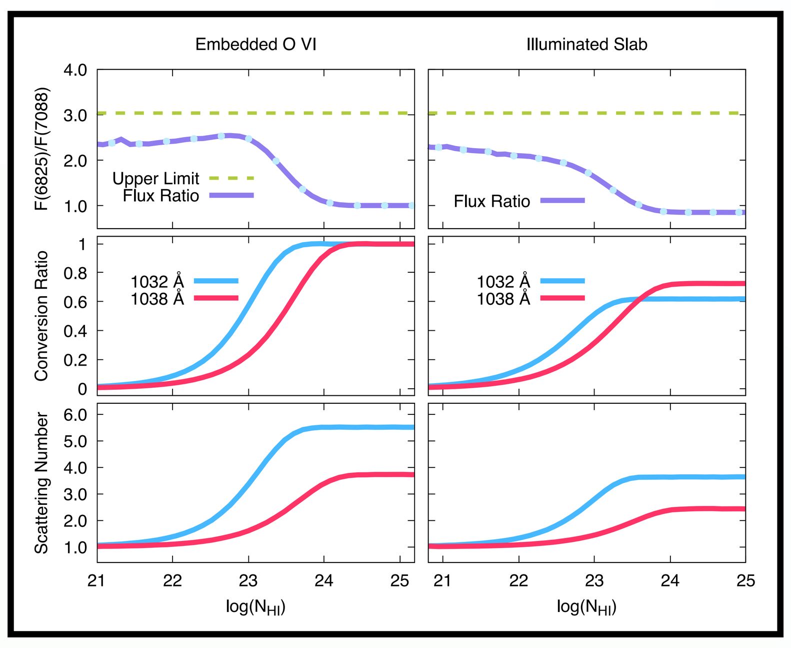
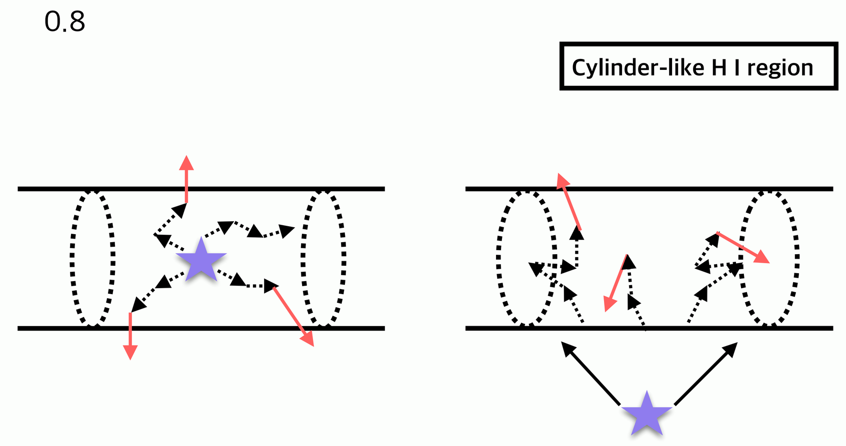


Fig 3. Flux ratio, Raman conversion efficiency and mean scattering number of Raman scattered O VI emergent from a slab with a finite thickness and infinite lateral dimensions.



- Optically thin regime : flux ratio approaches upper limit.
- Moderate column density $10^{22.5}$ cm^{-2} : exceeds upper limit.
- Scattering number converges to inverse of branching ratio.

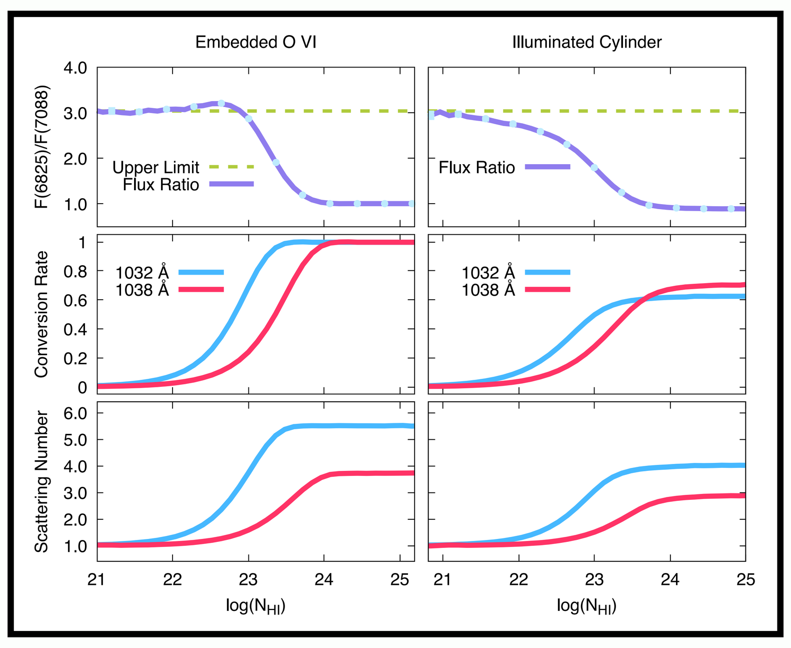
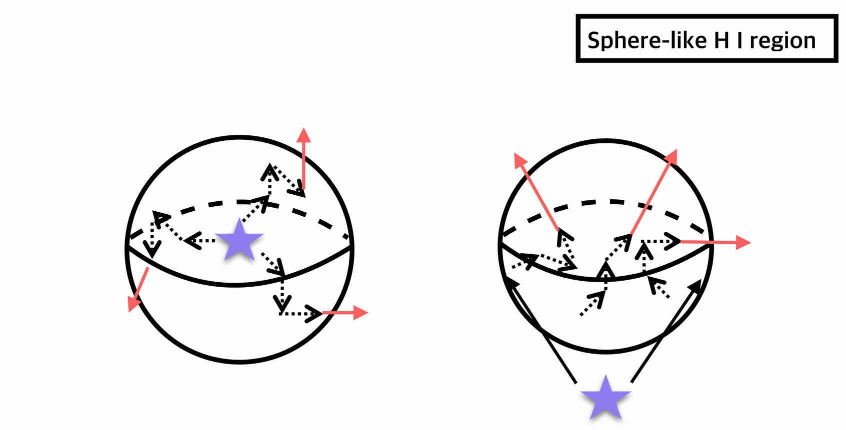


Fig 4. The same quantities for a cylindrical neutral region as in Fig 3.



- Flux ratio shows a dip feature at optically thick limit in illuminated case.
- Broad bump around N_{HI} = $10^{22.7}$ cm^{-2} in embedded case, which is maximum flux ratio obtained in this work.

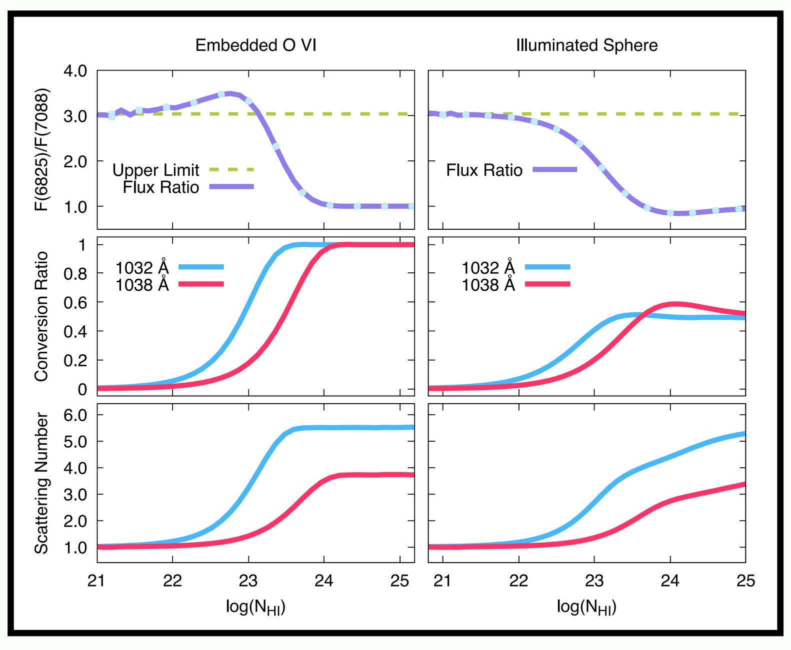


Fig 5. The same quantities for a spherical neutral region as in Fig 3.

3.2. Finite cylinder model & mock spectrum

Lee & Kang (2007) and Heo & Lee (2015) showed that the disparity of Raman O VI profiles is consistent with a Keplerian accretion disk of velocity scale ~30 km/s. We assume that O VI emission region is asymmetric in such a way that the entering side is significantly denser than the opposite side. We adopt a highly simplified H I region delineated by a finite cylinder specified by radius R and height H. The diameter of the neutral cylinder is set to equal the binary separation. We set R=5 and the H=1.

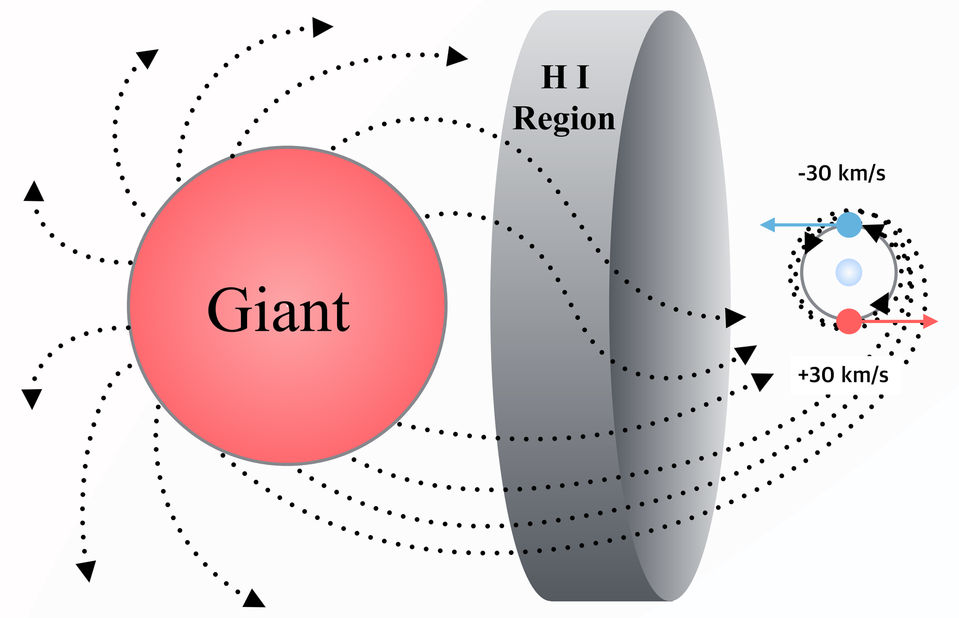


Fig 6. A schematic illustration of Raman scattering geometry adopted in this work for a symbiotic star. We adopt a highly simplified neutral region delineated by a finite cylinder with R/H = 5 in front of the giant component.

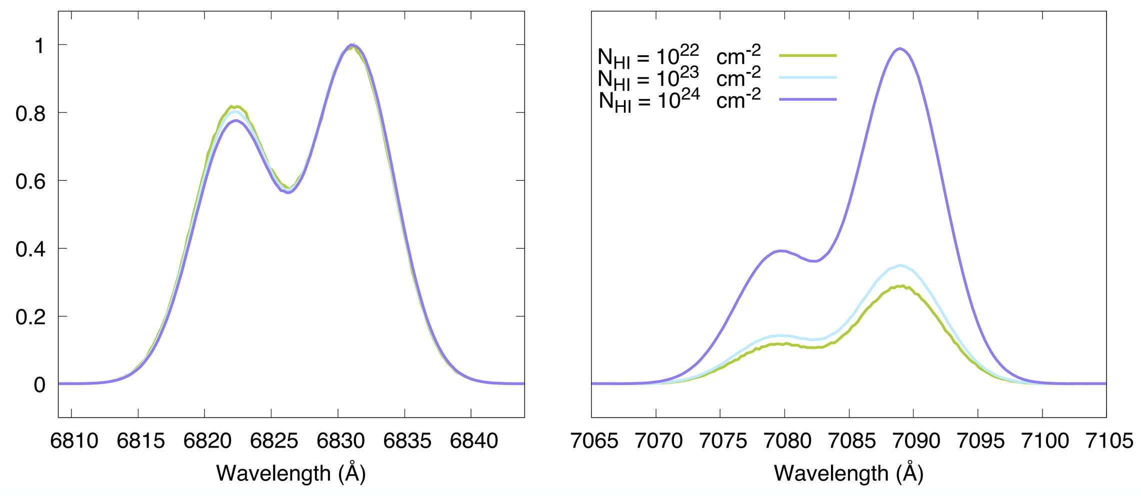


Fig 7. Mock spectra of Raman scattered O VI λλ 1032 and 1038 formed in the scattering geometry shown in Fig 6.

4. Comparison with CFHT spectra

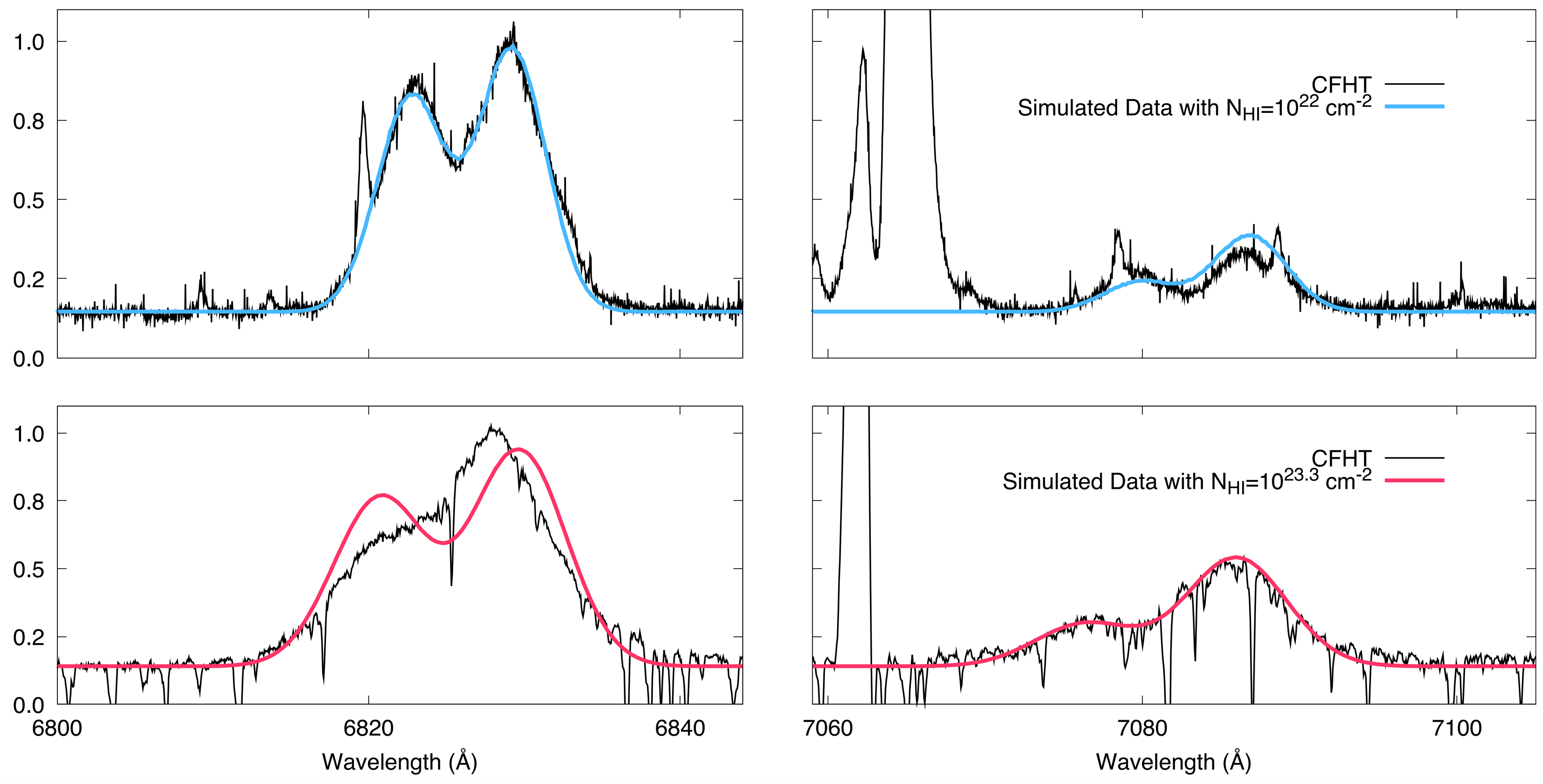
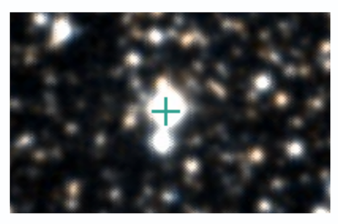
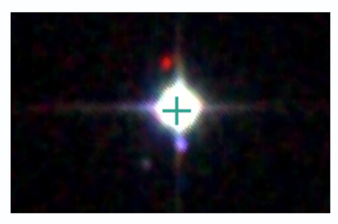


Fig 8. *Canada-France-Hawaii Telescope*

Fig 9. *Canada-France-Hawaii Telescope*



HM Sge



AG Dra

Top panels : 'D' type symbiotic star HM Sge (2014 August 16, total integration time 9,600s).
-Orbital period ~ 50 years
-Comparison with simulation : N_{HI} ~ 10^{22} cm^{-2}

Bottom panels : 'S' type symbiotic star AG Dra (2014 September 6, total integration time 2,000s).
-Orbital period ~ 550 days
-Comparison with simulation : N_{HI} ~ $10^{23.3}$ cm^{-2}

5. Discussion & Future works

1. Observed flux ratios of O VI λλ 1032, 1038 range between 2 and 7.
2. Maximum flux ratio of 3.5 is obtained in the case of a spherical neutral region with moderate column density of N_{HI} ~ $10^{22.7}$ cm^{-2} inside which the O VI emission source in embedded.
3. In case of optically thick limit of the illuminated geometry, flux ratio is less than 1 due to a significant fraction of O VI photons escaping from the neutral region through a few Rayleigh scattering near the illuminated boundary.
4. In a more realistic Raman scattering geometry, the HI region may take a much more complicated geometric shape requiring a more sophisticated consideration.
5. This work will be extended to spectropolarimetric analyses which will shed much light on the mass loss and transfer processes occurring in symbiotic stars.