Profile disparity of Raman-scattered O VI in symbiotic stars

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Abstract. Symbiotic stars are wide binary systems consisting of a hot compact star (usually a white dwarf) and a mass losing giant. Symbiotic activities are believed to occur through gravitational capture of a fraction of the slow stellar wind from the giant. Raman scattered features of O VI resonance doublet 1032 and 1038 appearing at around 6825 Å and 7082 Å are a unique spectroscopic diagnostic tool to probe the mass transfer process in symbiotic stars. The Raman O VI features often exhibit multiple peak structures and in many cases the blue peak of 7082 features is relatively more suppressed than that of 6825 features. We propose that the disparity of the two profiles is attributed to the local variation of optical depths of O VI, implying that the accretion flow is convergent in the red emission region and divergent in the blue emission region. It is argued in this presentation that Raman scattering by atomic hydrogen is a natural mirror to provide an edge-on view of the accretion disk and a lateral view of the bipolar outflow in symbiotic stars. We discuss the spectropolarimetric implications of this interpretation.

1. Introduction
Symbiotic stars are binary systems consisting of a hot white dwarf and a mass losing giant. They exhibit prominent emission lines with a broad range of ionization and excitation. The symbiotic activities are attributed to the mass transfer processes involving a gravitational capture of some fraction of the slow stellar wind from the giant component. One unique aspect of the spectra of symbiotic stars is the presence of the spectral features formed through Raman scattering of far UV radiation more energetic than Lyα by atomic hydrogen.

The Raman scattering process is the combination of the annihilation of the incident radiation with the excitation of the hydrogen atom and the creation of the Raman scattered radiation accompanied by the de-excitation of the hydrogen atom into the 2s state. For example, an O VI λ1032 photon is Raman scattered to appear at 6825 Å, and in a similar way an O VI λ1038 is Raman scattered to be emergent at 7082 Å. These two Raman O VI features at 6825 Å and 7082 Å are observed in about half of symbiotic stars and were first identified by Schmid [1]. Raman scattered line features observed thus far include He IIλ 1025, 972 and 949, Ne VIIλ 973 and C IIλ 1036 and 1037.

The scattering cross section for resonance doublet O VIIλ 1032 and 1038 is of order $10^{-22}$ cm$^2$. The cross section for O VIIλ 1032 is larger than for O VIIλ 1038, which results in about 5-10 times stronger Raman O VI feature at 6825 Å than 7082 Å. The small cross section for these Raman features implies that the operation of Raman scattering requires a very special condition of the existence of a highly thick H I region in the vicinity of a strong far UV source.
This condition is ideally met in symbiotic stars where the giant component provides a highly neutral region illuminated by the far UV nebular region surrounding the white dwarf. A number of young planetary nebulae are known to exhibit Raman scattered He II features (e.g. Pequignot et al. [2], Groves et al. [3], Kang et al. [4]).

The energy conservation relates the wavelength $\lambda_o$ to the that of the incident radiation by

$$\lambda_o^{-1} = \lambda_i^{-1} + \lambda_\alpha^{-1},$$  

where $\lambda_\alpha$ is the wavelength of Ly$\alpha$. Variation of this relation yields

$$\frac{\Delta \lambda_o}{\lambda_o} = \left(\frac{\lambda_o}{\lambda_i}\right) \frac{\Delta \lambda_i}{\lambda_i},$$

which leads to a broadened profile exhibited in the Raman scattered features. Therefore, the Raman O VI features exhibit broader profiles by a factor of $\sim 7$ than their parent emission lines in the far UV region. This relation is very important because the profile of a Raman scattered feature reflects only the kinematics between the far UV emission source and the H I region and is almost independent of the observer’s lie of sight. The profile broadening attributed to the inelasticity of scattering leads to Raman scattering to play a role of the natural mirror allowing the accretion disk from the vantage point of the giant.

2. Accretion of the Slow Stellar Wind in Symbiotic Stars

According to Mastrodemos & Morris [5] some fraction of the slow stellar wind from the giant can be captured gravitationally by the white dwarf to form an accretion disk. Accretion disks are often accompanied by the bipolar outflows. For example, Angeloni et al. [6] found that Sanduleak’s star exhibits a huge outflow extending up to 17 pc. However, the overall mass transfer processes in symbiotic stars are only poorly known.

Raman O VI features at 6825 Å and 7082 Å are known to exhibit complicated profiles including double-peak and triple-peak profiles. When we analyze the Raman scattered O VI at 7082 Å along with its stronger twin feature at 6825 Å, we find an interesting fact that the profiles of the 7082 and 6825 features differ in a systematic way that the blue part of the 7082 feature is relatively more suppressed than its counterpart of the 6825 feature. Because O VI 1032 and 1038 are formed in the same region, we may find the physical mechanism of the profile difference in the O VI emission region. Arising from transition $2S_{1/2} - 2P_{1/2,3/2}$, the statistical factor for O VI1032 is twice larger than that for O VI1038. In an optically thin emission region the flux ratio of O VI1032 and O VI1038 is two. As the optical depth increases, the flux ratio will approach the thermal limit of unity. In this way, the flux ratio may differ depending on the local variation of physical conditions in the O VI emission region.

In Fig. 1, we illustrate schematically the O VI emission region identified with the accretion disk around the white dwarf, where the accretion disk is in turn decomposed into two subcomponents of the blue emission region and the red emission region. We denote these two components by BER (blue emission region) and RER (red emission region). It is expected that the accretion flow is convergent in the red emission region leading to a flux ratio near 1, whereas the accretion flow is divergent in the blue emission region resulting in a flux ratio approaching two. In this way when we normalize the two Raman features so that the red peaks coincide, the blue peak of the Raman 6825 feature will be larger than that of the Raman 7082 feature.

3. Profile Disparity of the Raman Scattered O VI Features

Fig. 2 shows the line profiles of the Raman scattered O VI at 6825 Å and 7082 Å of the symbiotic nova V1016 Cygni presented by Heo & Lee [7]. In this spectrum the red peaks of the two features are stronger than the blue peaks, which implies that the accretion flow is convergent on the side
Figure 1. A schematic illustration of the formation of Raman scattered O VI at 6825 Å and 7082 Å in a symbiotic star. The O VI emission region is identified with the accretion disk formed via gravitational capture of a fraction of the slow stellar wind from the giant. Lying near the giant, the scattering neutral region commands an edge-on view of the O VI emission region. In this model, when the profiles are normalized so that the red peaks coincide, the blue peak of Raman 7082 is weaker than that of Raman 6825.

of the red emission region leading to enhanced emissivity. We assume that the H I region is stationary and that the effect of the observer’s line of sight is neglected. We transform from the observed wavelength space to the Doppler factor space, where the Doppler factor is measured with respect to the stationary H I region.

The two profiles are normalized in such a way that the red peaks of the same strength noting that the lower bound of the O VI flux ratio is 1:1. It happens that the flux ratio at the Doppler factor near zero is almost 2:1, which is the theoretical upper bound of the OVI flux ratio. The part of the O VI emission region with negligible Doppler factors may be identified with the region extended significantly far from the white dwarf. Lying in the shallow gravitational potential with low density, this region is plausibly characterized by the flux ratio of 2:1. We also note that the blue emission region exhibits the flux ratio of ~1.5. It turns out that the normalization of the equal strength of the red peaks allows the flux ratio to vary in the full range between one and two, which means that this normalization is the only theoretically admissible one.

We propose that the O VI emission region of V1016 Cyg is characterized by three regions, one is the blue emission region with the intermediate flux ratio of 1.5:1, another is the extended region with zero Doppler factor showing the flux ratio of 2:1 and the other is the red emission region with the flux ratio of 1:1. The flux ratio indicates that the red emission region is of the highest density and the centrally extended region of the lowest density. It is an interesting possibility that the red emission region with the highest density can be identified with a hot spot that is commonly observed in cataclysmic variables.

Figure 2. The line profiles of the Raman scattered O VI at 6825 Å and 7082 Å of the symbiotic star V1016 Cygni obtained with the BOES (Bohyunsan Optical Echelle Spectrograph) installed on the 1.8 m telescope at the Bohyunsan Optical Observatory on the night of 2005 November 7. The horizontal axis is the Doppler factor in units of km s⁻¹. The upper panel shows the flux ratio and the lower panel shows the line profiles.
4. Discussion

Schmid [8] proposed that multiple peak profiles exhibited in the Raman O VI are attributed to the expansion of the H I region, where the blue peaks are formed in the part of the H I that approaches the O VI emission region. In this picture, in order to obtain stronger red peak, the H I region that recedes from the O VI should extend much further than the approaching part. In this model where the O VI emission region is assumed to be point-like, it is very difficult to reconcile the fact that the profiles of the two Raman O VI features are different. One explanation may be that the scattering optical depth is very different for each velocity interval of H I, which would require a very contrived distribution of neutral material around the giant. Furthermore, the distribution of H I with respect to the point-like O VI emission region is axially symmetric, which makes it difficult to explain the phenomena of polarization flip.

The accretion disk component naturally leads to Raman O VI features with a double-peaked profile. With an additional contribution from the bipolar outflow, we expect that the profile will be augmented by another peak located redward of the accretion disk profile. In case the velocity scale of the bipolar outflow exceeds that of the accretion disk, the resultant profile will be triply peaked. One consequence of this view is the flip of the position angle of the polarization of the Raman O VI features in the reddest part.

One can find the phenomena of polarization flip from the Spectropolarimetric data compiled by Harries & Howarth [9], which appears to be in support of this view. Furthermore, Lee & Kang [10] proposed that the double peak profiles of the Raman O VI at 6825 in the symbiotic stars V1016 Cyg and HM Sge are consistent with the Keplerian motion of the O VI emission region around the white dwarf. Our future work includes a combined study of the hydrodynamics and radiative transfer of the slow stellar wind accretion in symbiotic stars.

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