Raman and Thomson Wings around Balmer Lines in the S-type Symbiotic Stars Z Andromedae and AG Draconis

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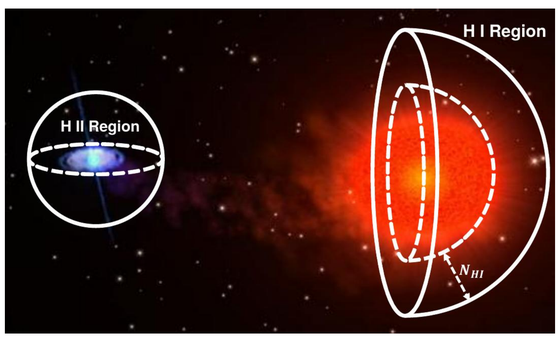
1. Abstract

Symbiotic stars are binary systems composed of a hot white dwarf and a mass losing giant. Broad wings around Balmer emission lines are found in many symbiotic stars including the two S-type symbiotic stars, Z Andromedae and AG Draconis. Monte Carlo simulations are carried out to produce Balmer wings from Thomson scattering with free electrons and Raman scattering with atomic hydrogen. Thomson wings of Hα and Hβ have the same widths in the Doppler space due to the cross section independent of wavelength. In contrast, Raman Ha wings are 3 times broader widths than Hβ counterparts, which is attributed to the different cross sections and branching ratios. The half width at half maximum (HWHM) is proportional to $\sqrt{T_e}$ for Thomson wings and $\sqrt{N_{HI}}$ for Raman scattering. We present our spectra of Z And and AG Dra obtained with the Canada-France-Hawaii Telescope, where H α wings are found to be broader than Hβ wings indicative of significant contribution of Raman scattering to the formation of the Balmer wings.

2. Symbiotic Stars



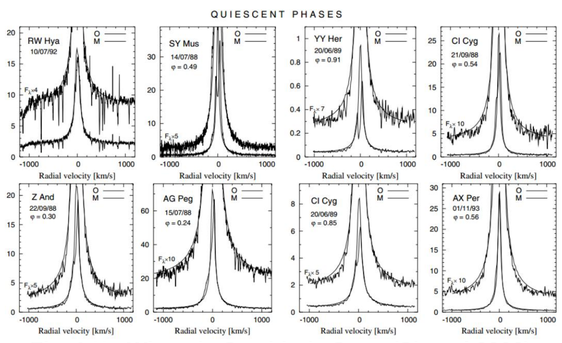
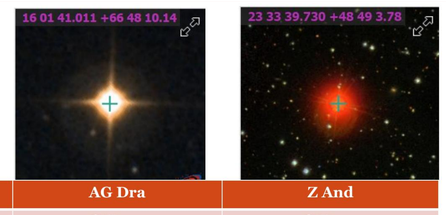


Fig. 1 Hα Wings in Symbiotic Stars (Skopal 2006)

Symbiotic stars are interacting binary system composed of a mass losing red giant and a white dwarf. The optical spectra of symbiotic stars show Raman scattered lines and strong broad Hα wings of which the widths are broader than 1,000 km/s. According to IR spectra, symbiotic stars are classified into 'S' type and 'D' type. D-type symbiotic stars exhibit an IR excess by a warm dust component with $T_e = 10^3 K$, but spectra of S-type don't show the excess.

3. AG Dra & Z And



	AG Dra	Z And
Type	S-Type	S-Type
P_{orbit}	550 Days	760 Days
M_{WD}	$0.5M_{sun}$	$0.75M_{sun}$
M_{Red}	$1.0M_{sun}$	$2.0M_{sun}$

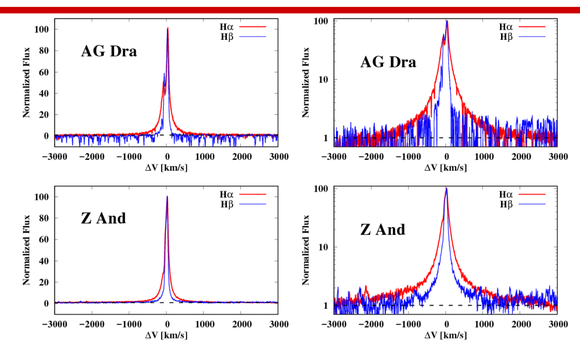
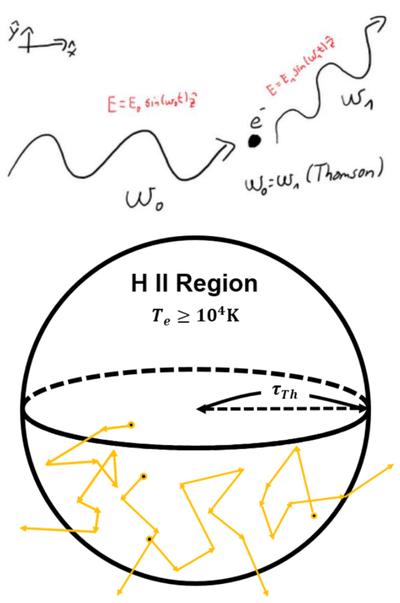


Fig. 2 The Spectra and Parameters of AG Dra and Z And

The left panel provides parameters and images of S-Type symbiotic stars, AG Dra and Z And. AG Dra is known to be a yellow symbiotic star having a K-type giant companion. Z And is regarded as a prototypical symbiotic star with an M-type giant.
In the right panels, we overplot their normalized CFHT spectra of Hα and Hβ in linear and logarithmic scales. The two spectra show different profiles and strengths of broad wings on $\Delta V > 500\ km/s$. We adopt two processes, Thomson scattering and Raman scattering to investigate the broad wings of Hα and Hβ.

4-1 Thomson Scattering Wings



In H II region, photons are Thomson scattered by free electrons. This cross section is wavelength independent $\sigma = 0.665 \times 10^{24}\ cm^2$. For this reason, Thomson wings show same widths in any emission lines.

We consider a uniform spherical region and simulate Thomson scattering wings for various electron temperature T_e. The wings trace the thermal **Gaussian distribution** of free electrons.

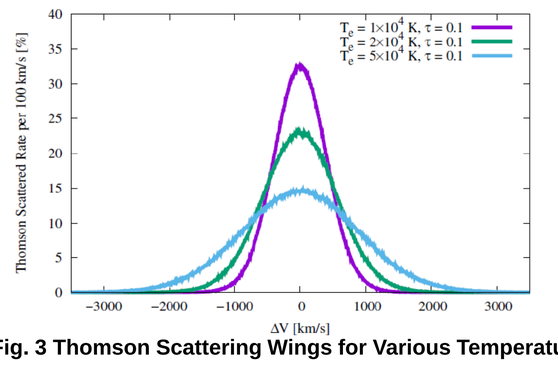
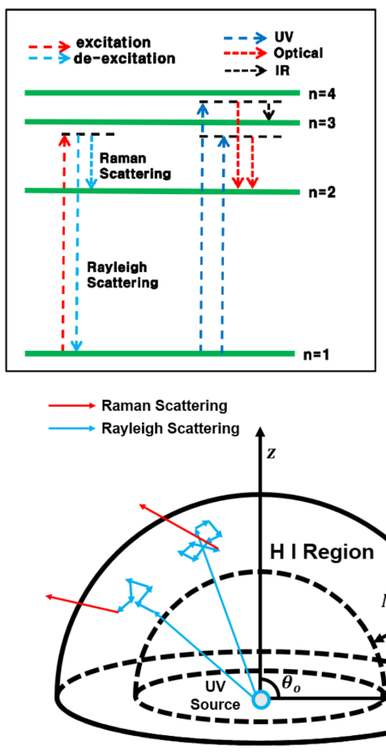


Fig. 3 Thomson Scattering Wings for Various Temperature

4-2 Raman Scattering Wings



Raman scattering is inelastic scattering by an atomic hydrogen. When UV photon excites bound electron from $n = 1$ to $n > 2$, excited electron is de-excited to $n = 1$ or intermediate states $n > 1$. The transitions between $n > 2$ and intermediate state is termed Raman scattering.

We assume a hemispherical H I region and flat UV continuum to compute Raman scattering wings of Hα and Hβ of which widths are different. The wing widths depend on H I column density N_{HI}. The profile follows a **Lorentzian function** as the total cross section is well approximated by a Lorentzian function.

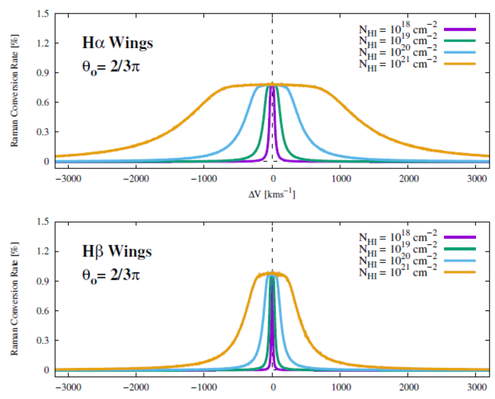
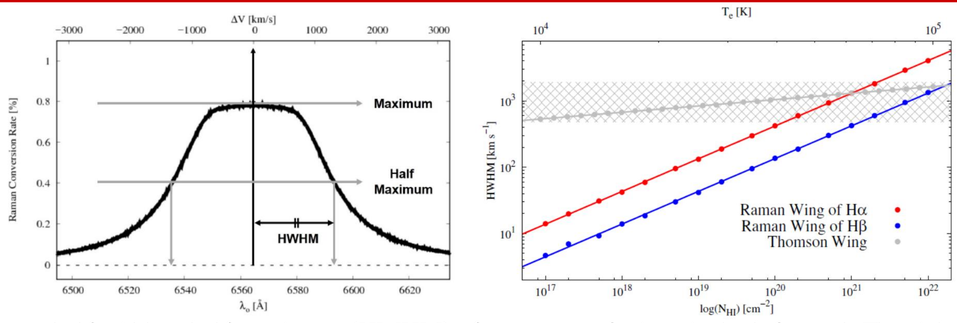


Fig. 4 Raman Scattering Wings for Various Column Density

4-3 Widths of Scattering Wings



We estimate a half width at half maximum (HWHM) of two types of wings in the left panel. The right panel shows dependence of HWHM on electron temperatures T_e for Thomson wings and HWHM on column densities N_{HI} for Raman wings. These relations are fitted as follows,

$$\mathrm{HWHM_{Raman\,H\alpha}} = 418\ N_{20}^{0.49}\ \mathrm{km\ s^{-1}} \qquad N_{20} = \frac{N_{HI}}{10^{20}\mathrm{cm^2}}$$

$$\mathrm{HWHM_{Raman\,H\beta}} = 135\ N_{20}^{0.49}\ \mathrm{km\ s^{-1}}$$

$$\mathrm{HWHM_{Thomson}} = 532\ T_4^{0.49}\ \mathrm{km\ s^{-1}}. \qquad T_4 = \frac{T_e}{10^4\mathrm{K}}$$

5. Results

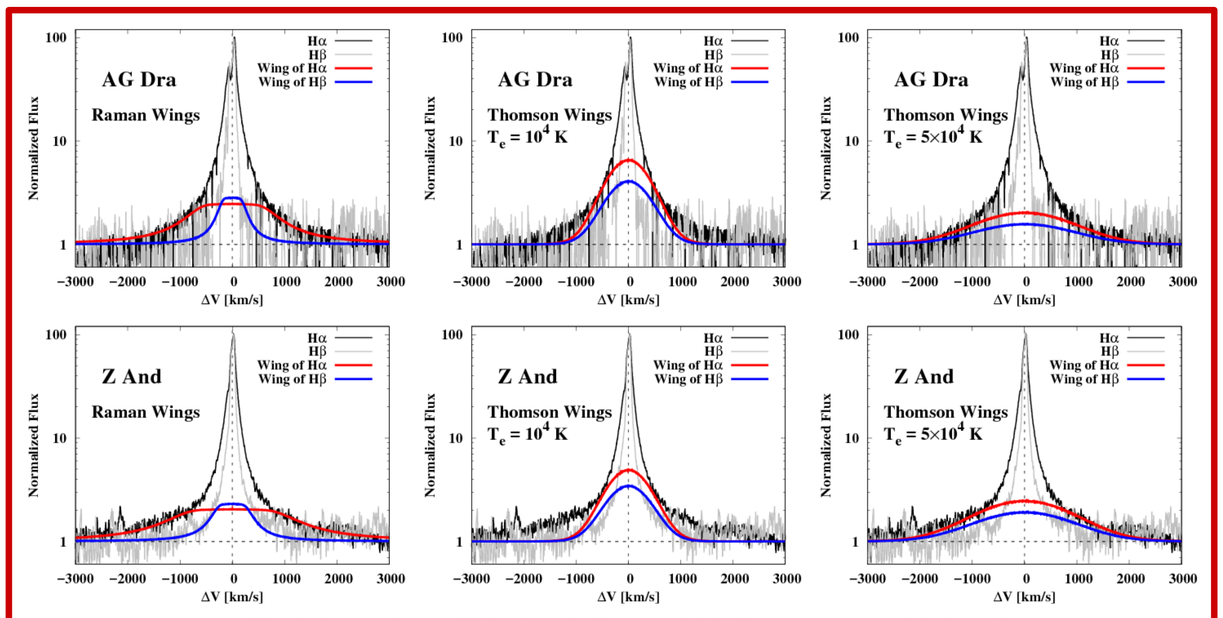


Fig. 5 Comparison of Simulated wings and CFHT spectra around Balmer lines

We show Balmer wings formed from Thomson and Raman scattering in logarithmic scale in order to clearly check the fit quality. The top panels are for AG Dra and the bottom panels for Z And. In the left panels, we fit broad wings using Raman scattering. We set column densities $N_{HI} = 5\times10^{20}$ cm^{-2} for AG Dra and 10^{22} cm^{-2} for Z And. In the center and right panels, we consider two types of Thomson wings, normal H II region for $T_e = 10^4\ K$ (center) and hot H II region for $T_e = 5\times10^4\ K$ (right).

We notice that Raman wings provide better fit than Thomson wings. When we consider only Thomson wings, the hot H II regions are more favorable than the normal H II region. However, Thomson cross section is too small to generate sufficient scattered photon flux in the hot H II region.

6. Summary & Future Works

1. Spectra of symbiotic stars show **broad wings around Hα.**
2. **Thomson wings** are broadened by high **electron temperature T_e.**
3. The HWHM of Thomson wings have to exceeded 550 km/s.
4. **Raman wings** are broadened by high **H I column density N_{HI}.**
5. Raman wings of Hα and Hβ show **different widths.**
6. Raman wings provide better fit than Thomson wings in S-type symbiotic star.
7. Spectropolarimetry and profile comparisons will shed more light on Balmer wings

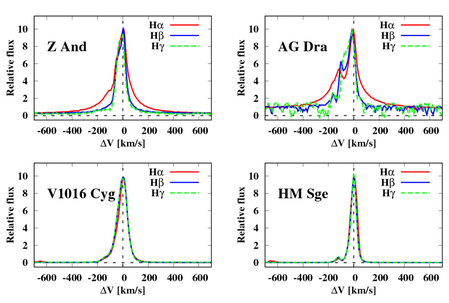


Fig. 6 Balmer lines of Symbiotic Stars

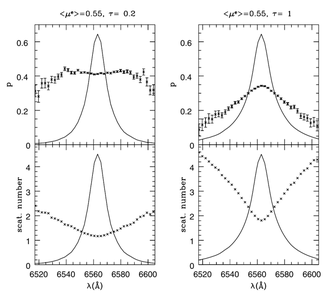


Fig. 6 Spectropolarimetric Results of Thomson scattering wings

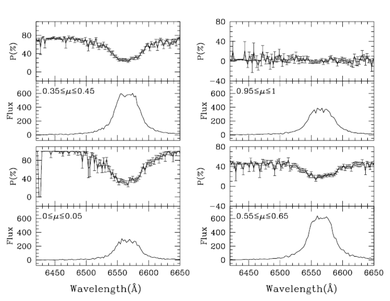


Fig. 6 Spectropolarimetric Results of Raman scattering wings

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