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Diagnostic of the symbiotic nebula by Thomson scattering

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We introduce the profile-fitting analysis of the extended wings of the strongest emission lines observed in the spectra of symbiotic stars by the electron-scattering process. Particularly, we modeled broad wings of the O VI 1032, 1038 Å doublet and the He II 1640 Å line measured in the archival FUSE and IUE spectra, respectively. By this way we determined the electron temperature and the electron-scattering optical depth of the layer of electrons, throughout which the line photons are transferred in direction to the observer. We selected and modeled the line profiles at different stages of the star's activity. Our profile-fitting analysis indicated a significant increase in the particle density around the white dwarf during active phases. The effect was significant during the bursts of AG Dra. According to other independent analyzes, the increase in the particle concentration around the accretor results from enhanced wind from the hot star. As the model parameters depend on the properties of the scattering environment, which are a function of the star activity, Thomson scattering can diagnose the symbiotic nebula during different levels of the star activity.

Diagnostic of the symbiotic nebula by Thomson scattering

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Abstract

We found that in ultraviolet spectra of symbiotic stars Z And, AG Dra and V1016 Cyg, taken by FUSE, ORFEUS and IUE satellites, there are present very broad wings of the strongest emission lines, which are created by the electron-scattering process. Here we introduce a profile-fitting analysis of the extended wings, which allowed us to determine the electron optical depth, τ_e, and the electron temperature, T_e, of the layer of electrons, throughout which the line photons are transferred in the direction of the observer. We selected the spectra at different stages of the star activity. Our results indicate an increase of particle density around the white dwarf during active phase. According to other independent analyses, the increase in the particle concentration around the accretor results from enhanced wind from the hot star. As the model parameters depend on the properties of the scattering environment, which are a function of the star activity, Thomson scattering thus can diagnose the symbiotic nebula during different levels of the star activity.

Introduction

Symbiotic stars are long period (in order of years) interacting binaries. They usually consists of a red giant, very hot compact stellar object, most probably a white dwarf, and the symbiotic nebula as a result of interaction between the two stars with its circumstellar matter, having origin in stellar wind of the giant and the white dwarf. During the so-called quiescent phases the system releases its energy at approximately constant rate. In active phase, it changes its radiation significantly, which is accompanied with brightenings by 1-3 mag in the optical and changes of its ionization structure (Skopal et al. 2009, and references therein).

Ionized and neutral part of the circumstellar environment of symbiotic binaries represent a very suitable medium for Rayleigh, Raman and Thomson scattering processes. In our contribution we introduce a diagnostic of the symbiotic nebula by the Thomson scattering effect

Thomson scattering wings

In the spectra of symbiotic stars we often observe very broad wings of the strongest emission lines. We assumed that they are due to the effect of electron-scattering process. This kind of scattering is characterized by its independency on wavelength and extremely small cross section, σ_T=6.652x10^{-25}cm^{2}, per one electron. Therefore the presence of sufficiently intense emission lines and large amount of free electrons makes the symbiotic nebula to be a good environment for observing the Thomson scattering effect. Our objective was to model the broad line wings providing this assumption and thus to determine two parameters: electron optical depth τ_e and electron temperature T_e of the layer of free electrons, throughout which the radiation passes from the white dwarf to the observer. We modeled profiles of emission lines OVI *λ1032Å/1038Å* archived in the FUSE and ORFEUS database and HeII *λ1640Å* archived in the IUE database for the symbiotic stars Z And, AG Dra and V1016 Cyg.

According to Castor, Smith and Van Blerkom (1970) we consider a simplified model of spectral line affected by Thomson scattering. We assumed that a layer, where the radiation of the line originates, is separated from the layer of free electrons, that lies above it. For an electron optical depth τ_e< *1* we can express a line profile as

$$\Psi(x) = (1-\tau_e)\Phi(x) + \tau_e \int_{-\infty}^{\infty} \Phi(x')\, R_e(x',x)\,dx', \qquad (1)$$

where *x* is the frequency displacement in terms of Doppler width of the line, R_e is redistribution function for Thomson scattering (Mihalas, 1970) and *Φ(x) is* the initial line profile before scattering, which consists of one (HeII line) or sum of Gaussians (OVI resonance lines).

Relationship between broad wings and nebular radiation

According to our model the shape of the wings depends on two parameters, τ_e and T_e. Both of them depend on the properties of the scattering environment (symbiotic nebula), which are a function of the star activity. The optical electron depth τ_e depends on the amount of free electrons, which collide with the line photons in direction to the observer. According to definition of the electron-scattering constant σ_T, the total optical depth τ_e can be expressed as

$$\tau_e = \sigma_T \int_{R_i}^{R_N} n_e(r)dr \approx \sigma_T \overline{n}_e R_N, \qquad (2)$$

where R_i and R_N are inner and outer border of the electron scattering layer and $\overline{n}_e$ is the mean electron concentration.

The scattering region (nebula) can be described with so-called emission measure, *EM*, which is a function of concentrations of ions (n_+) and electrons (n_e). Assuming that their ratio n_+/n_e*=0.83*, we can write

$$EM = \int_V n_+(r) n_e(r) dV \approx 0.83 \overline{n}_e^2 V, \qquad (3)$$

where *V* is the volume of the nebula. Approximating its shape by a sphere with the same emission measure, i.e.$V = {}^4/_3 \pi R_N^3$, and substituting $\overline{n}_e$ from Eq.(2) to Eq.(3), one can write the proportionality

$$\tau_e \propto \sqrt{EM}/\sqrt{R_N}, \qquad (4)$$

where R_N is the effective radius of the symbiotic nebula. The emission measure of the nebula is very sensitive to the changes of the properties of the white dwarf radiation and thus the activity level of the symbiotic star.

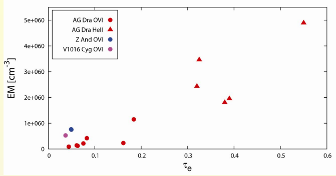

Fig. 2 The relation between electron optical depth τ_e and emission measure for different levels of activity for the three investigated stars.

Observational justification

We found that in the IUE spectra of the symbiotic star AG Dra, there are very broad wings in the profile of the HeII *λ1640Å* line during active phases, whereas during quiescent phases the broad wings are not detectable (see right panels of Fig. 1).

According to the spectral energy distribution (SED) throughout a wide spectral range, this finding supports the relation between the EM and τ_e within the symbiotic nebula (relation (4)). Our example in the figure 1 shows that during the quiescent phase there were no wings observed, i.e. τ_e< *0.01,* and the emission measure was 1,3x10^{59}cm^{-3}. However, during active phase, the broad wings became to be very pronounced (τ_e*=0.32),* and, simultaneously the emission measure increased by a factor of ~5 (Fig. 1).

It has been shown above that the electron optical depth, τ_e, is proportional to the emission measure. To demonstrate the relation (4) we determined τ_e from fitting the electron-scattering profiles observed at different stages of activity and different object. Corresponding emission measure was estimated from the U magnitude (Fig. 2). The higher values of τ_e for HeII *λ1640Å* line are estimated from observations during the outbursts of AG Dra in 1981 and 1994.

Discussion

The increase of τ_e during active phases indicate the increase of number of free electrons in the line of sight. The character of its changes can be either due to orbital motion of the binary, when the radiation passes different parts of ionized symbiotic nebula, or in creation of enhanced stellar wind from the hot star as a new source of nebula particles and thus free electrons. The mass loss rate and other parameters of this wind can be determined from the wings of Hα profile (Skopal, 2006). We suppose that there must be present also the effect of electron scattering and by its removal we should be able to determine the mass loss rate more precisely. According to the empirical relationship between EM and τ_e (Fig. 2) we can estimate the electron-scattering depth from the known EM and thus include its effect on the profile of the Hα line wings.

Conclusion

We have shown that Thomson scattering can be responsible for wide wings of the strongest spectral lines in the spectra of symbiotic stars. This scattering can diagnose the symbiotic nebula during different levels of the star activity and can be useful for more accurate determination of the mass loss rate from the white dwarf in the form of stellar wind.

Acknowledgement

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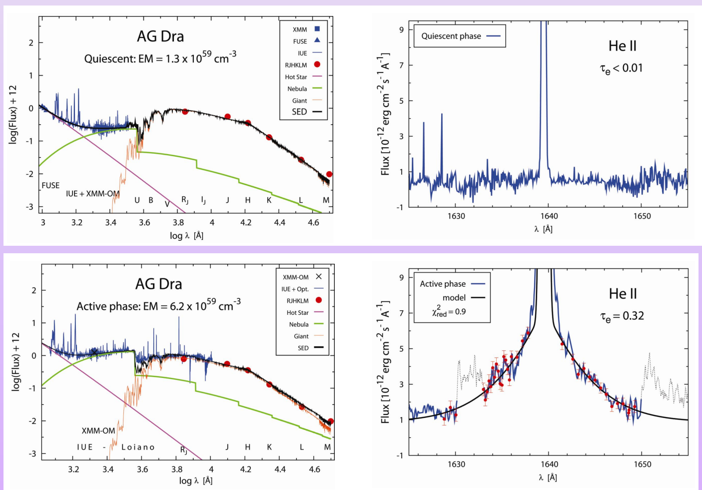

Fig. 1 Relation between the SED and the presence of broad wings in the HeII *λ1640Å* line profile during quiescent and active phases, respectively (Skopal et al. 2009).