CO MOLECULE IN TRANSITION REGION BETWEEN CHROMOSPHERE AND COOL STELLAR WIND: A NEW PROBE ON THE OUTER ATMOSPHERES OF COOL LUMINOUS STARS

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ABSTRACT. Presence of CO layer well separated from photosphere is confirmed and this revealed a presence of quasi-static turbulent transition layer in normal red (super)giant stars. This layer may be related to an outer part of the extended chromosphere and/or a cool part of the chromospheric inhomogeneity, and will play major role in stellar mass-loss.

As is well known, the circumstellar matter in outer envelope of cool luminous stars is being lost from the stellar system(Deutsch,1956), but it is not clear where the mass-flow starts. There is a suggestion that the mass-loss already starts in chromosphere(Goldberg,1979), but the observed flow velocities are smaller than the local escape velocity in chromosphere and it is not clear if the chromospheric expansion could be a direct origin of stellar mass-loss. Furthermore, presence of a static layer, possibly situated above the chromosphere, is suggested not only in Mira variable stars(Hinkle et al.,1982) but also in non-Mira stars(Hall,1980). While little attention has been given to such a static layer in recent theories of stellar mass-loss, we have found some convincing evidences on the presence of such a static layer in normal red giant and supergiant stars during our analysis of high resolution infrared spectra of CO first overtone bands(Tsuji,1986a; to be referred to as Paper I).

Although CO lines originating from such a static layer show little Doppler shift against photospheric lines, they could be recognized by the following facts: 1) Equivalent widths of low excitation lines show systematic excess as compared with expected ones based on model atmosphere(Fig.3 of Paper I), while higher excitation lines can quantitatively be well understood by the same model(Tsuji,1986b). 2) The low excitation lines show shifts and asymmetries that indicate excess absorption in blue wing in some stars and in red wing in other stars(Figs.4 & 5 in Paper I). 3) Radial velocities show differential variations between low excitation lines(remain almost stationary in the case of α Her shown in Fig.1) and high excitation lines(change is larger, possibly due to small amplitude pulsation of the photosphere). These observations suggest that at least a part of low excitation lines should be originating in a layer well separated from the photosphere. Further, comparison of the observed spectrum with predicted photospheric spectrum revealed residual absorption for low excitation lines while there appeared no residual for

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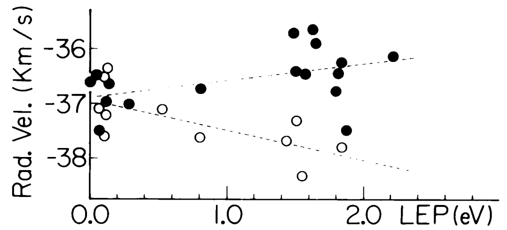

Fig.1 CO radial velocities in αHer plotted against lower excitation potential: Feb.19,1977(open circle) and June 24, 1977(filled circle).

TABLE 1 Physical properties of the quasi-static CO absorption layer

Star	Sp.Type	T_{ex}	v_{tur}	log N_{CO}
α Ori	$M2I_{ab}$	1450K	>9Km/s	20.1
μ Cep	$M2I_a$	1100	>9	19.8
ρ Per	M4II	1940	>5	19.8
α Her	M5II	1670	>5	20.0
SW Vir	M7III	2160	>5	19.9

high excitation lines. In low excitation lines, the contribution by the CO layer has been separated by subtracting the photospheric contribution from the observed profile. A curve-of-growth analysis on equivalent widths of the separated CO profiles gave the results summarized in TABLE 1: note that the excitation temperature is surprisingly high(this is based on more consistent analysis than in Paper I that gave lower temperature) and the turbulent velocity is rather large. Estimated total mass of the CO layer based on the deduced column density is as high as $10^{-4} M_{\odot}$.

As the excitation temperature is pretty high while the CO layer should be well separated from the photosphere as noted before, the CO layer may be an outer part of the extended chromosphere(which has been recognized only recently; see e.g., Linsky,1987) and/or a cool component of the chromospheric inhomogeneity. Anyhow, the CO absorption layer should represent a transition region between the chromosphere and the cool wind in luminous stars of non-coronal type. Probably, deposition of mass, momentum, and energy to the outer atmosphere from the photosphere may be sufficient to form the turbulent transition layer together with the extended chromosphere, but it may be not sufficient to be the direct driving force of stellar mass-loss. However, once the transition layer is formed, it provides an ideal environment for dust formation and radiation pressure on dust could drive mass-outflow. Such a hybrid model of mass-loss is well consistent with the known observations on the outer atmosphere of αOri,for example. Also, even if dust could not be formed, the Maxwellian tail of the turbulent motion could lead to mass-loss, since the local escape velocity in the transition layer may be already small enough to be comparable with the observed flow velocities.

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